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Original Article

Efficacy and safety of modified combined dorsal-volar approach for internal fixation in high-energy trauma-induced comminuted distal radius fracture with concomitant scaphoid fracture

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Abstract: This study investigated the clinical outcomes of the modified combined dorsal-volar approach for internal fixation of comminuted distal radius fractures complicated by scaphoid fractures resulting from high-energy trauma. A cohort of 100 patients with concurrent distal radius and scaphoid fractures underwent surgical management by this approach. Postoperative assessments included wrist joint function recovery, operative parameters (surgical time, intraoperative blood loss, and hospital stay), range of motion (ROM), functional scores (Disabilities of the Arm, Shoulder, and Hand [DASH], Bartra, and Gartland-Werley), fracture healing-related indicators, and serum inflammatory cytokine levels. Univariate and multivariate analyses were performed to identify independent predictors of wrist functional recovery. The results demonstrated an 88.0% excellent-to-good rate for postoperative wrist function. The mean surgical time was 141.39±20.21 minutes, with intraoperative blood loss averaging 114.84±24.87 mL and a mean hospital stay of 12.01±4.35 days. Significant improvements were observed in ROM, functional scores, and fracture healing-related measures, alongside a marked reduction in inflammatory cytokines. Age (odds ratio [OR] =14.194), DASH score (OR=1.395), and Gartland-Werley score (OR=1.431) were identified as independent prognostic factors for wrist functional recovery. These findings underscore the effectiveness of the modified combined dorsal-volar approach in restoring wrist joint function, facilitating fracture union, and mitigating inflammatory responses in patients with these conditions.

Keywords: Modified combined dorsal-volar approach for internal fixation, high-energy trauma, comminuted distal radius fracture, scaphoid fracture, wrist joint function

Introduction

Distal radius fractures (DRFs) account for 20% of bone injuries, primarily affecting the lower 2 to 3 cm of the radius, and are often associated with high-energy trauma or falls with both hands stretched out [1, 2]. Comminuted distal radius fractures (CDRFs), caused by high-energy injuries, are typically seen in younger, more demanding patients, and are relatively difficult to treat due to their associated comminution, bone loss, and soft tissue damage [3]. CDRFs combined with scaphoid fractures (SFs) account for 0.7%-4.0% of all upper limb fractures. SFs are frequently missed in diagnoses due to their insidious onset and atypical clinical symptoms, unusual anatomic location, and proximity to ipsilateral DRFs [4-6]. Furthermore, there was considerable variation in healing time between the two fracture types when treated with external fixation, highlighting the inadequacy of non-operative management for achieving optimal recovery in these patients [7, 8]. Despite numerous surgical procedures to treat CDRFs or SFs, effective therapies still require further validation.

Several studies have explored treatment optimization for CDRFs or SFs. For example, Gutiérrez-Espinoza et al. [9] found that volar plate fixation was as effective as conservative treatment (plaster fixation) in elderly patients

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with DRFs, significantly improving functional outcomes. Zhang et al. [10] showed that external fixators offer ideal clinical effect in treating CDRFs, contributing to an excellent or good rate of wrist joint function recovery as high as 89.0%. Alnaeem et al. [11] reported that percutaneous fixation demonstrated comparable union rates to non-surgical cast immobilization for acute nondisplaced SFs, with advantages in earlier return to work and accelerated functional recovery, without increasing the risk of complications. However, research on the treatment of CDRFs combined with SFs caused by high-energy injuries remains limited [12]. This study proposes that the modified combined dorsal-volar approach for internal fixation may achieve better clinical results.

This study introduced several notable innovations. First, the surgical technique itself represents a significant advancement. The novel modified combined dorsal-volar approach for internal fixation overcomes the inherent limitations of conventional single approaches (either volar or dorsal), offering a standardized surgical protocol for managing complex cases of CDRFs with concomitant SFs. Secondly, the research comprehensively elucidated the clinical advantages and underlying mechanisms of this combined approach through multidimensional assessments, including both biomechanical measurements (wrist range of motion [ROM]) and molecular biomarkers (bone metabolism markers and inflammatory cytokines). These findings not only facilitate informed decision-making for patients but also provide valuable insights for researchers to identify potential therapeutic targets. Lastly, employing multivariate regression analysis, the study systematically identified key determinants influencing functional recovery in patients with high-energy trauma-induced complex fractures, thereby contributing to evidence-based optimization of clinical management strategies.

Patients and methods

General data

This retrospective study was approved by the Ningxia Medical University General Hospital Ethics Committee. The participants were patients with high-energy trauma-induced CDRFs and SFs admitted to Ningxia Medical University General Hospital from January 2020 to January 2024. A total of 100 patients were treated with the modified combined dorsal-volar approach for internal fixation.

Patient enrollment and exclusion criteria

Inclusion criteria: 1) Diagnosis of high-energy trauma-induced CDRFs and SFs [12, 13]; 2) Treatment with the modified combined dorsal-volar approach for internal fixation; 3) Complete clinical data; 4) Normal communication and cognitive abilities; 5) Willingness to cooperate with the study; 6) Age range: 18-80; 7) First-time treatment for fractures, without prior surgical interventions.

Exclusion criteria: 1) Bilateral DRFs, forearm shaft fractures, or periarticular fractures of the ipsilateral elbow; 2) Periarticular open injuries of the ipsilateral elbow or open injuries of the forearm or wrist joint; 3) Vascular or nerve injury; 4) Presence of other carpal fractures and dislocations on the affected side, with only one of these injuries treated surgically and the other fracture sites treated conservatively; 5) Follow-up time <12 months; 6) Pre-existing wrist arthritis; 7) Significant systemic comorbidities (e.g., uncontrolled diabetes, immunocompromised state); 8) Previous surgical history involving the ipsilateral upper limb; 9) Concurrent neurological impairment affecting limb function.

Treatment methods

All patients were treated with the modified combined dorsal-volar approach for internal fixation. Operative Procedure: After successful general anesthesia, the affected limb was disinfected three times with conventional An'erdian, followed by surgical draping. A 33 KPa balloon tourniquet was applied. Two external fixation screws were placed parallel to the middle of the radius, and two threaded nails were inserted into the second metacarpal bone. The external fixator was connected to resist traction reduction. The normal height of the radius, radial inclination, and ulnar deviation were then restored. Fracture reduction was confirmed using C-arm fluoroscopy, and the external fixator screws were tightened once the reduction was satisfactory. Thereafter, an S-shaped incision was made over the wrist joint, from the palmar radiocarpal side to the dorsal radiocarpal side. Layers of skin, subcutaneous tissue, and fascia were carefully dissected. Blood clots were removed, and the area between the 3rd and 4th sheaths on the palmar and dorsal sides of the wrist was thoroughly irrigated to expose the comminuted distal radius fracture. The articular surface of the fractured end was reduced to the top of the articular surface, controlled by the reduction forceps, and cross-fixed with 6 titanium needles. After that, internal fixation was performed to ensure good joint alignment at the fractured end. Next, the radial dorsal incision was appropriately extended to the distal end, and the skin, subcutaneous tissue, and fascia were carefully incised. The joint capsule was cut to expose the scaphoid and lunate bones, revealing fractured distal scaphoid, dorsal scapholunate ligament tears, and scapholunate instability. The SF was cross-fixed with two 1.2 mm Kirschner wires, and the scapholunate joint was stabilized with a single 1.2 mm Kirschner wire placed volarly. During the operation, fracture alignment was confirmed, internal fixation was secured, and the scaphoid joint was stable. C-arm X-ray fluoroscopy confirmed proper reduction, alignment, and adequate length of internal fixation. The dorsal ligament of the wrist was then repaired. After rewashing with iodophor and normal saline, a loose tourniquet was used to stop the bleeding. After confirming good blood flow to the hand and proper instrument placement, the incision was sutured layer by layer with 4-0 sutures. A sterilized dressing was applied for pressure bandaging, and the procedure was completed.

Detection indicators

(1) Postoperative wrist joint function recovery. The degree of wrist function recovery was assessed by referring to the Gartland-Werley Score [14], which evaluates deformity, subjective evaluation of pain, ROM, and complications. The score ranges from 0 to 2 (excellent), 3 to 8 (good), 9 to 20 (fair), and ≥21 (poor). The score is directly proportional to the severity of wrist defects.

(2) Clinical indicators. The operative time, hospital stay, and intraoperative blood loss were recorded.

(3) ROM. Anteroposterior and lateral radiographs of bilateral wrist joints were taken. The angles of wrist dorsiflexion, palmar flexion, pronation, supination, radial deviation, and ulnar deviation were measured and compared before and after treatment.

(4) Upper limb function assessment (Disability of the Arm, Shoulder, and Hand (DASH) scale [15]). The DASH scoring is based on a 100-point assessment of upper limb pain, daily activities, work, and recreation. A higher DASH score indicates greater functional limitation.

(5) Bartra scale. The Bartra radiology score assesses radius height, radial inclination, ulnar deviation, articular surface flatness, and distal radioulnar joint alignment. A score ≥90 is considered excellent, 80~89 good, 70~79 acceptable, and ≤69 poor. The score is proportional to the degree of recovery.

(6) Fracture healing-related indicators. Morning fasting venous blood (2 mL) was collected from patients upon hospital admission (baseline) and at 6-month postoperative follow-up. The levels of bone-specific alkaline phosphatase (BALP), procollagen type I C-terminal propeptide (PICP), and osteocalcin (BGP) were measured using an automatic biochemical analyzer (Skillsmodel Biotech (Beijing) Co., Ltd., Catalyst One).

(7) Serum inflammatory cytokines. Serum concentrations of pro-inflammatory cytokines, including tumor necrosis factor-alpha (TNF-α), interleukin (IL)-1, and IL-6, were measured using enzyme-linked immunosorbent assay (ELISA; Bunsen (Tianjin) Health Technology Co., Ltd., B-0121, B-9893, B-0049) following standard protocols.

Among the evaluated measurements, postoperative wrist joint function recovery, clinical indicators, ROM, fracture healing-related markers, and serum inflammatory cytokine levels were identified as primary outcome measures. Secondary outcomes included upper limb function assessment using the DASH questionnaire and the Bartra Scale.

Statistical methods

Data were analyzed using SPSS 19.0. Categorical data were presented as number and percentage (n/%), while continuous data were expressed as mean ± SEM. Comparisons between groups were made using the χ^2 test for

Table 1. General information

Indicator	n=100
Age (years)	53.77±12.86
Sex	
Male	39 (39.00)
Female	61 (61.00)
AO classification of radial fractures	
C3	100 (100.00)
AO classification of scaphoid fractures	
A1-A2	24 (24.00)
B1-B3	63 (63.00)
C1-C3	13 (13.00)
Cause of injury	
Sports	13 (13.00)
Falls	51 (51.00)
Car accidents	36 (36.00)
Injured site	
Left wrist	50 (50.00)
Right wrist	50 (50.00)

Note: AO, Arbeitsgemeinschaft für Osteosynthesefragen.

Table 2. Postoperative wrist function recovery

Indicator	n=100
Excellent	37 (37.00)
Good	51 (51.00)
Fair	12 (12.00)
Poor	0 (0.00)

categorical data and t-test for continuous data. Intra-group comparisons of measured data before and after treatment were performed using paired t-tests. *P*-values <0.05 were considered statistically significant.

Results

General data

After strict screening based on the patient enrollment and exclusion criteria, 100 patients (61% female) were selected, with a mean age of (53.77±12.86) years. According to the Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification, all radial fractures were classified as C3 (100%). The SFs were mainly B1-B3 (63%), followed by A1-A2 (24%), and then C1-C3 (13%); the major cause of injury was falls (51%), followed by traffic accidents (36%), and sports injuries (13%). About 50% of the fractures occurred in the left wrist, and the other 50% in the right wrist. Please refer to **Table 1** for details.

Table 3. Clinical indicators

Indicator	n=100
Operative time (min)	141.39±20.21
Hospital stay (d)	12.01±4.35
Intraoperative blood loss (mL)	114.84±24.87

Efficacy and safety

All the operations went smoothly, with incisions healing by first intention. Two cases (2%) experienced red and swollen incisions, which improved after cleaning, dressing changes, and symptomatic treatment. There were no cases of extensor tendon irritation, distal locking staple penetration into the articular cartilage, or complications such as nerve or radial artery injury, fracture malunion, Sudek syndrome, or internal fixation failure.

Postoperative wrist function recovery

Among the 100 patients, 37 cases (37%) were rated as excellent, 51 cases (51%) as good, 12 cases (12%) as fair, and 0 cases as poor (**Table 2**).

Clinical indexes

Clinical indexes, including operative time, hospital stay, and intraoperative blood loss were evaluated, revealing a mean operative time of (141±20) min, a mean hospital stay of (12±4) days, and mean intraoperative blood loss of (115±25) mL. Details are shown in **Table 3**.

ROM

The ROM indicators were as follows: wrist dorsiflexion (62.27±5.58)°, palmar flexion (62.62±7.02)°, pronation (64.15±4.90)°, supination (61.69±5.50)°, radial deviation (23.92±3.86)°, and ulnar deviation (30.52±4.98)°, as shown in **Table 4**.

Various scale scores

The postoperative DASH score, Bartra score, and Gartland-Werley score of the 100 patients were (13.15±4.66), (85.76±5.12), and (4.36±2.42), respectively, as shown in **Table 5**.

Table 4. Range of motion

Indicator	n=100
Wrist dorsiflexion angle	62.27±5.58
Palmar flexion angle	62.62±7.02
Wrist pronation angle	64.15±4.90
Wrist supination angle	61.69±5.50
Wrist radial deviation angle	23.92±3.86
Wrist ulnar deviation angle	30.52±4.98

Bone healing-related biomarkers

Comparative analysis of bone healing-related biomarkers (BALP, PICP, and BGP) demonstrated significant postoperative elevation compared to preoperative baseline levels (all P<0.01) (**Figure 1**).

Inflammatory cytokine levels

Evaluation of pro-inflammatory cytokines (TNF-α, IL-1, and IL-6) in the cohort revealed significant postoperative reduction compared to preoperative values (all P<0.01) (**Figure 2**).

Univariate analysis of factors affecting postoperative wrist joint function

Patients whose postoperative wrist joint function was classified as "excellent" or "good" were grouped into the excellent group (n=88), while the remaining patients were classified as the non-excellent group (n=12). Univariate analysis revealed that age (P<0.001), DASH score (P<0.001), and Gartland-Werley defect score (P=0.017) were significantly associated with postoperative wrist joint function recovery, while gender, AO classification of SFs, cause of injury, injury site, Bartra score, bone healing-related biomarkers, and inflammatory cytokines were not (**Table 6**).

Multivariate analysis of factors affecting postoperative wrist function

Potential factors identified as significant in the univariate analysis were used as independent variables in a binary logistic regression model and assigned with values, to assess their effect on postoperative wrist function recovery. The multivariate analysis identified age (odds ratio [OR] =14.194), DASH score (OR=1.395), and Gartland-Werley defect score (OR=1.431) as independent risk factors for postoperative wrist function recovery (P<0.05) (**Tables 7**, **8**).

Table 5. Various scale scores

Indicator	n=100
DASH score	13.15±4.66
Bartra score	85.76±5.12
Gartland-Werley score	4.36±2.42

Note: DASH, Disability of the Arm, Shoulder, and Hand.

Discussion

Comminuted distal radius fractures (CDRFs) combined with scaphoid fractures (SFs) are often closely related to high-energy trauma, but the optimal treatment remains controversial [16]. Currently, commonly used therapies include internal fixation, open reduction, and internal fixation, plaster therapy, and headless compression screws. However, none of these approaches offer universal applicability, highlighting the need for continued exploration and optimization of treatment strategies for these complex cases [17].

The curative effect of CDRFs combined with SFs may be influenced by multiple factors, such as the severity of soft tissue trauma, ligament injury, fracture type, and the treatment scheme [18-20]. Treatment typically focuses on fixation and repair [21, 22]. In this study, a modified combined dorsal-volar approach was selected for internal fixation. The CDRF was treated first, followed by SF. This therapy first restores the normal height of the radius, radial inclination, and ulnar deviation angle using external fixation screws. Then, an S-shaped incision was made from the palmar to dorsal and radial sides of the wrist to achieve upper reduction of the fracture joint surface. Thereafter, titanium needles were used for cross-fixation to achieve proper joint alignment at the fracture end. Subsequently, a dorsal radial incision was extended to expose the scaphoid, with fixation of the scapholunate joint and repair of ligament tears performed using Kirschner wires.

Clinical data from 100 cases of high-energy trauma-induced CDRFs combined with SFs were analyzed in this study. All of them were treated with the modified combined dorsal-volar approach for internal fixation. The operations were successfully completed, with incisions healing in one stage. Two cases developed red and swollen incisions, which resolved with cleaning, dressing changes, and symptom-

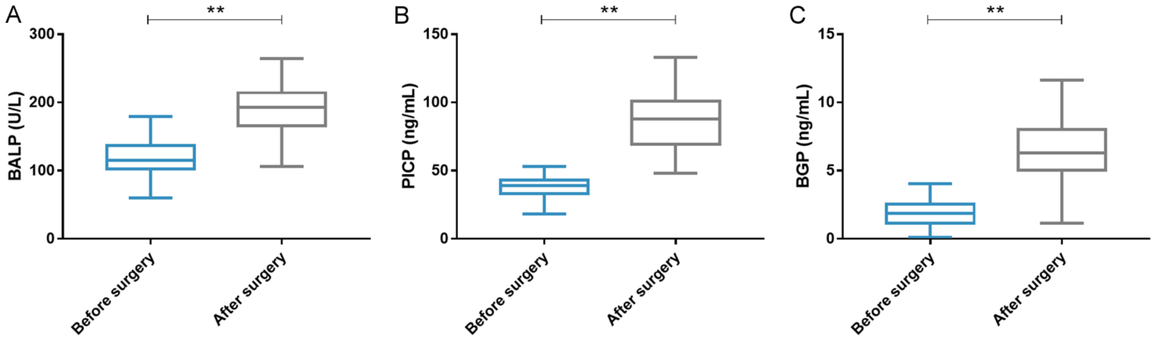

Figure 1. Comparison of bone healing-related biomarkers before and after surgery. A. Pre- and post-operative BALP levels. B. Pre- and post-operative PICP levels. C. Pre- and post-operative BGP levels. Note: BALP, bone-specific alkaline phosphatase; PICP, procollagen type I C-terminal propeptide; BGP, osteocalcin. **P<0.01.

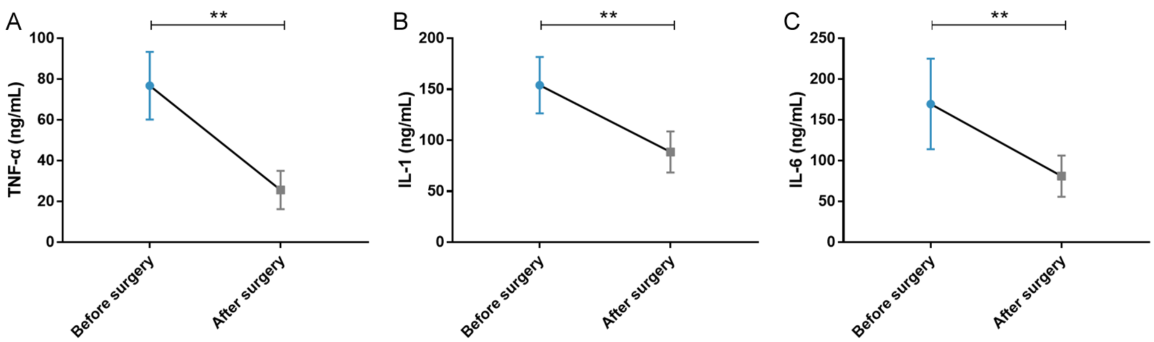

Figure 2. Comparison of inflammatory cytokine levels before and after surgery. A. Pre- and post-operative TNF-α levels. B. Pre- and post-operative IL-1 levels. C. Pre- and post-operative IL-6 levels. Note: TNF-α, tumor necrosis factor-alpha; IL-1/6, interleukin 1/6. **P<0.01.

atic treatment, suggesting that the modified combined dorsal-volar approach for internal fixation is clinically effective in managing CDRFs and SF caused by high-energy injuries. None of the patients had extensor tendon irritation symptoms, distal locking staples penetrating the articular cartilage surface, or complications such as nerve and radial artery injuries, fracture malunion, Sudek syndrome, or internal fixation failure, indicating a favorable safety profile.

The excellent and good rate of postoperative wrist function recovery in these 100 patients was as high as 88%, suggesting that the modified combined dorsal-volar approach for internal fixation can achieve better postoperative wrist function recovery. Moreover, the modified combined dorsal-volar internal fixation approach demonstrated dual therapeutic benefits in managing CDRFs with concomitant SFs, showing both enhanced osseous consolidation and marked attenuation of systemic inflammatory responses. Univariate analysis revealed no significant correlations between postoperative wrist functional recovery and gender, AO classification, cause of injury, injury site, or Bartra score. However, age, DASH score, and Gartland-Werley score demonstrated notable associations with functional outcomes. Multivariate logistic regression analysis further identified advanced age, higher DASH scores, and elevated Gartland-Werley scores as independent risk factors for impaired postoperative recovery. Patients with these risk factors had a significantly increased likelihood of suboptimal wrist functional recovery.

The modified combined dorsal-volar approach for internal fixation offers several advantages: The volar incision approach can completely expose the volar surface of the distal radius through the flexor carpi radialis tendon and the radial artery, with minimal damage to the soft tissues and no negative impact on the continuity of the dorsal soft tissues [23]; The technique

Table 6. Univariate analysis of factors affecting postoperative wrist joint function in patients

Indicator	Excellent group (n=88)	Non-excellent group (n=12)	χ^2/t	P
Age (years)			12.342	<0.001
<60	66 (75.00)	3 (25.00)		
≥60	22 (25.00)	9 (75.00)		
Sex			2.859	0.091
Male	37 (42.05)	2 (16.67)		
Female	51 (57.95)	10 (83.33)		
AO classification of scaphoid fractures			0.194	0.908
A1-A2	21 (23.86)	3 (25.00)		
B1-B3	56 (63.64)	7 (58.33)		
C1-C3	11 (12.50)	2 (16.67)		
Cause of injury			1.770	0.413
Sports	10 (11.36)	3 (25.00)		
Falls	46 (52.27)	5 (41.67)		
Car accidents	32 (36.37)	4 (33.33)		
Injured site			0.379	0.538
Left wrist	43 (48.86)	7 (58.33)		
Right wrist	45 (51.14)	5 (41.67)		
DASH (points)	12.58±4.21	17.33±5.79	3.496	<0.001
Bartra Scale (points)	85.99±5.00	84.08±5.87	1.216	0.227
Gartland-Werley Scale (points)	4.15±2.26	5.92±3.06	2.434	0.017
Preoperative BALP (U/L)			0.103	0.748
<120	47 (53.41)	7 (58.33)		
≥120	41 (46.59)	5 (41.67)		
Preoperative PICP (ng/mL)			0.088	0.767
<38	40 (45.45)	6 (50.00)		
≥38	48 (54.55)	6 (50.00)		
Preoperative BGP (ng/mL)			0.750	0.387
<2	47 (53.41)	8 (66.67)		
≥2	41 (46.59)	4 (33.33)		
Preoperative TNF-α (ng/mL)			1.694	0.193
<80	54 (61.36)	5 (41.67)		
≥80	34 (38.64)	7 (58.33)		
Preoperative IL-1 (ng/mL)			0.475	0.491
<155	46 (52.27)	5 (41.67)		
≥155	42 (47.73)	7 (58.33)		
Preoperative IL-6 (ng/mL)			1.339	0.247
<170	45 (51.14)	4 (33.33)		
≥170	43 (48.86)	8 (66.67)		

Note: AO, Arbeitsgemeinschaft für Osteosynthesefragen; DASH, Disability of the Arm, Shoulder, and Hand; BALP, bone-specific alkaline phosphatase; PICP, procollagen type I C-terminal propeptide; BGP, osteocalcin; TNF-α, tumor necrosis factor-alpha; IL-1/6, interleukin 1/6.

provides a good tension band effect, effectively preventing the loss of bone graft fragments [24]; After surgery, the pronator quadratus can be repaired to the maximum extent, reducing the risk of flexor tendon and median nerve irritation caused by steel plates and screws [25].

This study had several limitations that warrant attention for future research. First, the absence of a control group necessitates comparative studies to rigorously evaluate its specific clinical benefits. Second, the lack of mid-to-long-term (3-5 year) functional outcome data

Table 7. Variable assignment

Indicator	Variable	Assignment
Age (years)	X1	<60 =0, ≥60 =1
DASH (points)	X2	Continuous variable
Gartland-Werley defect score (points)	X3	Continuous variable
Postoperative wrist function	Y	Excellent =0, non-excellent =1

Note: DASH, Disability of the Arm, Shoulder, and Hand.

Table 8. Multivariate analysis of factors influencing postoperative wrist function recovery

Indicator	β	SE	Wald	P	OR	95% CI
Age (years)	2.653	0.887	8.948	0.003	14.194	2.496-80.721
DASH (points)	0.333	0.106	9.841	0.002	1.395	1.133-1.718
Gartland-Werley defect score (points)	0.358	0.163	4.839	0.028	1.431	1.010-1.968

Note: DASH, Disability of the Arm, Shoulder, and Hand.

highlights the need for extended follow-up investigations to better assess its sustained clinical efficacy. Third, while certain bone metabolism markers and inflammatory factors were examined, the fundamental mechanisms underlying these observations require further investigation through additional mechanistic studies. Future research efforts should prioritize addressing these limitations, emphasizing longitudinal evaluation and systematic optimization of the treatment strategy.

Conclusion

The modified combined dorsal-volar approach for internal fixation is a promising option for managing high-energy trauma-induced CDRFs with SFs. It demonstrates significant practical value, primarily manifested by its satisfactory therapeutic efficacy and safety profile. Moreover, this approach plays a crucial role in restoring patients' wrist joint function, promoting bone healing, and reducing serum inflammation markers.

Disclosure of conflict of interest

None.

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