Article

Comparative Assessment of Ultra-Minimally Invasive Approach versus Thoracoscopic Internal Fixation for Multiple Rib Fractures and Associated Thoracic Trauma

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AIM: This study aims to comparatively evaluate the ultra-minimally invasive rib fixation versus thoracoscopic internal fixation for pulmonary function recovery and prognosis in patients with multiple rib fractures and associated thoracic trauma.
METHODS: This retrospective analysis included 120 patients with multiple rib fractures complicated by thoracic trauma admitted to Huai'an 82 Hospital between January 2020 and November 2024. Based on different surgical approaches, the patients were divided into a control group (n = 68), who received thoracoscopic internal fixation of rib fractures, and an observation group (n = 52) who underwent ultra-minimally invasive rib fracture fixation. Several surgical indices were comparatively assessed, including clinical efficacy, surgical parameters, complication rates, visual analogue scale (VAS) scores (pre- *vs* post-operation), pulmonary function tests, serum inflammatory marker levels, and quality of life assessments.
RESULTS: The overall treatment efficacy between the observation and control groups [98.08% (51/52) *vs* 89.71% (61/68)] was not statistically significant ($p = 0.146$). The observation group had significantly shorter operation time, extubation time, time to ambulation, and hospitalization time than the control group, along with significantly reduced intraoperative bleeding ($p < 0.001$). The groups showed significant reductions in VAS scores at 12-h, 24-h, 48-h, and 72-h postoperatively compared to the preoperative baseline, with the observation group showing significantly lower scores than the control group at all time points ($p < 0.05$). Furthermore, significant increases in peak expiratory flow (PEF), forced vital capacity (FVC), and forced expiratory volume in 1 second (FEV1) were observed at 14 days after the procedure compared with their preoperative values, with the observation group indicating significantly higher values ($p < 0.05$). Similarly, C-reactive protein (CRP), tumor necrosis factor-α (TNF-α), and interleukin-6 (IL-6) levels were substantially elevated in both groups at 48h postoperatively compared with their preoperative values; however, the observation group demonstrated significantly lower levels than the control group ($p < 0.05$). Three months after the procedure, both groups showed significant improvement in all eight areas of the 36-Item Short-Form Health Survey (SF-36) domains compared with preoperative values, with the observation group demonstrating significantly higher scores than the control group ($p < 0.05$). Additionally, the overall postoperative complications rate did not differ substantially between the two groups [13.46% (7/52) *vs* 16.18% (11/68); $p = 0.680$].
CONCLUSIONS: Compared with thoracoscopic internal fixation for multiple rib fractures complicated by thoracic trauma, ultra-minimally invasive rib fracture fixation offers clear advantages, including shorter operative time, reduced intraoperative bleeding, and faster postoperative recovery, while significantly improving pulmonary function and inflammatory marker levels.

Keywords: multiple rib fractures; thoracic trauma; ultra-minimally invasive rib fixation; thoracoscopic rib internal fixation

Introduction

Multiple rib fractures are common complications of chest trauma. The resulting flail chest, severe pain and respiratory dysfunction significantly increase the risks of pulmonary infection, acute respiratory distress syndrome, and other complications, leading to a relatively high fatality rate [1–3]. Traditional conservative treatment mainly focuses on analgesia and mechanical ventilation; however, it often leads to delayed recovery of pulmonary function and prolonged hospitalization [4,5].

In recent years, surgical internal fixation has become a crucial treatment modality for moderate to severe rib fractures. Minimally invasive techniques further enhanced rib fracture management by reducing surgical trauma and promoting postoperative recovery. Approaches such as thoracoscopy-assisted and ultra-minimally invasive approaches aim to achieve stable fracture fixation while minimizing tissue disruption. Furthermore, these methods have been reported to decrease postoperative pain, shorten hospitalization, and improve functional outcomes compared with traditional open surgery [6,7]. However, the comparative efficacy of various minimally invasive techniques, such as thoracoscopic versus ultra-minimally invasive fixation,

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remains to be investigated. Particularly, thoracoscopy-assisted fixation, which enables direct visualization and precise fracture reduction, can effectively reduce lung tissue injury and improve prognosis [6,8]. Despite these advantages, thoracoscopy-assisted fixation still poses challenges, such as greater surgical trauma and a higher risk of intercostal nerve injury [9].

The ultra-minimally invasive rib fracture fixation techniques, including percutaneous internal fixation and 3D navigation-assisted small incision fixation, have gained increasing attention for their advantages, such as small incisions, reduced muscle dissection, and rapid postoperative recovery [7]. Prior evidence indicates that these techniques can further minimize surgical trauma and postoperative pain; however, compelling evidence regarding their long-term impact on pulmonary function recovery remains limited [10]. Multiple studies have affirmed the efficacy of minimally invasive rib fixation. For instance, Wang *et al*. [11] demonstrated that thoracoscopic-assisted fixation provides superior visualization and stable fixation outcomes, while significantly reducing postoperative pain and hospitalization compared with conventional open modalities [11].

Concurrently, the advances in ultra-minimally invasive (UMI) approaches, such as those described by Long *et al*. [12], highlight their potential to reduce soft-tissue dissection and enhance rapid recovery. A meta-analysis by Long *et al*. [13], reported that surgical stabilization offers better outcomes than conservative management in patients with multiple rib fractures. Furthermore, a study by Tichenor *et al*. [14] assessed technical optimization and compared different minimally invasive plating systems, demonstrating significant variations in operative efficiency.

Currently, there is limited clinical evidence comparing the efficacy of the two surgical procedures in patients with multiple rib fractures and associated thoracic trauma, especially regarding their effects on pulmonary function indicators, complication rates, and quality of life. The primary innovation of this study lies in its direct, head-to-head comparative design, which simultaneously evaluates clinical efficacy, surgical trauma, pulmonary function, systemic inflammatory response, and patient-reported quality of life. This comparative assessment provides a holistic evidence base for differentiating these two advanced minimally invasive techniques. The study aims to compare ultra-minimally invasive fixation with thoracoscopic internal fixation regarding pulmonary function recovery and prognosis in patients with multiple rib fractures, thereby guiding surgical decision-making, optimizing treatment, and improving patients' quality of life.

Methods

Study Participants

This retrospective study enrolled 120 individuals with multiple rib fractures and associated chest trauma admitted to Huai'an 82 Hospital between January 2020 and November 2024. Based on the surgical approach received, they were divided into two groups: the control group ($n = 68$) and the observation group ($n = 52$). Patients in the control group received thoracoscopic internal fixation while patients in the observation group were treated with ultra-minimally invasive rib fracture fixation. A flow chart of patient selection is shown in Fig. 1.

Inclusion criteria for patient selection were as follows: (1) presence of $\geq$2 rib fractures concomitant with hemopneumothorax of equal or greater degree, confirmed by chest computed tomography (CT) and X-ray; (2) time from injury to hospital admission $<$12 hours; (3) those with no surgical contraindications; (4) pulmonary function tests performed both preoperatively and 14 days after the procedure; (5) stable vital signs with sufficient surgical tolerance; and (6) availability of complete clinical data. During patient recruitment, the exclusion criteria were set as below: (1) history of thoracic surgery; (2) comorbid malignant tumors; (3) coexisting inflammatory diseases (e.g., rheumatoid arthritis or systemic lupus erythematosus); (4) multiple or compound injuries; (5) severe vital organ dysfunction (e.g., heart, liver, or kidney failure) or uncontrolled systemic inflammation (C-reactive protein (CRP) $>$20 mg/L); and (6) severe lung infections or chronic lung diseases.

The study complied with the fundamental principles of the Declaration of Helsinki and received approval from the Ethics Committee of Huai'an 82 Hospital (No. HA82YY202511). Additionally, written informed consent was obtained from each study participant.

Surgical Treatment Methods

Patients in the control group underwent thoracoscopic internal fixation. Under general anesthesia with double-lumen endotracheal intubation to achieve single-lung ventilation, patients were placed in a standard lateral decubitus position. A 1-cm incision was made at the 7th–8th intercostal space along the mid-axillary line to serve as an observation port, through which a 30° thoracoscope was inserted for pleural cavity examination. Depending on the location of the rib fracture, 1 or 2 additional 5-mm incisions were made as operative ports. Hematocele and fibrin clots were aspirated, and pulmonary injury was assessed under direct visualization. Fractured bone ends were elevated and reduced employing endoscopic instruments, and when necessary, a 3–5 cm auxiliary incision was established to enhance visualization. A locking compression plate of appropriate length was introduced into the thoracic cavity through the operative port, with 3–4 screws fixed on each side of the fracture to achieve stable fixation. After fixation, thoracoscopic re-examination confirmed hemostasis. A 28F chest tube was inserted, followed by all incisions closed in layers. Drainage characteristics and volume were closely monitored after the procedure.

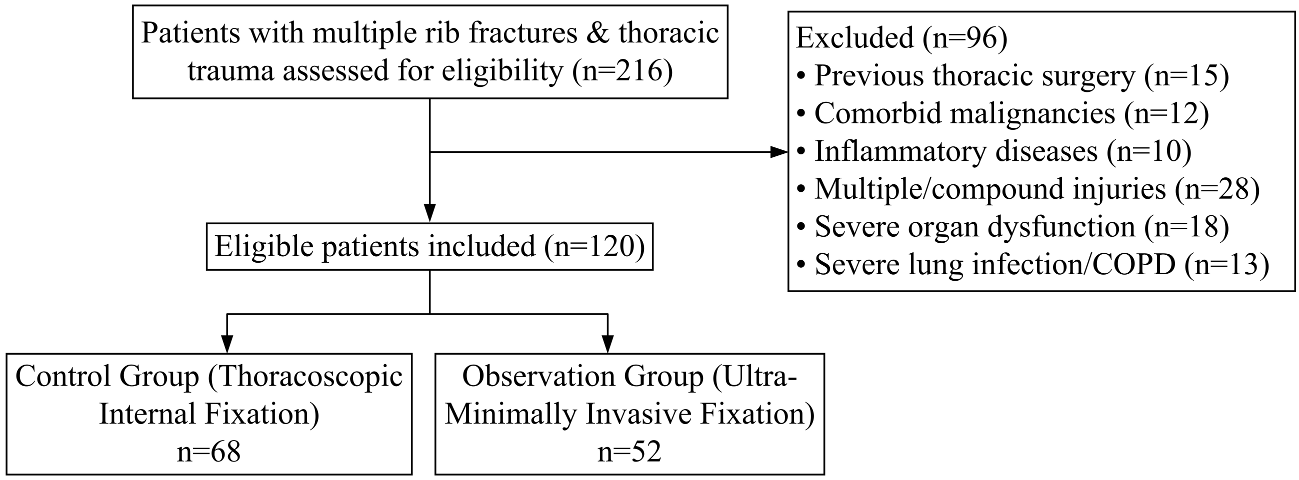

Fig. 1. A flow diagram of patient selection and study design. COPD, chronic obstructive pulmonary disease.

Patients in the observation group received ultra-minimally invasive rib fracture fixation. After induction of general anesthesia, patients were positioned either supine or in the contralateral lateral decubitus position, depending on fracture location. Under fluoroscopic (C-arm) guidance, the fracture site was precisely localized. A 2–3 cm incision was created over the corresponding anatomical site of the fracture, followed by blunt dissection through subcutaneous tissue and muscle layers to expose the fracture ends. The periosteum was gently elevated using a specialized periosteal elevator while protecting the intercostal neurovascular bundle. A reduction clamp was inserted through the incision, and the fractured segments were realigned under fluoroscopic guidance. An appropriate shape-memory alloy clamp or mini-titanium plate of suitable size was then implanted and secured to ensure stable fixation. Final fluoroscopic imaging was performed to confirm reduction and appropriate device positioning. The muscular layer, subcutaneous tissue, and skin were sequentially sutured.

All surgical procedures were performed by the same team of experienced thoracic surgeons, each with over 5 years of specialization in rib fixation techniques.

Observation Indicators

This study examined the following observational indicators. (1) Surgical parameters included operative time, intraoperative bleeding, extubation time, time to ambulation, length of hospitalization, fracture healing time, and fracture alignment rate. (2) Pain assessment was performed using the visual analogue scale (VAS) [15], with a score ranging from 0 to 10, with higher scores indicating more severe pain. VAS scores were documented preoperatively and at 12, 24, 48, and 72 hours postoperatively. (3) Pulmonary function was evaluated using peak expiratory flow (PEF), forced vital capacity (FVC), and forced expiratory volume in one second (FEV1), measured preoperatively and 14 days after the procedure using a pulmonary function analyzer (AS-507, Minolta, Tokyo, Japan). (4) Serum inflammatory markers, including CRP, tumor necrosis factor-α (TNF-α), and interleukin-6 (IL-6), were assessed using 3 mL fasting venous blood samples obtained between 7:00 and 8:00 AM on the day before surgery (baseline) and at 48 hours postoperatively. All samples were processed within 1 hour of collection via enzyme-linked immunosorbent assay (ELISA). (5) Health-related quality of life assessed using the 36-Item Short-Form Health Survey (SF-36) [16], which examines eight health domains: physical functioning (PF), role-physical (RP), bodily pain (BP), general health (GH), vitality (VT), social functioning (SF), role-emotional (RE), and mental health (MH). Each domain scored between 0 and 100, with higher scores indicating better quality of life. These evaluations were conducted preoperatively and 3 months after the procedure. (6) Postoperative complications were also assessed, which included pulmonary infection, hemothorax, atelectasis, and pneumothorax.

Evaluation of Clinical Efficacy

Therapeutic efficacy was evaluated at 6 months post-surgery [17]. "Marked effectiveness" was defined as normal respiration, absence of pain, no thoracic deformity, symmetrical bilateral thoracic configuration, and satisfactory fracture alignment. "Effectiveness" was defined as slightly impaired breathing, localized residual pain, near-symmetrical thoracic shape, and improved but partially sub-optimal fracture alignment. "Ineffectiveness" was defined as mild respiratory dysfunction, significant chest wall pain, visible thoracic deformity, poor fracture alignment, and displacement exceeding 3 mm. The total effective rate was calculated as: total effective rate = (significantly effective cases + effective cases) / total cases $\times$ 100%.

Statistical Analysis

Data were analyzed using SPSS 22.0 software (IBM Corporation, Armonk, NY, USA). The normality of continuous

Table 1. Comparison of baseline characteristics between the two patient groups.

Group	Control group (*n* = 68)	Observation group (*n* = 52)	t/χ^2	*p*-value
Male [*n* (%)]	42 (61.76)	36 (69.23)	0.722	0.395
Age (year)	40.12 ± 7.36	40.65 ± 7.58	0.386	0.700
Hypertension [*n* (%)]	12 (17.65)	9 (17.31)	0.002	0.961
Diabetes mellitus [*n* (%)]	7 (10.29)	5 (9.62)	0.015	0.902
Coronary heart disease [*n* (%)]	5 (7.35)	3 (5.77)	0.119	0.730
ASA physical status [n (%)]			0.382	0.826
I	20 (29.41)	18 (34.62)		
II	40 (58.82)	28 (53.85)		
III	8 (11.76)	6 (11.54)		
Fracture laterality [*n* (%)]			0.276	0.600
Unilateral fracture	45 (66.18)	32 (61.54)		
Bilateral fracture	23 (33.82)	20 (38.46)		
Injury mechanisms [*n* (%)]			0.654	0.884
Traffic injury	29 (42.65)	21 (40.38)		
Heavy object injury type	19 (27.94)	17 (32.69)		
Falling injury	16 (23.53)	10 (19.23)		
Other reasons	4 (5.88)	4 (7.69)		
Number of rib fractures	4.22 ± 1.14	4.04 ± 1.32	0.800	0.425
Flail chest [n (%)]	15 (22.06)	10 (19.23)	0.143	0.705
Lung compression volume (%)	25.81 ± 8.40	24.32 ± 9.11	0.928	0.355
Hemothorax volume (mL)	285.52 ± 105.74	270.83 ± 98.35	0.777	0.439

Note: ASA, American Society of Anesthesiologists.

Table 2. Comparison of clinical efficacy between the two groups [*n* (%)].

Group	*n*	Significant effectiveness	Effectiveness	Ineffective	Total effective rate
Control group	68	37 (54.41)	24 (35.29)	7 (10.29)	61 (89.71)
Observation group	52	36 (69.23)	15 (28.85)	1 (1.92)	51 (98.08)
χ^2					2.110
p-value					0.146

variables was assessed using the Shapiro-Wilk test. Variables following a normal distribution were expressed as $\bar{x}$ ± s, and between-group comparisons were conducted using the independent sample *t*-test. For variables measured at multiple time points (e.g., VAS scores), a two-way repeated measures analysis (analysis of variance (ANOVA)) was employed to examine the effects of time, group, and their interaction. If a significant interaction was observed, a simple effects analysis with Bonferroni corrected post-hoc comparisons was conducted to identify the source of the difference. The Greenhouse-Geisser correction was applied when the sphericity assumption was violated. Categorical variables were expressed as %, and the χ^2 test was used for between-group comparisons. Statistical significance was achieved at α = 0.05.

Results

Comparison of Baseline Characteristics Between the Two Patient Groups

There were no statistically significant differences in demographics (gender or age), fracture characteristics (laterality, number of rib fractures and proportion of flail chest), severity of injury (lung compression volume, hemothorax volume and injury mechanisms), comorbidities (hypertension, diabetes mellitus, and coronary heart disease), or American Society of Anesthesiologists (ASA) physical status between the two groups (all $p > 0.05$). These findings confirm that the control and observation groups were comparable at baseline characteristics before surgical intervention (Table 1).

Comparison of Clinical Efficacy Between the Two Groups

The total effective treatment rate was 98.08% (51/52) in the observation group and 89.71% (61/68) in the control group. Although the observation group demonstrated a relatively higher rate, the difference between the two groups was statistically insignificant (p = 0.146, Table 2).

Comparison of Surgery-Related Indicators Between the Two Groups

The observation group showed substantially shorter operation time, extubation time, time to ambulation, and length of hospital stay than the control group, along with a significantly decreased intraoperative bleeding ($p < 0.001$). Fur-

Table 3. Comparison of surgery-related indicators between the two groups.

Group	Control group (n = 68)	Observation group (n = 52)	t/χ^2	p-value
Operative time (minutes)	65.21 ± 17.24	48.55 ± 14.29	5.641	<0.001
Intraoperative bleeding (mL)	50.39 ± 10.78	32.41 ± 8.64	9.847	<0.001
Extubation time (days)	6.86 ± 2.01	4.23 ± 1.27	8.255	<0.001
Time to ambulation (days)	3.73 ± 1.15	2.14 ± 0.95	8.080	<0.001
Hospitalization time (days)	11.84 ± 2.21	7.62 ± 2.06	10.672	<0.001
Fracture healing time (months)	2.51 ± 0.74	2.42 ± 0.68	0.684	0.496
Fracture alignment rate [n (%)]	63 (92.65)	50 (96.15)	0.176	0.675

Table 4. Comparison of VAS scores before and after surgery between the two groups ($\bar{x} \pm s$, points).

Group	n	Preoperative	12 hours postoperative	24 hours postoperative	48 hours postoperative	72 hours postoperative
Control group	68	7.51 ± 1.37	5.85 ± 1.13†	4.02 ± 0.84†	3.22 ± 0.75†	2.25 ± 0.64†
Observation group	52	7.64 ± 1.44	5.12 ± 0.98†*	3.25 ± 0.77†*	2.87 ± 0.65†*	1.98 ± 0.47†*

Note: VAS, visual analogue scale. Data were analyzed by two-way repeated-measures (analysis of variance (ANOVA)). Main effect of time: F = 315.472, $p < 0.001$; main effect of group: F = 28.917, $p < 0.001$; time-by-group interaction: F = 5.635, $p < 0.001$. Post-hoc pairwise comparisons were performed with the Bonferroni correction. †: Within the same group, significantly different from the preoperative value ($p < 0.05$). *: At the same time point, significantly different from the control group ($p < 0.05$).

Table 5. Comparison of pulmonary function indicators before and after surgery between the two groups ($\bar{x} \pm s$).

Group	n	PEF (L/s)		FVC (L)		FEV1 (L)	
		Preoperative	14 days postoperative	Preoperative	14 days postoperative	Preoperative	14 days postoperative
Control group	68	3.72 ± 0.95	6.07 ± 1.02*	2.02 ± 0.45	2.69 ± 0.53*	1.14 ± 0.23	1.98 ± 0.34*
Observation group	52	3.65 ± 0.83	6.75 ± 1.14*	1.95 ± 0.36	2.94 ± 0.58*	1.17 ± 0.19	2.17 ± 0.41*
t		0.422	3.438	0.919	2.458	0.762	2.773
p-value		0.674	0.001	0.360	0.015	0.447	0.006

Note: PEF, peak expiratory flow; FVC, forced vital capacity; FEV1, forced expiratory volume in 1 second. Compared with preoperative levels, *$p <$ 0.05.

Table 6. Comparison of serum inflammatory marker levels before and after surgery between the two groups ($\bar{x} \pm s$).

Group	n	CRP (mg/L)		TNF-α (pg/mL)		IL-6 (pg/mL)	
		Preoperative	48 hours postoperative	Preoperative	48 hours postoperative	Preoperative	48 hours postoperative
Control group	68	8.51 ± 1.12	11.76 ± 2.88*	185.79 ± 9.24	202.38 ± 10.14*	50.12 ± 5.58	60.77 ± 6.02*
Observation group	52	8.62 ± 1.18	10.07 ± 2.59*	185.48 ± 9.53	194.83 ± 9.95*	50.43 ± 5.69	56.03 ± 5.86*
t		0.521	3.326	0.180	4.075	0.299	4.323
p-value		0.603	0.001	0.858	<0.001	0.765	<0.001

Note: CRP, C-reactive protein; TNF-α, tumor necrosis factor-α; IL-6, interleukin-6. Compared with preoperative levels, *$p < 0.05$.

Table 7. Comparison of quality of life (SF-36) scores (Part I) before and after surgery between the two groups ($\bar{x} \pm s$, points).

Group	n	Mental health		Role-emotional		Social functioning		Vitality	
		Preoperative	3 months postoperative	Preoperative	3 months postoperative	Preoperative	3 months postoperative	Preoperative	3 months postoperative
Control group	68	68.34 ± 2.41	83.01 ± 3.05*	68.26 ± 2.33	82.45 ± 2.47*	64.96 ± 2.28	82.59 ± 3.56*	62.78 ± 3.11	81.74 ± 4.06*
Observation group	52	68.21 ± 2.39	85.48 ± 2.96*	68.19 ± 2.28	84.12 ± 2.71*	65.01 ± 2.31	84.69 ± 3.48*	62.64 ± 2.86	84.03 ± 3.89*
t		0.297	4.452	0.165	3.518	0.118	3.233	0.253	3.118
p-value		0.767	<0.001	0.870	0.001	0.906	0.002	0.801	0.002

Note: Compared with preoperative levels, *$p < 0.05$. SF-36, 36-Item Short Form Health Survey.

Table 8. Comparison of quality of life (SF-36) scores (Part II) before and after surgery between the two groups ($\bar{x} \pm s$, points).

Group	n	General health		Bodily pain		Role-physical		Physical functioning	
		Preoperative	3 months postoperative	Preoperative	3 months postoperative	Preoperative	3 months postoperative	Preoperative	3 months postoperative
Control group	68	66.48 ± 2.74	79.65 ± 3.92*	59.32 ± 2.24	81.05 ± 3.79*	65.47 ± 2.56	78.63 ± 3.15*	67.43 ± 2.56	83.05 ± 3.95*
Observation group	52	66.32 ± 2.65	81.75 ± 4.01*	59.46 ± 2.38	83.18 ± 3.64*	65.58 ± 2.76	80.96 ± 3.21*	67.38 ± 2.61	85.11 ± 3.24*
t		0.322	2.879	0.330	3.103	0.225	3.982	0.105	3.055
p-value		0.748	0.005	0.742	0.002	0.822	<0.001	0.916	0.003

Note: Compared with preoperative levels, *$p < 0.05$.

Table 9. Comparison of postoperative complications between the two groups [n (%)].

Group	n	Pulmonary infection	Hemothorax	Atelectasis	Pneumothorax	Total incidence rate
Control group	68	5 (7.35)	3 (4.41)	1 (1.47)	2 (2.94)	11 (16.18)
Observation group	52	2 (3.85)	2 (3.85)	2 (3.85)	1 (1.92)	7 (13.46)
χ^2						0.170
p-value						0.680

thermore, no statistically significant differences were found in fracture healing time or fracture alignment rate ($p > 0.05$, Table 3).

Comparison of VAS Scores Before and After Surgery Between the Two Groups

The VAS scores were analyzed using a two-way repeated-measures ANOVA, with time points (preoperative, 12 hours, 24 hours, 48 hours, and 72 hours) as the within-subjects factor and treatment group (Control vs. Observation) as the between-subjects factor. The analysis revealed significant main effects of time (F = 315.472, $p < 0.001$), group (F = 28.917, $p < 0.001$), and a significant time-by-group interaction (F = 5.635, $p < 0.001$).

The significant interaction effect indicated that the changing pattern of VAS scores over time differed between the two groups. Post-hoc pairwise comparisons with Bonferroni correction revealed that, within each group, postoperative VAS scores at each time point were significantly lower than preoperative values (all $p < 0.001$). Furthermore, at each postoperative time point (12 hours, 24 hours, 48 hours, and 72 hours), VAS scores in the observation group were significantly lower than those in the control group (all $p <$ 0.05). A comparison of VAS scores between the two groups is summarized in Table 4.

Comparison of Pulmonary Function Indicators Before and After Surgery Between the Two Groups

There was no statistically significant difference in the preoperative pulmonary function indicators between the two groups ($p > 0.05$). At the 14-day time point after surgery, PEF, FVC, and FEV1 in both groups demonstrated considerable improvement compared with preoperative levels, with the observation group demonstrating significantly higher values than the control group ($p < 0.05$, Table 5).

Comparison of Serum Inflammatory Marker Levels Before and After Surgery Between the Two Groups

As detailed in Table 6, no differences in preoperative serum inflammatory marker levels were found between the two groups ($p > 0.05$). At 48 hours postoperatively, CRP, TNF-α, and IL-6 levels increased substantially in both experimental groups compared with the preoperative levels. However, the observation group showed significantly lower levels of these markers than the control group ($p < 0.05$, Table 6).

Comparison of the Quality of Life Before and After Surgery Between the Two Groups

There was no statistically significant difference in SF-36 scores between the two groups preoperatively (all $p > 0.05$). Three months postoperatively, all eight dimensions of the SF-36 scores in both groups showed significant improvement compared to preoperative levels (all $p < 0.05$). Furthermore, the observation group scored significantly higher than the control group in all dimensions (including mental health, role-emotional, social functioning, vitality, general health, bodily pain, role-physical, and physical functioning) ($p < 0.05$, Tables 7,8).

Comparison of Postoperative Complications Between the Two Groups

The overall incidence of postoperative complications in the observation and control groups was 13.46% (7/52) and 16.18% (11/68), respectively, with no statistically significant difference between the two groups ($p = 0.680$, Table 9). All cases of pulmonary infection were effectively controlled with intravenous antibiotics guided by drug sensitivity results, along with respiratory management and physiotherapy. Patients with hemothorax were managed with continuous chest tube drainage and received blood transfusions when necessary, with none of them requiring reoperation for hemostasis. Atelectasis was resolved with bronchoscopic sputum suctioning, respiratory exercises, and postural drainage. Similarly, pneumothorax cases were successfully managed with closed thoracic drainage, with no patient undergoing secondary surgical intervention.

Discussion

Multiple rib fractures accompanied by thoracic trauma represent a common yet severe clinical condition in thoracic surgery, usually resulting from high-energy impact injuries. These injuries are often accompanied by pulmonary contusion and hemopneumothorax, leading to respiratory dysfunction and significantly affecting patient prognosis [18–20]. Although conventional treatment strategies provide certain degrees of rib fixation, their efficacy in improving pulmonary function and overall patient outcomes remains limited [21,22]. With advances in surgical technology, thoracoscopic internal fixation has been widely adopted due to its minimally invasive advantages.

As an emerging surgical approach, ultra-minimally invasive rib fixation aims to further reduce surgical trauma. This procedure differs from thoracoscopic internal fixation in terms of fracture stabilization and postoperative recovery. This study compares the effects of these two approaches on pulmonary function recovery and overall prognosis in patients with multiple rib fractures and thoracic trauma. It offers a comprehensive assessment of differences in clinical efficacy, surgical parameters, complication rates, pain intensity, inflammatory markers, and quality of life, thereby providing evidence to optimize surgical methods in clinical practice.

Although thoracoscopic-assisted fixation has proven effective, the comparative effectiveness of this approach versus emerging UMI techniques remain inadequately explored. Prior studies have primarily assessed each technique individually, resulting in a lack of evidence to evaluate their relative advantages in postoperative recovery, systemic inflammatory response, and patient-centered outcomes. Therefore, this study aimed to address this gap by conducting a direct, head-to-head comparison to examine whether the UMI approach offers tangible advantages over conventional thoracoscopic fixation, thereby providing evidence-based guidance for selecting surgical strategies.

Our results showed that although the overall clinical efficacy rates between ultra-minimally invasive rib fixation and thoracoscopic internal fixation did not differ substantially, the ultra-minimally invasive approach demonstrated significant advantages. This method showed shorter operative time, reduced intraoperative bleeding, earlier extubation, faster mobilization, and a shorter length of hospital stay. Consistent with our findings, Wu *et al*. [23] reported that compared with TiNi clamping fixators under complete thoracoscopy, pre-shaped locking titanium plates applied in minimally invasive plate osteosynthesis significantly reduced operative time, drainage duration, and hospitalization length, while also decreasing intraoperative bleeding. These findings align with the core principles of minimally invasive surgery, highlighting the distinct benefits of ultra-minimally invasive techniques in minimizing surgical trauma and improving postoperative recovery. The reductions in operative time and blood loss not only reduce surgical risks but also alleviate physiological stress on patients, thereby facilitating rapid functional recovery and subsequent rehabilitation. Importantly, the reduction in trauma was evident not only in objective clinical indicators but also in patients' subjective recovery experiences.

Furthermore, postoperative changes in VAS scores revealed that patients in the ultra-minimally invasive group reported significantly lower pain levels at all assessed time points compared to the thoracoscopic group. Improved pain control may be attributed to several factors, including reduced intercostal nerve disturbance, less chest wall muscle injury, and a consequently milder inflammatory response. These findings are consistent with the well-established advantages of minimally invasive techniques reported in previous literature. For instance, Lo *et al*. [10] reported that ultra minimally invasive surgical stabilization of Rib fractures (uMI-SSRF) techniques are designed to minimize surgical incisions and tissue dissection, directly resulting in lower postoperative pain scores, a finding strongly supported by our study. Unlike study, such as Zhang *et al*. [7], which primarily assessed the feasibility and short-term outcomes of minimally invasive fixation guided by anatomical landmarks, our study provides a direct comparative analysis of two distinct minimally invasive techniques (ultra-minimally invasive vs. thoracoscopic), thereby offering a more nuanced understanding of their differential effects on recovery parameters.

Pulmonary function parameters, such as PEF, FVC, and FEV1, improved significantly in both groups, with greater enhancement observed in the observation group. From a respiratory physiological standpoint, rib fractures disrupt chest wall stability and can potentially lead to a "flail chest" effect, reducing adequate intrathoracic negative pressure and compromising ventilation [24]. The primary goal of surgical fixation is to re-establish thoracic stability. Ultra-minimally invasive techniques are likely to achieve superior biomechanical reconstruction by enabling more precise fracture alignment with minimal disruption to chest wall structures. Although the inter-group differences in pulmonary function parameters (PEF, FVC, FEV1) at 14 days postoperatively were statistically significant, the absolute differences were modest (less than 0.5–0.7 L/s or L), suggesting that the short-term clinical relevance may be limited. However, these early improvements are biologically plausible, reflecting a faster initiation of the recovery trajectory. The significantly lower postoperative pain scores (VAS) in the ultra-minimally invasive group likely contributed to earlier and more effective coughing and deep-breathing exercises, crucial for preventing atelectasis and promoting pulmonary hygiene.

Therefore, while these early statistical differences may not necessarily translate into immediate major clinical benefits, they may lay the foundation for the more pronounced and meaningful clinical advantages, which are likely to result in more pronounced improvement in pulmonary function and quality of life observed at the 3-month follow-up. Moreover, reduced postoperative pain enables earlier deep breathing and effective coughing in patients, which is beneficial for preventing atelectasis and improving pulmonary function.

Differences in inflammatory markers offer valuable insights into the biological effects of the two surgical approaches. Although postoperative levels of CRP, TNF-α, and IL-6 increased in both groups at 48 hours, the elevation was significantly smaller in the ultra-minimally invasive group compared to the conventional thoracoscopic group. This finding suggests a direct association between the extent of surgical trauma and the intensity of systemic inflammatory response. Clinically, excessive inflammation can exacerbate local tissue edema, impair wound healing, and, in severe cases, lead to systemic inflammatory response syndrome affecting multiple organs. Hence, minimizing surgical trauma and modulating the inflammatory response are crucial for improving patient outcomes.

The reduced systemic inflammatory response observed in the ultra-minimally invasive group adds a significant biological dimension to its advantages. This finding aligns with the fundamental principle that less surgical trauma elicits a milder inflammatory reaction. While previous studies have often reported clinical outcomes such as pain and shorter hospital stays [7,23], our quantitative analysis of inflammatory markers, specifically CRP, TNF-α, and IL-6, provides stronger objective evidence supporting the lower biological stress associated with the ultra-minimally invasive approach. This biomarker-based assessment provides a potential mechanistic explanation for how reduced surgical invasiveness translates into enhanced physiological outcomes.

Quality-of-life assessment revealed significant improvements across multiple SF-36 domains in both study groups at 3 months postoperative, with greater enhancement observed in the observation group. This finding holds important clinical implications, indicating not only objective physical recovery but also improvements in psychological and social well-being. The better outcomes in the observation group may be attributed to faster postoperative recovery, early return to daily activities, and reduced pain level, all of which contribute to improved mental health and overall quality of life. While the between-group differences in SF-36 scores were statistically significant, the clinical relevance of these approximately 2-point improvements remains uncertain, given the absence of a clearly defined Minimal Clinically Important Difference (MCID) for this specific population. However, the consistent pattern of improvement across multiple domains supports the notion that improved outcomes are associated with tangible benefits, including reduced pain and faster recovery observed in the ultra-minimally invasive group. Although the incidence of postoperative complications did not differ significantly between the two groups, the ultra-minimally invasive group exhibited slightly lower rates of common complications, including pulmonary infection, hemothorax, atelectasis, and pneumothorax, compared to the thoracoscopic group, further supporting its clinical advantages.

The comprehensive assessment of quality of life using the SF-36 survey at 3 months postoperatively represents a key strength of our study. Several previous studies, such as the meta-analysis by He *et al*. [6] and the cohort study by Wang *et al*. [11], have emphasized the need for more patient-reported outcome measures to precisely evaluate the real-world benefits of surgical stabilization. Our study addresses this gap by demonstrating that the ultra-minimally invasive technique not only yields superior clinical and inflammatory outcomes but also achieves substantially better quality-of-life scores across multiple domains. This holistic approach, integrating objective clinical parameters, biological markers, and patient-centric quality-of-life metrics, provides a more holistic evaluation of treatment efficacy and underscores the broader significance of this study in advancing beyond technical achievement toward comprehensive patient recovery.

Despite several promising results, this study has certain limitations. First, its retrospective design may introduce selection bias and uncontrolled confounding factors. Second, although the sample size was adequate for preliminary comparisons, it may not offer sufficient statistical power to detect differences in rare complications or long-term outcomes. Third, all surgical procedures were performed by an experienced surgical team at single center, which may affect the generalizability of the findings. Therefore, future prospective, multicenter, randomized controlled trials with larger sample sizes and more extended follow-up periods are warranted to validate these results and further elucidate the long-term safety and efficacy of ultra-minimally invasive rib fixation.

Conclusions

Ultra-minimally invasive rib fracture fixation offers a short operative time, lower intraoperative bleeding, and fast postoperative recovery. This approach shows significant advantages in reducing postoperative pain, promoting pulmonary function recovery, attenuating systemic inflammatory responses, and improving quality of life. Therefore, in clinical practice, ultra-minimally invasive rib fracture fixation may be a superior surgical option for appropriately selected patients with multiple rib fractures and associated chest trauma.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

GX designed the study, performed the research, and drafted the manuscript. HZ contributed to data collection and analysis. Both authors contributed to editorially important changes in the manuscript. Both authors read and approved the final manuscript. Both authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was conducted following the principles of the Declaration of Helsinki and was approved by the Ethics Committee of Huai'an 82 Hospital (No. HA82YY202511). Written informed consent was obtained from all participants.

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Conflict of Interest

The authors declare no conflict of interest.

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