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REVIEW ARTICLE

Efficacy and safety of volar locking plate versus cast immobilization for distal radius fractures: a systematic review and meta-analysis of randomized controlled trials

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ABSTRACT
Volar locking plates (VLPs) are increasingly used for distal radius fractures (DRFs), yet their efficacy compared to cast immobilization remains debated. This meta-analysis aimed to compare VLPs versus cast immobilization for DRFs across various follow-up durations. Randomized controlled trials reporting patient-reported functional scores, wrist range of motion (ROM), radiological assessments, and complications were included. Meta-analysis was performed for 6-week, 3-month, 6-month, 12-month, and >12-month follow-ups. Subgroup analysis stratified studies by age group, ≥60 years and <60 years. VLPs showed significantly lower Disabilities of the Arm, Shoulder, and Hand (DASH) scores at 6 weeks ($p<0.001$), 3 months ($p<0.001$), 12 months ($p = 0.012$), and >12 months ($p<0.001$), and lower PRWE scores at 6 weeks ($p<0.001$), 3 months ($p=0.048$), and >12 months ($p = 0.032$). Wrist ROM favored VLPs at 6 weeks ($p < 0.05$), with higher flexion and supination at 3 months ($p=0.027$) and 12 months ($p = 0.003$). Radiologically, VLPs showed improved parameters at 3- and 12-month follow-up. Overall complications did not significantly differ. Subgroup analysis in patients <60 years generally supported these findings, while in patients ≥60 years, radiological outcomes aligned, yet only lower DASH scores were observed with VLPs at 3 months ($p<0.001$). VLPs may offer superior clinical, functional, and radiological outcomes compared to cast immobilization at 3- and 12-month follow-up for patients <60 years, with comparable safety profiles. For patients ≥60 years, VLPs may yield better radiological outcomes at 3- and 12-month follow-up, though clinical benefits remain uncertain.

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Volar locking plate; immobilization; surgical; conservative; distal radius fractures

Introduction

Distal radius fractures (DRFs) represent one of the most common fractures, with a pooled incidence of 212.0 (95% confidence intervals [CIs], 178.1 to 252.4) per 100,000 person-years [1]. Various treatment modalities are available for DRFs, ranging from casting immobilization to percutaneous pinning, external fixation, or internal fixation. However, achieving consensus on the most effective treatment modality remains challenging. Conservative approaches, such as casting immobilization, remain as one of the main options for DRFs, particularly among elderly patients [2]. However, over recent decades, the volar locking plates (VLPs) have emerged as the treatment of choice [3].

While cast immobilization offers a safer and cost-effective non-invasive method, it necessitates a longer recovery time and may not always ensure optimal fracture reduction [4]. On the other hand, open reduction internal fixation (ORIF) with VLPs presents advantages such as superior fracture alignment, accelerated functional recovery, and earlier resumption of activities [2]. Nonetheless, it is associated with higher costs and notable postoperative complication rates, reaching up to 16.5% [5].

The debate between VLPs and conservative treatment for DRFs has persisted for decades, with ongoing controversy regarding the superiority of one method over the other in managing DRFs. Previous systematic reviews have demonstrated better radiographic outcomes with VLP compared to conservative treatment [5–8]. However, when assessing functional outcomes, existing evidence suggests no clinically significant differences between the two approaches [9, 10]. A network meta-analysis (NMA) indicated that VLPs may provide optimal early and sustained functional outcomes for both adult and elderly patients with DRF [11]. Conversely, another NMA suggested that while VLPs may lead to clinically significant improvements in short-term (≤3-month) functional outcomes, outcomes at 12 months appear similar regardless of treatment received [12].

The inconsistent findings from previous meta-analyses may be attributed to various factors, including the inclusion of randomized controlled trials (RCTs) with retrospective and prospective cohort, mixed outcomes across different time frames, or the focus on one or two outcomes among patient-reported functional outcomes, range of motion (ROM), radiographic outcomes, and complications. Therefore, our primary objective in this meta-analysis, exclusively incorporating RCTs, is to compare functional, radiographic, and clinical outcomes between VLPs and conservative treatment for adult patients with DRFs, while considering varying follow-up durations. Prior evidence suggests that older age may correlate with reduced benefits from VLPs compared to cast immobilization for DRFs [13]. Hence, our study conducted a subgroup analysis based on age (≥60 vs. <60) to provide further insights into the efficacy of VLP compared to conservative treatment for DRFs.

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Materials and methods

The present systematic review and meta-analysis was conducted and reported in accordance to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.

Search strategy

A systematic electronic search was performed across multiple databases, including PubMed, EMBASE, Web of Science, Scopus, ClinicalTrials.gov., and Cochrane Library. The search terms included, but were not limited to, DRF, Colles fractures, open reduction, internal fixation, volar locked plating, locking plate, closed reduction, nonsurgical treatment, conservative treatment, plaster, casting, and immobilization. Relevant RCTs involving human subjects published before February 2024 were retrieved. The reference lists of potentially eligible articles and relevant reviews were manually searched for additional studies that missed at the electronic search.

Eligible criteria

Relevant RCTs comparing the effectiveness of VLPs with conservative treatment for patients with DRFs were included in the meta-analysis based on predefined inclusion criteria: 1) Patients aged ≥ 18 years with DRFs of any clinical presentation; 2) Treatment group patients underwent ORIF with VLPs, while patients in the control group received closed reduction and casting/plaster immobilization; 3) studies provided at least one of the following outcome categories: patient-reported functional outcomes, wrist ROM, radiographic outcomes, and complications.

Exclusion criteria comprised animal studies, in-vitro experiments, ongoing trials, non-RCTs, studies involving chronic injury to the distal radius, and studies lacking sufficient data. Eligibility assessment was conducted by two independent reviewers. Any discrepancies among reviewers were resolved through discussions.

Data extraction

Data extraction was conducted independently by two reviewers following a predefined form. Any discrepancies among reviewers were solved by discussion. Extracted data included: 1) study characteristics: author, year of publication, region, sample size, and follow-up time; 2) patients' information: age, sex, and fracture classification (AO type); 3) patient-reported functional outcomes: Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire, the Patient-rated Wrist Evaluation (PRWE), Visual Analogue Scale (VAS) for pain; 4) wrist ROM: grip strength, flexion, extension, supination, pronation, ulnar deviation, and radial deviation; 5) radiographic assessment: radial inclination, radial height, volar tilt, ulnar variance, and step off; 6) incidences of complications: complex regional pain syndrome (CRPS), tenosynovitis, tendon rupture, malunion, infection, and etc. When wrist ROM was reported exclusively as a percentage relative to the contralateral (normal) wrist, these percentages were converted into degree measurements based on normal physiological ROM values. Standard values used for conversion were 85 degrees for flexion, 80 degrees for extension, 85 degrees for supination, 80 degrees for pronation, 35 degrees for ulnar deviation, and 20 degrees for radial deviation [14]. Data extraction for patient-reported functional scores, wrist ROM, and radiographic outcomes was performed based on follow-up duration. For complication outcomes, incidence rates at the last follow-up were retrieved.

Quality assessment

The methodologic quality of each included RCTs was evaluated using the Cochrane Collaboration's risk of bias tool [15]. This tool assesses the risk of bias across seven domains, including random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other bias. Within each domain, studies were categorized as having low, unclear, or high risk of bias.

Statistical analysis

Statistical analysis was performed using Stata software version 15.0 (Stata Corporation, College Station, TX, USA). Standardized mean differences (SMDs) and corresponding 95% CIs were used as summary statistics for continuous variables. Odd ratios (ORs) and corresponding 95% CIs were used as summary statistics for dichotomous variables. A two-tailed p value of <0.05 was considered statistically significant. Between-study heterogeneity was evaluated using the chi-squared Q test and quantified with I^2 statistic. A chi-squared value of $p<0.1$ or $I^2>50\%$ was considered as significant heterogeneity, and a random-effects model was used for data pooling. Outcomes exhibiting low heterogeneity were pooled using a fixed-effects model.

Data for patient-reported functional scores, wrist ROM, and radiographic outcomes were pooled based on follow-up duration. Complication outcomes were summarized by presenting incidence rates at the last follow-up. Sensitivity analysis was performed by excluding studies that included AO facture type B and by removing each study outcome to estimate the impact of individual studies on the overall effect size. Subgroup analysis was conducted to explore the influence of age (≥ 60 vs. < 60) on assessed outcomes whenever adequate data were available. Publication bias was evaluated using Begg's and Egger's regression tests if an outcome included more than 10 studies. When a significant publication bias occurred ($p<0.05$), a trim and fill analysis was further preformed to estimate the magnitude of bias effect.

Results

Search results

The preliminary electronic database search yielded 2,210 citations. Following the removal of duplicates, and prospective and retrospective records, 890 studies underwent screening based on titles and abstracts. Of these, 810 studies were subsequently excluded, leaving 80 publications for full-text review to determine eligibility. Eventually, 14 trials met the inclusion criteria for the meta-analysis [4, 16–28]. The PRISMA flow diagram of study selection process was presented in Figure 1.

Study characteristics

The overall study population comprised 2,431 patients with DRFs, of whom 1,175 were treated with VLPs and 1,256 received cast immobilization. Four studies included patients with age ≥ 60, three with age ≥ 65, and two with age ≥ 70. These nine trials were categorized into the subgroup of patients aged ≥ 60 for subgroup analysis. All studies had a greater proportion of female participants. Final follow-up duration ranged from 3 months to 3 years, with seven trials reporting a 12-month follow-up. Two trials exclusively included patients with extra-articular fractures, three included patients with intra-articular fractures only, while seven trials included both intra- and extra-articular fractures. Additionally, two trials also incorporated partial articular fractures. A summary of study characteristics is presented in Table 1.

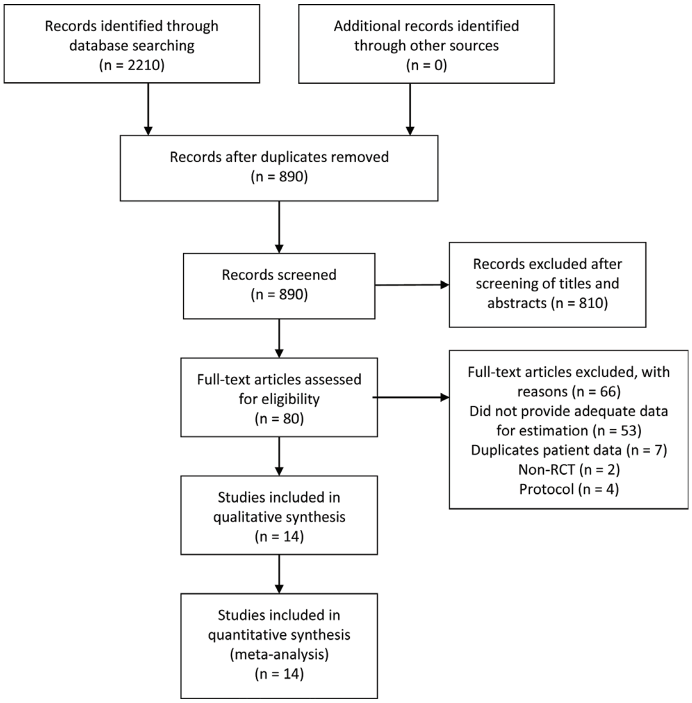

Figure 1. The PRISMA Flow Diagram of literature search and study selection.

Quality assessment

Most studies had a low risk of bias in terms of random sequence generation, allocation concealment, and incomplete outcome data. The risk of bias regarding selective reporting and other bias was largely unclear. All included trials had high performance and detection bias due to the inability to blind surgeons, investigators, or participants, given the nature of treatment modalities (Supplementary Table 1).

Patient-reported functional scores

Functional outcomes were analyzed across various follow-up durations, including 6 weeks, 3 months, 6 months, 12 months, and >12 months (24–36 months). Compared with cast immobilization, VLPs demonstrated significantly lower DASH scores at 6-week (SMD = –0.98; 95% CI, –1.39, –0.57; $p<0.001$; $I^2=36.7\%$), 3-month (SMD = –0.48; 95% CI, –0.67, –0.30; $p<0.001$; $I^2=51.3\%$), 12-month (SMD = –0.50; 95% CI, –0.89, –0.11; $p=0.012$; $I^2=91.5\%$), and >12-month (SMD = –0.56; 95% CI, –0.88, –0.25; $p<0.001$; $I^2=0\%$) follow-up (Figure 2). No significant difference between the two groups was observed at the 6-month follow-up (Figure 2) studies exclusively, including patients aged 60 years or older (≥60 years) demonstrated significantly lower DASH scores with VLPs compared to cast immobilization at 3 and >12 months follow-up. Similarly, in studies exclusively including patients younger than 60 years old (<60 years), significantly lower DASH scores were observed with VLPs compared to cast immobilization at 3- and 12-month follow-up (Table 2).

In addition, VLPs were associated with significantly lower PRWE scores at 6-week (SMD = –0.86; 95% CI, –1.18, –0.54; $p<0.001$; $I^2=0\%$), 3-month (SMD = –0.42; 95% CI, –0.84, –0.00; $p=0.048$; $I^2=89.0\%$), and >12-month (SMD = –0.37; 95% CI, –0.71, –0.03; $p=0.032$; $I^2=53.5\%$) follow-up (Figure 3). Subgroup analysis among patients aged ≥60 years demonstrated significantly lower PRWE scores with VLPs compared to cast immobilization at >12-month follow-up. Moreover, in one study including patients aged <60 years, VLPs were associated

Table 1. Basic characteristics of the included studies.

Author	Level of Evidence	Fracture	Intervention (*n*)	Age (year)	Gender (M/F)	AO type	Control (*n*)	Age (year)	Gender (M/F)	AO type	Follow-up (month)
Ahmed2023	-	Extra-articular	30	42.7 ± 9.2	8/22;	-	66	41.6 ± 12.7	25/41	-	6
Arora2021	Level I	Extra- and intra-articular	36	75.9 (65–88)	8/28;	A2: 3; A3: 7; C1: 4; C2: 12; C3: 10;	37	77.4(65–89)	10/27;	A2: 3; A3: 9; C1:11; C2: 8; C3: 6;	12
Bartl2024	-	Intra-articular	86	75.3 ± 6.7	9/77;	C1: 36; C2: 35; C3: 15;	88	74.4 ± 7.1	12/76;	C1: 40; C2: 35; C3: 13;	12
Chung2020	Levels I and II	Extra- and intra-articular	65	67 (6.2)	10/55	A2: 33; A3: 4; C1: 3; C2: 20; C3: 31; Missing: 4;	109	76(10)	16/93	A1: 1; A2: 40; A3: 12; C1: 10; C2: 25; C3: 2; Missing: 19;	24
Drobetz2016	Level II	Extra-, intra-, partial articular	29	51.1 (16.0)	9/15;	A2: 0; A3: 4; B2: 3; C1: 7; C2: 8; C3: 2;	27	52.5(16.5)	13/13	A2: 2; A3: 7; B2: 3; C1: 6; C2: 7; C3: 1;	3
Lawson2021	-	Extra- and intra-articular	81	70.5 (7.0)	11/70;	A: 55; C: 26;	85	71.3(7.6)	10/75;	A: 49; C: 35;	24
Martinez-mendez2017	Level I	Intra-articular	50	67 (8)	11/39;	C1: 23; C2: 23; C3:4;	47	70(7)	10/37;	C1: 22; C2: 20; C3: 5;	24
Mulders2019	Level I	Extra-articular	47	59 (42.0–66.0)	16/31	A2: 10; A3: 37;	43	60(52.0–65.0)	7/36;	A2: 13; A3: 30;	12
Saving2019	Level I	Extra- and intra-articular	58	80 (70–90)	3/55;	A2: 6; A3: 33; C1: 11; C2: 7; C3: 1;	64	78(70–98)	8/56;	A2: 10; A3: 28; C1: 20; C2: 6; C3: 0;	12
Selles2021	Level I	Intra-articular	44	62 (49–66)	8/36;	C: 44;	46	59(53–67)	6/40;	C: 46;	12
Shaikh2023	-	Extra- and intra-articular	534	64.90 ± 3.70	208/326	A2: 189; A3: 55; C1: 178; C2: 73; C3: 39;	529	65.16 ± 3.90	199/330	A2: 182; A3: 64; C1: 204; C2: 57; C3: 22;	12
Sharma2014	-	Intra- and partial articular	32	48.10 ± 10.30	12/20;	B: 15; C: 17;	32	52.39 ± 9.05	14/18	B: 13; C: 19;	12–24
Südow2022	Level I	Extra- and intra-articular	33	80 (70–90)	-	-	33	78 (70–98)	-	-	36
Thorninger2022	Level II	Extra- and intra-articular	50	75 (70–80)	9/41;	-	50	74 (69–82)	10/40;	-	12

M/F: male/female.

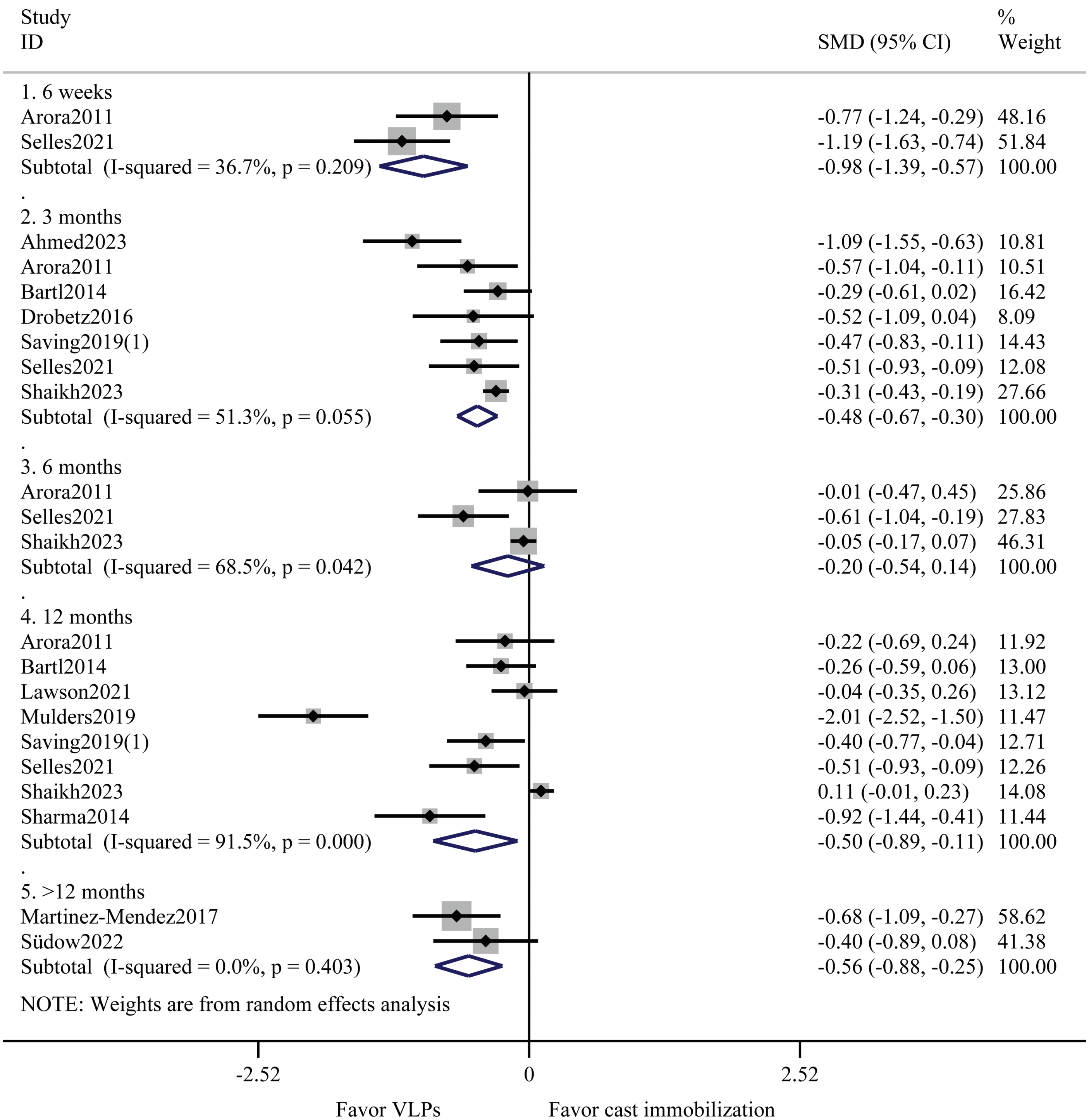

Figure 2. Forest plot of the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire comparing volar locking plate versus cast immobilization for distal radius fractures, analyzing based on follow-up duration.

with significantly lower PRWE scores across the 6-week to 12-month follow-up periods (Table 2).

Wrist functional outcomes

Compared with cast immobilization, patients treated with VLPs exhibited significantly greater extension (SMD = 3.26; p = 0.012; I^2 = 98.2%), flexion (SMD = 1.88; p = 0.011; I^2 = 96.4%), supination (SMD = 2.17; p = 0.029; I^2 = 97.8%), pronation (SMD = 1.43; p = 0.020; I^2 = 95.4%), ulnar deviation (SMD = 2.31; p = 0.015; I^2 = 97.6%), and radial deviation (SMD = 2.01; p = 0.018; I^2 = 97.1%) at 6-week follow-up. At 3-month follow-up, VLPs were associated with significantly greater flexion (SMD = 0.69; 95% CI, 0.08, 1.30; p = 0.027; I^2 = 94.4%) and supination (SMD = 0.76; 95% CI, 0.05, 1.48; p = 0.036; I^2 = 95.7%) (Table 3). No significant differences were found between groups for all ROM outcomes at the 6-month follow-up. However, at 12-month follow-up, VLPs were associated with significantly greater flexion (SMD = 1.00; 95% CI, 0.34, 1.66; p = 0.003; I^2 = 95.7%), supination (SMD = 0.78; 95% CI, 0.17, 1.39; p = 0.012; I^2 = 95.1%), and pronation (SMD = 0.40; 95% CI, 0.02, 0.78; p = 0.041; I^2 = 88.4%) when compared to cast

Table 2. Subgroup analysis results of patient-report functional outcomes.

Outcomes	Number of study	SMD	95% CI	p	I^2 (%)
DASH score					
< 60 years					
6-week	1	−1.19	−16.3, −0.74	< 0.001	-
3-month	2	−0.79	−1.36, −0.23	0.06	69.7
6-month	1	−0.61	−1.04, −0.19	0.04	-
12-month	3	−1.14	−2.02, −0.26	0.011	90.0
> 12-month	-				
≥ 60 years					
6-week	1	−0.77	−1.24, −0.29	0.002	-
3-month	4	−0.33	−0.44, −0.23	< 0.001	0
6-month	2	−0.05	−0.17, 0.07	0.397	0
12-month	5	−0.13	−0.34, 0.09	0.260	65.2
> 12-month	2	−0.56	−0.88, −0.25	< 0.001	0
PRWE score					
< 60 years					
6-week	1	−0.76	−1.18, −0.33	0.001	-
3-month	1	−0.56	−0.98, −0.13	0.010	-
6-month	1	−0.62	−1.04, −0.19	0.004	-
12-month	1	−0.46	−0.88, −0.04	0.030	-
> 12-month					
≥ 60 years					
6-week	1	−0.99	−1.47, −0.50	< 0.001	-
3-month	3	−0.28	−0.79, 0.23	0.274	91.4
6-month	3	−0.13	−0.29, 0.04	0.147	18.2
12-month	5	−0.09	−0.29, 0.11	0.374	52.6
> 12-month	3	−0.37	−0.71, −0.03	0.032	53.5

DASH, Disabilities of the Arm, Shoulder, and Hand questionnaire; PRWE, Patient-rated Wrist Evaluation; SMD: standardized mean difference; CI: confidence interval.

immobilization (Table 3). Similarly, at >12-month follow-up, VLPs were associated with significantly greater supination (SMD = 0.68; 95% CI, 0.45, 1.39; $p < 0.001$; $I^2 = 1.5\%$) and pronation (SMD = 0.54; 95% CI, 0.21, 0.87; $p = 0.001$; $I^2 = 49.3\%$) compared to cast immobilization. Significantly greater grip strength (in kilograms) was observed in the VLPs group compared to the cast immobilization group at 6-weeks, 3-month, 6-month, and 12-month follow-up (Table 3).

In the subgroup of patients aged ≥60 years, no significant differences in wrist extension, flexion, supination, pronation, ulnar deviation, and radial deviation were observed at 6-week to 36-month follow-up, except for significantly greater pronation (SMD = 0.47; 95% CI, 0.05, 0.89; $p = 0.027$; $I^2 = 60.1\%$) at >12-month follow-up and grip strength at 6-weeks, 3-month, 6-month, and 12-month follow-up (Supplementary Table 2). Similarly, in the subgroup of patients aged <60 years, the outcomes were generally consistent with the overall results, with additional significant findings observed in 3-month extension (SMD = 1.58; 95% CI, 0.86, 2.29; $p < 0.001$; $I^2 = 77.6\%$) and 3-month radial deviation (SMD = 2.24; 95% CI, 1.35, 3.14; $p < 0.001$; $I^2 = 82.0\%$) (Supplementary Table 2).

Radiographic outcomes

In comparison to cast immobilization, VLPs were associated with significantly larger volar tilt and at 3-month (SMD = 0.66; 95% CI, 0.08, 1.25; $p < 0.001$; $I^2 = 60.0\%$) and 12-month (SMD = 1.02; 95% CI, 0.23, 4.80; $p = 0.011$; $I^2 = 97.0\%$) follow-up; higher radial inclination at 3-month (SMD = 0.73; 95% CI, 0.09, 1.37; $p = 0.026$; $I^2 = 96.4\%$), 12-month (SMD = 1.18; 95% CI, 0.43, 1.93; $p = 0.002$; $I^2 = 97.3\%$), and >12-month (SMD = 1.77; 95% CI, 0.44, 3.10; $p = 0.009$; $I^2 = 97.3\%$) follow-up; greater radial height at 12-month (SMD = 0.74; 95% CI, 0.06, 1.42; $p = 0.034$; $I^2 = 96.2\%$) and >12-month (SMD = 1.91; 95% CI, 1.20, 2.62; $p < 0.001$; $I^2 = 70.0\%$) follow-up; and lower ulnar variance at 3-month (SMD = −0.91; 95% CI, −1.03, −0.79; $p < 0.001$; $I^2 = 1.3\%$) and 12-month (SMD = −1.29; 95% CI, −1.70, −0.89; $p < 0.001$; $I^2 = 89.9\%$) follow-up (Table 4). Only one study, Sharma et al. [26], included patients aged <60 years and provided radiographic outcomes. Excluding the study outcome of Sharma et al., subgroup outcomes of patients ≥60 years were consistent with the overall outcomes (Supplementary Table 3).

Complications

No significant differences were observed between the VLPs and cast immobilization groups regarding overall complications, tendon rupture, carpal tunnel syndrome (CTS), and wound infection (deep/superficial) (Table 5). However, patients receiving VLPs exhibited significantly lower incidences of chronic regional pain syndrome (CRPS) and malunion compared to those treated with cast immobilization (Table 5). Subgroup outcomes were generally consistent with the overall results, indicating that the significantly lower incidences of CRPS appeared to be primarily attributed to the subgroup of patients aged ≥60 years, while the significantly lower incidences of malunion were mainly attributed to the subgroup of patients aged <60 years (Table 5).

Sensitivity analysis

Sensitivity analysis was initially performed using the leave-one-out approach for all outcomes. The direction and magnitude of pooled estimates for patient-reported functional scores, wrist functional outcomes, radiographic outcomes, and most complication outcomes remained consistent with studies removed in turn. However, in the analysis of overall complications rate, upon excluding the study of Arora et al., a significantly lower rate was observed in the VLPs group compared to the cast immobilization group (OR = 0.61; 95% CI, 0.40, 0.92; $p < 0.001$). Subsequently, sensitivity analysis was conducting excluding the studies of Drobetz et al. and Sharma et al., the two studies that included patients with OA fracture type B. The direction and magnitude of pooled estimates for all the assessed outcomes

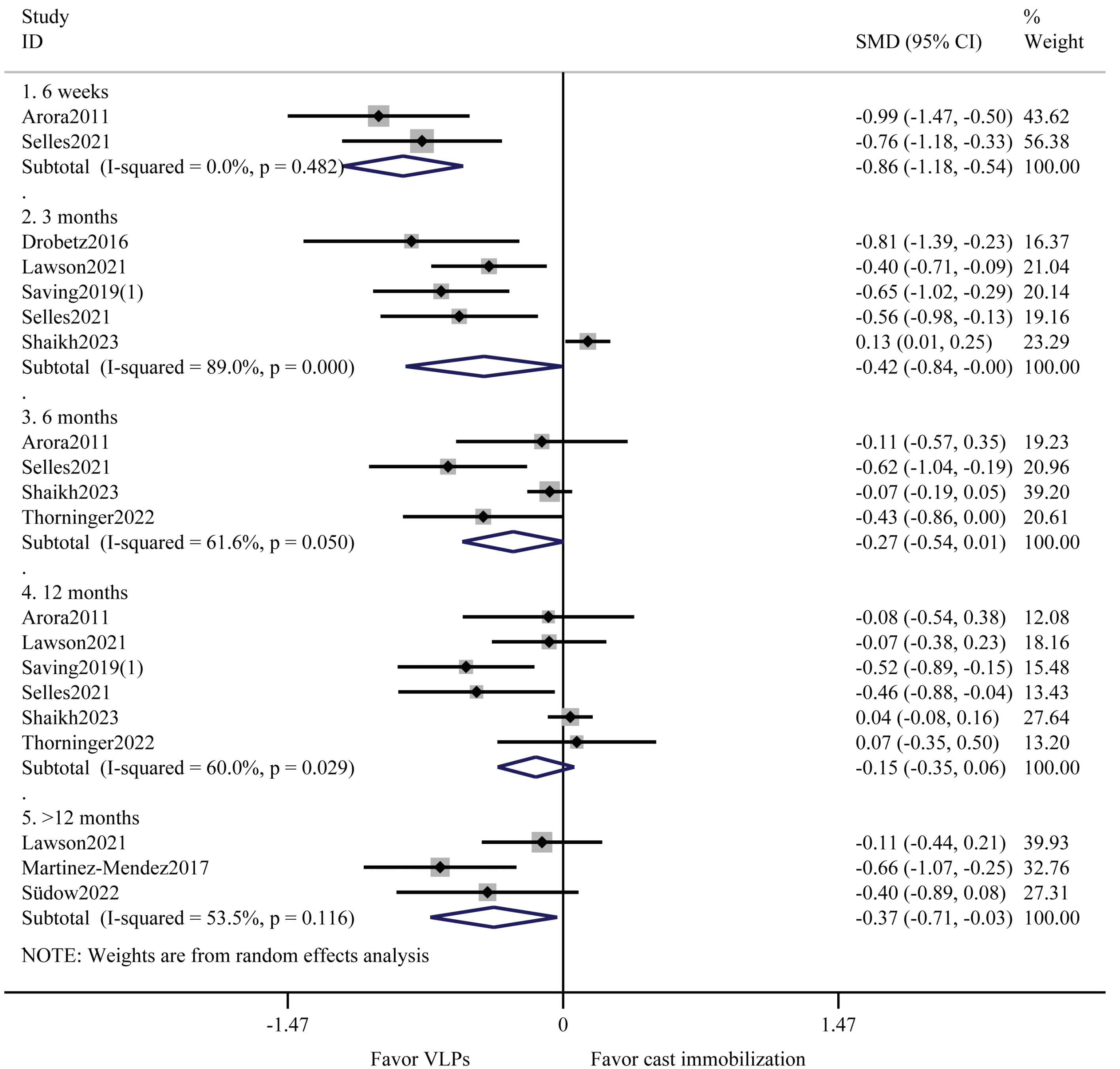

Figure 3. Forest plot of the Patient-rated Wrist Evaluation (PRWE) comparing volar locking plate versus cast immobilization for distal radius fractures, analyzing based on follow-up duration.

remained consistent with studies removed, indicating the reliability of the meta-analyses.

Publication bias

Publication bias was evaluated using outcomes of 12-month DASH score and overall complication rate. No evidence of publication bias was found concerning the overall complication rate (Begg's $p = 0.161$; Egger's $p = 0.328$). However, significant publication bias was detected regarding the 12-month DASH score (Begg's $p = 0.019$; Egger's $p = 0.015$). A trim and fill analysis was conducted, and despite this bias, a significantly better 12-month DASH score was still observed in the VLPs group, indicating that the impact of publication bias on this outcome was not significant.

Discussion

The main finding of the current meta-analysis is that the use of VLPs leads to faster functional recovery, improved fracture alignment, and similar safety profiles compared to cast immobilization. In terms of patient-reported outcomes, individuals treated with VLPs showed better DASH and PRWE scores at 6-week and 3-month follow-up. Regarding wrist functional outcomes, the advantages of VLPs were most pronounced at 6-week and 3-month follow-up, demonstrating enhanced wrist extension, flexion, supination, pronation, ulnar deviation, and radial deviation compared to cast immobilization. Additionally, VLPs yielded superior radiographic outcomes, including better volar tilt, radial inclination, and ulnar variance at 3-month follow-up. These findings consistently highlight improved short-term

(6 weeks to 3 months) clinical, functional, and radiographic outcomes for VLPs compared to cast immobilization in the treatment of DRFs, aligning with previous analyses and guidelines [29, 30]. The decision of treatment modality for DRF patients depends on various factors, including fracture pattern, comorbidities, patients' functional requirements, and orthopedists' clinical expertise. Therefore, for patients seeking enhanced joint function and faster recovery, VLPs may represent a preferred option.

An important limitation of previous reviews was the restriction of follow-up analysis to a maximum of 12 months [31–33]. In our analysis, we extended the comparison of outcome metrics to >12 months (24–36 months) follow-up to investigate whether VLP treatment offers sustained long-term benefits for DRF patients. Our results revealed that the use of VLPs yielded superior DASH scores, pronation, radial inclination, and radial height outcomes compared to cast immobilization at 12-month follow-up, with these benefits persisting at >12-month follow-up. While this subgroup analysis included only two to four trials, indicating relatively limited evidence, it does suggest the potential for VLPs to provide sustained long-term benefits for DRF patients compared to cast immobilization. Future studies should place greater emphasis on long-term outcome assessments to confirm the enduring efficacy of VLPs for DRFs.

Nevertheless, the interpretation of the present findings should be approached with caution. Is has been suggested in several studies that age is a predictor of clinical and radiographic outcomes following treatment procedures in DRFs patients [13, 34]. Therefore, we further performed subgroup analysis based on age. In the subgroup of age ≥60 years, patients who underwent VLPs exhibited significantly better radiographic outcomes, including volar tilt, radial inclination, and ulnar variance at 3-month and 12-month follow-up. However, the use of VLP was associated with better DASH only at 3-month follow-up and did not have beneficial effects on wrist ROM at any follow-up durations. Several studies have suggested that there is no clinically significant association between radiographic parameters and functional outcomes [35, 36], and that restoration of normal radiographic outcomes is not a positive predictor of functional outcomes [37, 38]. The absence of correlation between radiographic and functional outcomes might be attributed to decreased functional demands placed on the upper limbs, a phenomenon often linked to the aging process [39]. Additionally, one of the concerns regarding cast immobilization is the high rate of malunion. Results of our analysis found no significant difference in the incidence of malunion between VLPs and cast immobilization in patients aged ≥60 years. Furthermore, there is continued doubt about the functional implications of distal radius malunion in elderly patients, as many of them achieve satisfactory functional outcomes despite experiencing malunion following DRFs [39, 40]. Considering this, in elderly patients with lower functional demanding, a conservative approach might be a more cost-effective choice.

In the subgroup of patients aged <60 years, patient-reported functional outcomes, wrist functional outcomes, and complication rates were mostly consistent with the overall outcomes, suggesting that the beneficial results of VLPs compared with cast immobilization might be mostly attributed to younger age patients. Numerous previous meta-analyses have focused only on elderly patients aged ≥60 years [9, 10, 31]. Our meta-analysis filled the gap by presenting meta-analyzed results in DRFs patients aged <60 years. Our findings demonstrated early recovery of functional outcomes with the use of VLPs in this age group, which was manifested as better DASH score and wrist ROM at both 6-week and 3-month follow-up. Younger patients have good bone substance and require better joint function during recovery. Hence, VLPs might be a better choice in this age group.

Table 3. Meta-analysis results of wrist functional outcomes.

Outcomes	Number of study	SMD	95% CI	p	I^2 (%)
Extension (°)					
6-week	4	3.26	0.71, 5.81	0.012	98.2
3-month	6	0.65	−0.03, 1.34	0.063	95.4
6-month	4	0.57	−0.28, 1.41	0.189	95.7
12-month	7	0.42	−0.20, 1.05	0.184	95.4
> 12-month	4	0.90	−0.70, 2.49	0.271	97.3
Flexion (°)					
6-week	4	1.88	0.43, 3.32	0.011	96.4
3-month	6	0.69	0.08, 1.30	0.027	94.4
6-month	4	0.91	−0.01, 1.82	0.052	96.2
12-month	6	1.00	0.34, 1.66	0.03	95.7
> 12-month	4	0.96	−0.27, 2.19	0.126	95.8
Supination (°)					
6-week	4	2.17	0.23, 4.11	0.029	97.8
3-month	6	0.76	0.05, 1.48	0.036	95.7
6-month	4	1.14	−0.06, 2.33	0.062	97.6
12-month	7	0.78	0.17, 1.39	0.012	95.1
Pronation (°)					
6-week	4	1.43	0.22, 2.63	0.020	95.4
3-month	6	0.16	−0.03, 0.35	0.102	46.0
6-month	4	0.49	−0.16, 1.15	0.141	93.1
12-month	7	0.40	0.02, 0.78	0.041	88.4
Ulnar deviation (°)					
6-week	4	2.31	0.46, 4.16	0.015	97.6
3-month	4	0.58	−0.24, 1.39	0.168	93.1
6-month	3	0.09	−0.16, 0.34	0.473	0
12-month	6	0.56	−0.09, 1.22	0.090	92.4
Radial deviation (°)					
6-week	4	2.01	0.34, 3.68	0.018	97.1
3-month	4	1.16	v0.04, 2.36	0.058	96.3
6-month	3	-0.03	−0.28, 0.22	0.816	0
12-month	6	0.13	−0.63, 0.88	0.744	94.3
> 12-month	3	0.69	−1.30, 2.67	0.499	97.4
Grip strength (kg)					
6-week	3	3.31	0.32, 6.31	0.030	98.3
3-month	3	1.88	0.50, 3.25	0.008	95.1
6-month	3	1.73	0.48, 2.98	0.007	94.4
12-month	4	0.80	0.14, 1.46	0.017	88.3
> 12-month	1	0.40	−0.03, 0.83	0.067	-

SMD: standardized mean difference; CI: confidence interval.

Table 4. Meta-analysis results of radiological outcomes.

Outcomes	Number of study	SMD	95% CI	p	I^2 (%)
Volar Tilt (°)					
Postoperative	3	0.99	0.50, 1.48	< 0.001	60.0
6-week	-	-	-	-	-
3-month	4	0.66	0.08, 1.25	0.025	93.4
6-month	-	-	-	-	-
12-month	4	1.02	0.23, 1.81	0.011	97.0
> 12-month	2	2.21	−1.18, 5.59	0.201	98.1
Radial inclination (°)					
Postoperative	5	0.53	−0.03, 1.16	0.065	89.7
6-week	2	1.92	−0.24, 4.09	0.082	96.6
3-month	5	0.73	0.09, 1.37	0.026	96.4
6-month	-	-	-	-	-
12-month	6	1.18	0.43, 1.93	0.002	97.3
> 12-month	3	1.77	0.44, 3.10	0.009	93.5
Radial height (mm)					
Postoperative	1	1.47	0.91, 2.02	< 0.001	-
6-week	1	2.01	1.41, 2.61	< 0.001	-
3-month	2	−0.09	−0.22, 0.03	0.122	0
6-month	-	-	-	-	-
12-month	4	0.74	0.06, 1.42	0.034	96.2
> 12-month	2	1.91	1.20, 2.62	< 0.001	70.0
Ulnar variance (mm)					
Postoperative	4	−0.82	−1.66, 0.03	0.057	91.8
6-week	1	−3.21	−3.96, −2.46	< 0.001	-
3-month	4	−0.91	−1.03, −0.79	< 0.001	1.3
6-month	-	-	-	-	-
12-month	6	−1.29	−1.70, −0.89	< 0.001	89.9
> 12-month	3	−1.11	−3.69, 1.47	0.400	98.2

SMD: standardized mean difference; CI: confidence interval.

Table 5. Meta-analysis results of complication outcomes.

Outcomes	Number of study	OR	95% CI	*p*	I^2 (%)
Overall compilation					
Overall	11	0.70	0.44, 1.09	0.114	71.3
< 60 years	2	0.59	0.24, 1.42	0.235	54.4
≥ 60 years	8	0.74	0.42, 1.31	0.303	78.5
Tendon rupture					
Overall	10	1.80	0.72, 4.53	0.208	0
< 60 years	1	2.89	0.29, 28.63	0.370	-
≥ 60 years	8	1.53	0.53, 4.40	0.427	0
Carpal tunnel syndrome					
Overall	10	0.74	0.38, 1.43	0.369	26.9
< 60 years	3	0.57	0.02, 13.45	0.725	76.3
≥ 60 years	7	0.85	0.51, 1.42	0.535	0
Chronic regional pain syndrome					
Overall	9	0.41	0.23, 0.72	0.002	0
< 60 years	2	0.25	0.04, 1.55	0.136	0
≥ 60 years	6	0.43	0.23, 0.79	0.006	0
Malunion					
Overall	7	0.17	0.04, 0.64	0.009	66.1
< 60 years	2	0.04	0.01, 0.32	0.002	0
≥ 60 years	4	0.25	0.04, 1.51	0.131	77.1
Wound infection					
Overall	7	1.44	0.61, 3.38	0.406	0
< 60 years	2	4.18	0.46, 38.71	0.208	0
≥ 60 years	5	1.19	0.47, 3.02	0.707	0

OR: odd ratio; CI: confidence interval.

Certain limitations of the present study should be noted. To maximize the level of evidence, we exclusively included RCTs in the meta-analysis. However, despite this rigorous approach, the inclusion of 14 RCTs involving 2,431 DRF patients still represents a relatively small sample size, which might be insufficient to draw definitive conclusions. Several factors, including patients' comorbidities and fracture types, have been suggested to potentially influence treatment outcomes in DRFs [41]. However, due to scattered data, relevant subgroup analyses on these factors could not be conducted. Functional and radiographic outcomes were pooled based on follow-up times, and each follow-up included less than 10 study data points, with some outcomes having only two study data points. Thus, the findings of the current meta-analysis may not be conclusive until stronger evidence is presented in future studies.

Conclusion

The findings of this meta-analysis indicated that the use of VLPs leads to superior clinical, functional, and radiographic outcomes, with comparable safety profiles compared to cast immobilization, particularly in the short term (6 weeks to 3 months). Moreover, these benefits may extend to long-term follow-up periods (12 months to 36 months). However, age emerges as a crucial factor in treatment considerations for DRF patients. For patients under 60 years of age, VLPs demonstrate clear advantages, showing better clinical, functional, and radiological outcomes at both 3- and 12-month follow-up intervals while maintaining safety profiles similar to cast immobilization. Conversely, in patients aged 60 and above, VLPs may offer improved radiological outcomes compared to cast immobilization at 3- and 12-month assessments. Nonetheless, these improved radiographic outcomes may not necessarily translate into better clinical and functional outcomes.

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Contributorship statement

F.X.L. and L.T. conceived and designed the analysis; F.X.L., YZ.T., and L.C.C. performed study search and data collection; F.X.L., Y.Z.T., and L.C.C. contributed data or analysis tool; F.X.L., Y.Z.T., and L.C.C. performed the analysis; F.X.L. drafted and revised the manuscript; all authors contributed to the final version of manuscript.

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