Ding *et al. World Journal of Emergency Surgery* (2025) 20:33
https://doi.org/10.1186/s13017-025-00607-5

World Journal of Emergency Surgery

RESEARCH

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A China-Based exploration of surgical timing for polytrauma with a focus on fracture reconstruction

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Abstract

Background For patients with severe polytrauma and fractures, early fracture reconstruction surgery under stable conditions can significantly reduce pulmonary and other complications. However, premature surgical intervention may heighten infection risk, adversely affecting the patient's prognosis. Consequently, determining the optimal timing of surgery is crucial for patients with multiple traumatic injuries. Given China's healthcare context, this study will assess injury severity and perform definitive fracture reconstruction at specified post-trauma intervals. Postoperative infection rates, including wound infections, other complication incidences, hospital stay duration, treatment costs, and long-term outcomes will be observed and compared to identify the optimal timing for surgical intervention. This study also aims to develop effective polytrauma management models. By applying accessible criteria and choosing suitable timing for fracture reconstruction, we can better assess patient conditions, reduce complications, and minimize the surgery's "second hit" effect, addressing an important research gap regarding optimal surgical timing for polytrauma in China.

Methods This study collected data on 200 patients treated at our hospital between March 2023 and March 2024, with an average age of 47.24 ± 16.56 years and an average Injury Severity Score (ISS) of 25.85 ± 13.35. A total of 250 fractures received definitive fixation in the initial surgery, including femoral fractures ($n = 75$), spinal fractures ($n = 46$), pelvic ring fractures ($n = 49$), tibial fractures ($n = 25$), acetabular fractures ($n = 12$), humeral fractures ($n = 12$), and other fractures ($n = 5$) (including clavicle, radius and ulna, calcaneus, and patella). Among these patients, 151 underwent single-fracture reconstruction, 42 had two fractures reconstructed, and 5 had three fractures treated during the first surgery. The study protocol excluded patients with absolute contraindications, including bacteremia and infections near the surgical site. Additional inclusion criteria required stable vital signs (temperature < 38.5 °C with a downward trend, systolic blood pressure > 100 mmHg, stable traumatic brain injury status) and blood routine (white blood cell count < 22.0×10^9/L with a neutrophil percentage < 90%, both trending downward; platelet count > 50×10^9/L; hemoglobin > 90 g/L). Based on these criteria, historical cohorts were identified and assigned to either an experimental group or a control group. Observed outcomes included postoperative complications, wound healing grades, inflammatory markers, changes in vital signs, length of hospital stay, costs, and long-term follow-up results.

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Results Among the patients, 97 underwent surgery after meeting the specified criteria for fracture reconstruction, while 103 received surgery without meeting these criteria. Patients who met the surgical criteria demonstrated superior outcomes, with lower complication rates (including pneumonia and respiratory distress syndrome), improved surgical incision healing, faster postoperative consciousness recovery, shorter overall and ICU stays, reduced hospitalization costs, greater joint mobility at the 9-month follow-up, and higher quality of life assessments compared to those who did not meet the criteria. Among patients who met the criteria, those with spinal fractures experienced better quality of life outcomes, and those with femoral fractures showed improved fracture healing.

Conclusions For polytrauma patients with fractures, performing surgery once surgical requirements are met results in fewer early postoperative pulmonary complications, quicker recovery of consciousness, lower wound infection rates, shorter hospital and ICU stays, reduced costs, and improved postoperative outcomes. This protocol is safe and effective for most polytrauma patients requiring fixation, particularly those with mechanically unstable femoral, pelvic, acetabular, or spinal fractures.

Keywords Multiple trauma, Surgical treatment strategy, Timing of fracture fixation, Postoperative complications

Background

Globally, trauma has become the fourth leading threat to human health [1]and is the leading cause of death among young adults under 44 in China [2]. During the early stages of in-hospital treatment for polytrauma, life-threatening complications, such as massive hemorrhage, the lethal triad, and septic shock, are common. In later treatment stages, challenges arise from organ failure, wound infections, and fracture reconstruction issues, all of which impact patient outcomes [3, 4]. Managing polytrauma patients is a complex and dynamic process [5]. Early definitive treatment is crucial; selecting the optimal timing for surgery and promptly performing fracture reconstruction and limb rehabilitation in severe polytrauma cases can significantly reduce pulmonary and other early complications [6]. However, in patients whose physiological functions have not yet stabilized, early fracture surgery is associated with severe complications, as excessive surgical intervention may cause further soft tissue injury and blood loss, worsening the patient's condition [6]. Currently, there are no clear guidelines on the optimal timing for early surgery in polytrauma patients with fractures [7]. Thus, establishing a clear model for polytrauma management and identifying physiological indicators in severe polytrauma patients to guide fracture reconstruction timing is essential for effective treatment.

Internationally, polytrauma management strategies have continued to evolve. The Early Total Care (ETC) approach, introduced in the 1980s, was based on advancements in fracture fixation and anesthesia techniques [8]. However, ETC's "second hit" effect—triggering systemic inflammation—led to the development of the Damage Control Orthopedics (DCO) approach [9]. DCO defers definitive surgery until the patient's physiological functions stabilize, but it has been associated with poorer recovery and a higher incidence of complications [10]. Early Appropriate Care (EAC) [11] aims to perform definitive fracture fixation within 36 h post-injury, after sufficient resuscitation (lactate $<$ 4.0 mmol/L, base excess $\geq$-5.5 mmol/L, pH $\geq$ 7.25). It was later recognized, however, that reducing metabolic acidosis alone should not be the sole criterion for resuscitation success. EAC has faced criticism, as metabolic status, while significant, is not the only factor that should guide treatment [12].

Recently, the Safe Definitive Surgery (SDS) strategy [13–15] was introduced to balance the approaches of Damage Control Orthopedics (DCO) and Early Appropriate Care (EAC). The SDS strategy categorizes patients into marginal, unstable, and extreme groups to determine DCO indications, resulting in a lower complication rate [16, 17]. However, including "severe thoracic, pelvic, and/or limb injuries" as criteria for unstable or other classifications has led to delays in definitive fixation for some patients, which is not universally endorsed. Patients with severe thoracic injuries face a higher risk of pulmonary complications when definitive fixation is delayed [18]. Although various institutions have researched parameter definitions for risk factors across two different time periods, there is still a lack of objective criteria for assessing patient status [19]. Early fixation often has advantages, but the timing must be individualized based on the patient's condition and injury severity. This nuanced approach helps ensure optimal outcomes in complex trauma cases [20].

In summary, early fracture fixation can significantly reduce pulmonary and other early complications, shorten hospital stays and costs, enhance patient mobility, and alleviate pain and systemic inflammatory response syndrome (SIRS) associated with unstable fractures [21]. The pathophysiology of polytrauma involves a complex network of interactions: acute hemorrhage and hypoperfusion, along with soft tissue injury, activate the immune system, triggering coagulation and inflammatory responses. Various cellular and humoral defense mechanisms are activated, leading to specific changes within the inflammatory cascade. This defense mechanism represents an exaggerated response to harmful stressors, with inflammation driven by damage-associated molecular patterns (DAMPs) [22] and pathogen-associated molecular patterns (PAMPs) [23]. In severe trauma cases, this immune response can become unbalanced [24], resulting in a systemic inflammatory response. Immune homeostasis is disrupted, and the intense trauma load may trigger acute genetic changes [25]. Excessive immune cell activation may cause an "inflammatory storm," a response confirmed only in circulating neutrophils (known as the "genetic storm" hypothesis), which may persist throughout hospitalization [26]. For patients with unstable vital signs or severe trauma, performing extensive surgery prematurely (e.g., complete internal fixation) may trigger a "second hit," where the surgery-induced inflammatory response exacerbates systemic injury, potentially increasing the incidence of acute respiratory distress syndrome (ARDS) and multiple organ failure (MOF) [27].

Unlike other developed Western countries, China's trauma care system differs significantly from those of Western nations like the United States and Germany, where advantages lie primarily in well-established pre-hospital emergency networks and tiered trauma centers [28]. China is actively promoting the establishment of regional and tiered trauma centers [29]. However, challenges in trauma care remain, including uneven distribution of medical resources, inadequate trauma care infrastructure, and insufficient early trauma management and multidisciplinary collaboration. These issues are compounded by systemic institutional limitations, regional disparities, and a lack of standardized training among healthcare professionals [30]. With advances in resuscitation, inflammation control, and coagulation management, treatment decision-making has become increasingly modular [31]. However, there are currently no reports on the optimal timing of fracture surgery for polytrauma patients in China. In most Chinese hospitals, the timing of surgery is typically inclined toward Damage Control Orthopedics (DCO) or delayed treatment to avoid secondary surgical injury. Our study is conducted within the practical context of China's polytrauma management model.

In the absence of bacteremia or infection at the surgical site [32], stable vital signs are a crucial inclusion criterion, requiring patients to maintain stable hemodynamics [33] and avoid shock. During initial resuscitation, blood pressure in hypotensive patients may be stabilized with vasopressors. Severe traumatic brain injury affects surgery [34], primarily by influencing vital signs such as respiration, heart rate, and hemodynamics, which increases the risk of intraoperative complications. A stable intracranial condition is defined as one where, after initial treatment (e.g., medication or surgery), there is no significant increase in intracranial bleeding, cerebral edema, or intracranial pressure spikes. It is unnecessary to wait for the patient's consciousness to recover; stable vital signs alone are sufficient for proceeding with surgery [35].

For polytrauma patients managed with the DCO strategy or delayed surgery, factors influencing the timing of definitive fixation include skin injuries, visceral organ damage, non-orthopedic surgeries, and fever [36]. We recommend that febrile patients undergo surgery only when their temperature is below 38.5 °C. Additionally, for patients with preoperative temperatures above 38.0 °C, the temperature should show a downward trend over the previous two days, indicating temporary control of internal inflammation and suggesting that the patient can tolerate surgery.

The SDS strategy includes numerous inflammatory markers [19], which can be cumbersome and may hinder frontline clinicians' judgment. We aim to use simple, readily available criteria for patient assessment, with hemoglobin as a key parameter in routine blood tests due to its role in determining surgical tolerance. For elective surgeries, hemoglobin levels should generally be no less than 10 g/dL. Other trauma guidelines suggest maintaining hemoglobin between 7 and 9 g/dL for polytrauma patients with ongoing bleeding risk [37]. Considering that some polytrauma patients may experience substantial intraoperative bleeding (e.g., in pelvic fractures), we recommend a preoperative hemoglobin level above 9 g/dL to prevent severe postoperative anemia and hemodynamic instability. For most elective surgeries, a platelet count of at least 50 × 10^9/L is recommended to ensure sufficient coagulation capacity and minimize bleeding risk [38].

The white blood cell count and neutrophil percentage are key indicators of inflammation and potential infection, offering a direct assessment that aids in distinguishing infection types, evaluating infection severity, and predicting disease progression [39, 40].

Currently, no studies correlate polytrauma surgical timing with these indicators. To enable earlier fracture fixation, we recommend that patients meet criteria of a white blood cell count $< 22 \times 10^9$/L and a neutrophil percentage < 90% for surgical eligibility. Additionally, if the white blood cell count exceeds 15.0×10^9/L or the neutrophil percentage is above 85%, both should show a downward trend, signaling temporary control of the inflammatory response and the creation of an optimal surgical window.

Methods

From March 2023 to March 2024, 200 polytrauma patients with fractures admitted to the emergency surgery department of our hospital were selected. Inclusion criteria for fracture types focused on sites receiving initial definitive fixation rather than temporary fixation.

In total, 250 fractures received definitive fixation in the first surgery, including the femur ($n=75$), spine ($n=46$), pelvic ring ($n=49$), tibia ($n=25$), acetabulum ($n=12$), humerus ($n=12$), and other fractures ($n=31$) (e.g., clavicle, radius and ulna, calcaneus, scapula, patella). A retrospective study was conducted on patients undergoing initial surgery for single fracture reconstruction ($n=151$), two-fracture reconstructions ($n=42$), and three-fracture reconstructions ($n=5$). Associated injuries included thoracic ($n=143$), abdominal ($n=73$), and head trauma ($n=123$). The Injury Severity Score (ISS) selection criteria were defined. Data recorded included fracture characteristics, ISS, complications, vital signs, consciousness assessment, pain level, inflammatory markers, length of hospital stay, nursing records, surgical procedure names, and long-term follow-up results. Injury Severity Score (ISS) selection criteria were defined. Data recorded included fracture characteristics, ISS, complications, vital signs, consciousness assessment, pain level, inflammatory markers, length of hospital stay, nursing records, surgical procedure names, and long-term follow-up results.

Inclusion criteria

All 200 cases involved polytrauma patients as defined by the 2014 "New Berlin Definition" [41], which estimates a mortality rate of up to 30% for polytrauma patients. The criteria specify significant injury (≥3 AIS points) in at least two distinct anatomical regions, along with at least one of the following five parameters: hypotension (SBP < 90 mmHg), altered consciousness (GCS score < 8), acidosis (BE ≥ 6.0), coagulopathy (INR > 1.4 or APTT > 40 s), or age > 70 years. Polytrauma assessment is generally based on the Abbreviated Injury Scale (AIS) and the Injury Severity Score (ISS). Exclusion criteria included fractures from low-energy mechanisms, fractures secondary to tumors, and fractures in skeletally immature patients.

Our protocol recommends that patients meet the following preoperative criteria: (1) Stable vital signs: ① Body temperature < 38.5℃; if above 38.0℃, it should show a downward trend over the previous two days; ② Systolic blood pressure > 100 mmHg, maintained with vasopressors if necessary; ③ Stable traumatic brain injury status, with no signs of increased intracranial bleeding, worsening cerebral edema, or sudden intracranial pressure spikes. (2) Routine blood tests: ① White blood cell count $< 22.0 \times 10^9$/L; if $> 15.0 \times 10^9$/L, it must show a downward trend over the preceding two days; ② Neutrophil percentage < 90%; if > 85%, it should also trend downward over the previous two days; ③ Platelet count $> 50 \times 10^9$/L, with PT (11–14 s) and APTT (25–37 s) within normal limits; ④ Hemoglobin > 90 g/L. (3) No bacteremia and no infection near the surgical site. (4) Exclusion of patients with chronic fractures. Additionally, in both the experimental and control groups, no patients undergoing surgery had bacteremia or infections near the surgical area.

Measurements of outcome

Complications include sepsis, septicemia, deep vein thrombosis (DVT), multiple organ failure, pneumonia, and acute respiratory distress syndrome (ARDS). Sepsis [42] is defined as an infection with a confirmed site (e.g., pneumonia, abdominal, or urinary tract infection) and a qSOFA score increase > 2. Septicemia is indicated by a positive blood culture and at least two of the following criteria: temperature > 38.3 °C or < 36.0 °C; tachycardia > 90 bpm; tachypnea > 20 breaths per minute or arterial CO_2 partial pressure ($PaCO_2$) < 32 mmHg; hyperglycemia (blood glucose > 7.7 mmol/L) without diabetes; acute change in mental status; leukocytosis (WBC count $> 12 \times 10^9$/L); leukopenia (WBC count $< 4 \times 10^9$/L); or a normal WBC count with > 10% immature cells [43]. Proximal DVT in the knee joint is diagnosed via ultrasound. Multiple organ failure is defined as the failure of two or more organs for at least three consecutive days, with a score above 4 [44]. ARDS is characterized by a PaO_2/FiO_2 ratio below 200 for over four consecutive days without pneumonia [45] and diffuse infiltrates on chest X-ray. Pneumonia is defined by a quantitative culture obtained through bronchoscopy and bronchoalveolar lavage, performed at the discretion of the attending trauma intensivist, typically in response to new pulmonary infiltrates on chest X-ray and purulent sputum, with a temperature above 38 °C and/or WBC count over 10,000/mL [45].

The timing of surgery is crucial for preventing or mitigating the "second hit" effect and can significantly influence its occurrence. Beyond monitoring complications (e.g., multiple organ failure, acute respiratory distress syndrome) to evaluate the "second hit" effect, a range of biomarkers, inflammatory indicators, and vital signs should be considered, including complete blood count (CBC), C-reactive protein (CRP), and procalcitonin (PCT).

Changes in vital signs serve as early warning signals of the "second hit" effect. Persistent hypotension, elevated heart rate, tachypnea, and decreased oxygenation are critical indicators. We use the following criteria to assess the severity of the "second hit": ① Temperature fluctuations: Postoperative temperature elevation is common due to surgical impact; among the 200 cases analyzed, 82.5% ($n=165$) exhibited elevated temperature after surgery. Thus, the "temperature trend over the first three postoperative days" can serve as an assessment criterion. ② Level of consciousness: The Glasgow Coma Scale (GCS) score is used to measure consciousness. ③ Blood pressure variations: During resuscitation, unstable hemodynamics are often managed with vasopressors. Changes in vasopressor usage can substitute for direct blood pressure measurements, enabling us to assess stability by tracking vasopressor types and dosages used three days before and after surgery. ④ Respiratory function: Similar to blood pressure monitoring, we assess changes in spontaneous breathing capacity via ventilator usage, providing insight into the surgery's impact on vital sign recovery.

Incision Healing Classification: Postoperative incision healing is monitored based on documented descriptions in medical and nursing records and classified as follows: (a) Grade A Healing: The incision site shows no redness, pain, subcutaneous fluid accumulation, infection, inflammation, or adverse reactions such as fat liquefaction. (b) Grade B Healing: The incision site exhibits inflammatory responses, including redness, induration, hematoma, or fluid accumulation, but no abscess formation. (c) Grade C Healing: The incision site shows clear signs of suppuration, requiring suture removal or incision drainage to clear necrotic tissue.

Inflammatory Indicators: Like body temperature, both white blood cell (WBC) count and neutrophil percentage tend to increase postoperatively due to surgical impact. Among the 200 cases analyzed, postoperative WBC count and neutrophil percentage rose in 77.5% ($n = 155$) and 72.5% ($n = 145$) of patients compared to preoperative levels. Therefore, we monitor these trends over the first three postoperative days. Additionally, changes in C-reactive protein (CRP) and procalcitonin (PCT) levels before and after surgery are included in the analysis.

Long-term follow-up outcomes include three key aspects: ① Fracture healing status at 9 months postoperatively. ② Joint mobility: For injuries in various regions, follow-up assessments are conducted using the Harris Hip Score [46], Constant Shoulder Score [47], Knee injury and Osteoarthritis Outcome Score (KOOS) [48], and the Oswestry Disability Index (for spinal injuries) [49]. Patients scoring below 70 on the percentile scale are categorized as having "poor joint mobility." ③ Quality of life: Quality of life is assessed using the FS Post-Fracture Quality of Life Survey, which evaluates physical function, physical role, bodily pain, general health, vitality, social function, role limitations due to emotional issues, and mental health. For ease of interpretation, patients reporting "very poor" or "poor" outcomes in at least four of these eight domains are classified as having "poor quality of life"; otherwise, they are considered to have an acceptable quality of life.

Statistical analysis

Independent sample t-tests were used to compare continuous variables, while Pearson's chi-square test was applied for categorical variables. Based on adherence to our protocol for surgical timing, the study population was divided into experimental and control groups. Logistic regression models were constructed for binary outcomes. For length of hospital stay (LOS), ICU stay duration, and costs, a generalized linear regression model with a negative binomial distribution was used, as these variables are non-negative integers with a right-skewed distribution. Univariate and multivariate logistic regression, along with negative binomial regression, were applied to identify potential risk factors, including patient age, gender, Injury Severity Score (ISS), fracture type, and other injuries (e.g., head, chest, and abdominal trauma). All analyses were conducted by statisticians not involved in patient treatment, using the SPSS statistical software package. Statistical significance was set at $p < 0.05$ (two-tailed).

Statement of ethical approval

This study was approved by the Ethics Committee of Qilu Hospital of Shandong University (approval number: KYLL-202405-044.), Jinan, Shandong, China.

Results

A retrospective evaluation of 200 cases treated at our hospital between March 2023 and March 2024 was conducted based on established criteria. The cohort included 138 males and 62 females, with an average age of 47.24 ± 16.56 years and a mean Injury Severity Score (ISS) of 25.85 ± 13.35. Among these cases, 123 had head injuries, 143 had chest injuries, and 72 had abdominal injuries. Table 1 provides a statistical analysis of these factors and fracture types, showing that grouping was associated with age and ISS score, while no association was found with other factors.

Among patients who met surgical criteria, 40.2% experienced complications, compared to 59.2% in those who did not meet the criteria ($p = 0.0072$). Pneumonia occurred in 23.7% and 42.7% of these groups, respectively ($p = 0.0047$, Table 2); deep vein thrombosis (DVT) in 22.6% and 26.7% ($p = 0.672$); and acute respiratory distress syndrome (ARDS) in 3.1% and 15.5% ($p = 0.0067$). There were 3 cases of sepsis, 4 cases of bacteremia, and 3 cases of multiple organ failure, all occurring in patients who did not meet surgical criteria. Due to the limited number of these cases, statistical analysis was not performed. A multivariate logistic regression model accounted for potential confounding factors such as age, gender, ISS, fracture type, and the type and severity of other system injuries. The analysis showed that both advanced age ($p = 0.0074$) and higher ISS scores ($p = 0.0057$) were associated with an increased complication rate.

Notably, among patients with postoperative thoracic complications (ARDS and pneumonia), 83.8% ($n = 57$) had chest injuries. The incidence of thoracic

Table 1 Comparisons of demographic information in patients satisfying vs. Not satisfying surgical criteria

	All patients($n=200$)	protocol-compliant case($n=97$)	protocol deviation case($n=103$)	*p* value
Male	138	61	77	0.07
Female	62	36	26	-
Mean age (years)	47.46 ± 16.56	45.38 ± 16.97	48.79 ± 16.08	0.175
Mean ISS	25.85 ± 13.35	23.47 ± 12.37	28.69 ± 14.05	0.053
femoral fracture	70	28	42	0.078
pelvic fracture	49	23	26	0.801
Spinal fracture	45	21	24	0.780
Acetabular fracture	12	8	4	0.194
Tibial fracture	25	11	14	0.630
Humeral fracture	12	8	4	0.194
Other fractures	28	18	10	0.0702
With head injury	123	61	62	0.627
Without head injury	77	35	42	-
With chest injury	143	68	75	0.671
Without chest injury	57	29	28	-
With abdominal injury	72	37	35	0.54
Without abdominal injury	128	60	68	-
Patients with 1 fracture	151	72	79	0.862
Patients with 2 fractures	42	20	22	-
Patients with 3 fractures	5	3	2	-

Table 2 Comparisons of complication rates in patients meeting vs. Not meeting surgical criteria

	All patients	protocol-compliant case	protocol deviation case	*p* value
With complications	100	39	61	0.0072
Without complications	100	58	42	
Pneumonia	67	23	44	0.0047
Without pneumonia	133	74	59	
Deep vein thrombosis (DVT)	49	22	27	0.672
Without deep vein thrombosis (DVT)	151	75	76	

Table 3 Comparisons of changes of vital signs in patients satisfying vs. Not satisfying surgical criteria

Changes in basic vital signs	All patients	protocol-compliant case	protocol deviation case	*p* value
Decreased body temperature	131	64	67	0.647
No decrease in body temperature	69	31	38	-
stability of blood pressure	9	3	6	0.465
Unstable blood pressure	15	3	12	-
Respiratory improvement	11	5	6	0.326
No Breathing improved	34	10	24	-
Improvement in consciousness	28	16	12	0.0112
No improvement in consciousness	32	8	24	

complications was 39.3% in patients with chest injuries, compared to 19.3% in those without ($p < 0.01$). Additionally, analysis of the association between femoral fractures, pelvic/acetabular fractures, and lower extremity deep vein thrombosis revealed no statistically significant correlation.

Among the 200 patients, 65.5% ($n = 131$) exhibited a downward trend in temperature within the first three days postoperatively. In the experimental and control groups, this proportion was 68.1% and 66.3%, respectively ($p = 0.647$, Table 3). A total of 12% ($n = 24$) of patients required vasopressors pre- and post-surgery. Of these, six patients met surgical criteria, with three showing stable blood pressure compared to pre-surgery levels, while three showed no improvement or worsened. In the control group, 18 patients received vasopressors, with six showing improvement and 12 showing no improvement or worsening postoperatively ($p = 0.465$). Mechanical ventilation was used pre- and postoperatively in 22.5% ($n = 45$) of patients, including 11 in the experimental group and 34 in the control group. The likelihood of improved spontaneous breathing was 33.3% in the experimental group and 20% in the control group ($p = 0.465$). Among patients with poor or unchanged consciousness,

Table 4 Comparisons of changes of inflammatory marker or LOS or costs in patients satisfying vs. Not satisfying surgical criteria

Inflammatory marker changes or length of hospital stay or costs	All patients	protocol-compliant case	protocol deviation case	p value
Decreased white blood cell count	131	62	69	0.223
No decrease in white blood cell count	46	17	29	-
Decreased neutrophil percentage	129	58	71	0. 776
No decrease in neutrophil percentage	48	21	27	-
Postoperative decrease in CRP	90	44	46	0.877
Postoperative increase in CRP	98	49	49	-
Postoperative decrease in PCT	98	42	56	0.296
Postoperative increase in PCT	46	24	22	-
Length of hospital stay (days)	21.02 ± 13.13	18.03 ± 8.50	15.25 ± 12.26	0.0014
ICU length of stay (days)	12.17 ± 10.33	8.93 ± 6.42	15.25 ± 12.26	<0.001
Cost (ten thousand yuan)	17.01 ± 17.51	12.56 ± 8.53	21.2 ± 22.20	<0.001

30% ($n = 60$) showed no significant change within the first three days postoperatively. This included 24 patients who met surgical criteria and 36 who did not, with an improvement probability of 66.7% ($n = 16$) in those meeting criteria and 33.3% ($n = 12$) in those not meeting criteria ($p = 0.0112$). No statistically significant differences were found in outcomes other than consciousness recovery.

Nineteen patients experienced Grade 2 or Grade 3 healing, with 3 cases of Grade 2 and 2 cases of Grade 3 healing in the experimental group, and 5 cases of Grade 2 and 9 cases of Grade 3 healing in the control group. Among these 19 patients, 78.9% had open injuries. Defining Grade 2 and Grade 3 healing as "poor healing," the incidence of poor healing was 5.2% ($n = 5$) in the experimental group and 13.6% ($n = 14$) in the control group ($p = 0.0415$).

Among 176 patients, the three-day postoperative trend in white blood cell (WBC) count and neutrophil percentage was assessed. Within three days post-surgery, the WBC count showed a downward trend in 78.5% ($n = 62$) of the experimental group and 70.4% ($n = 69$) of the control group ($p = 0.223$, Table 4). The neutrophil percentage decreased in 74.4% ($n = 58$) of the experimental group and 72.4% ($n = 71$) of the control group ($p = 0.776$). In a comparison of pre- and postoperative CRP levels among 188 patients, 90 showed a decrease and 98 showed an increase, with improvement rates of 63.6% ($n = 42$) in the experimental group and 50.0% ($n = 49$) in the control group ($p = 0.877$). Similarly, for pre- and postoperative PCT levels among 144 patients, the improvement rate was 52.7% ($n = 49$) in the experimental group and 71.8% ($n = 56$) in the control group ($p = 0.296$). None of the inflammatory indicators studied reached statistical significance.

The average hospital stay was 18.03 ± 8.50 days in the experimental group and 23.83 ± 15.78 days in the control group ($p = 0.0014$). The ICU stay duration averaged 8.93 ± 6.42 days in the experimental group and 15.25 ± 12.26 days in the control group ($p < 0.001$). The average cost was 125,600 ± 85,300 RMB in the experimental group and 212,000 ± 222,000 RMB in the control group ($p < 0.001$).

Table 5 Comparison of Long-term follow-up results vital signs in patients satisfying vs. Not satisfying surgical criteria

Long-term follow-up results	All patients	protocol-compliant case	protocol deviation case	p value
Fracture healed	90	42	48	0.920
Fracture not healed	21	9	12	-
Good joint mobility	56	32	24	0.0097
Poor joint mobility	55	18	37	-
Good quality of life	65	41	24	0.0028
Poor quality of life	46	16	30	-

Long-term Follow-up Outcomes: Due to time constraints and loss to follow-up, only 111 patients were assessed at 9 months postoperatively, with 5 patients deceased. The fracture healing rate was 81.1% ($n = 90$), with healing rates of 82.4% ($n = 42$) in the experimental group and 80.0% ($n = 48$) in the control group. Good joint mobility outcomes were achieved in 50.4% ($n = 56$) of patients, with 64.0% ($n = 32$) in the experimental group and 39.3% ($n = 24$) in the control group ($p = 0.0097$, Table 5). The proportion of patients with an "acceptable quality of life" was 71.9% ($n = 41$) in the experimental group and 44.4% ($n = 24$) in the control group ($p = 0.0028$).

Among the 111 patients in the follow-up survey, 41.4% ($n = 12$) of those with spinal injuries reported a better quality of life, compared to 64.6% ($n = 17$) of those without spinal injuries ($p < 0.05$). Severe femoral fractures are often challenging to heal; in the follow-up results, the healing rate for femoral fractures was 68.6% ($n = 24$), compared to 86.8% ($n = 66$) for non-femoral fractures ($p = 0.022$).

Discussion

In China, pre-hospital emergency care primarily relies on independent emergency command centers and large hospitals. The pre-hospital emergency care model is varied and often influenced by individual interests, making objective and scientific triage challenging for hospitals [50]. In-hospital emergency care is categorized into three types: the multidisciplinary team (MDT) model, led by the critical care unit with participation from other departments; the integrated emergency care model; and the most common approach, involving temporary specialized consultations. Common issues include poor coordination, low efficiency, and a lack of long-term planning. Our emergency care model is based on the integrated approach. Additionally, there is no trauma registry system. Although China has a large and diverse trauma patient population, the lack of data registration significantly limits information availability for scientific research [51].

The primary goal of our surgical protocol is to optimize the treatment of polytrauma patients by reducing complications and improving postoperative recovery. The efficacy of any treatment protocol relies on the following key characteristics: ① simplicity, ease of recall, and ease of implementation; ② association with consistent outcomes, regardless of the decision-makers involved; and ③ applicability to a broad patient population without altering risk. Vital signs and inflammatory markers are routinely accessible, rapidly obtained, and low-cost, making them well-suited for large-scale use. Moreover, the selected parameters are controllable, maintainable, and monitorable. For instance, hemodynamically unstable patients can be stabilized with medication and monitored via electrocardiography.

Studies indicate that in patients with traumatic brain injury (TBI) and fractures, the incidence of delayed fracture healing decreases as TBI severity increases, suggesting that the central nervous system may regulate bone metabolism [52]. TBI appears to enhance this effect, promoting fracture healing, with similar patterns observed in patients with concomitant spinal cord injuries [53]. Conversely, limb fractures may negatively regulate brain injury, potentially exacerbating it [54]. Our study also demonstrates that fracture reconstruction under appropriate conditions can facilitate recovery of consciousness in patients. For patients with severe brain injury and shock, resuscitation should prioritize maintaining blood volume to keep central venous and pulmonary artery pressures within normal ranges rather than dehydration therapy. Once shock is corrected, internal fixation of fractures should be performed as early as possible. Certain types of cranial trauma may serve as absolute contraindications for surgeries in other areas; however, this is not definitive and depends on the likelihood of severe complications, such as elevated intracranial pressure, cerebral edema, or brain herniation, which can affect other vital signs (e.g., heart rate, respiration, blood pressure, temperature), thereby increasing surgical risk and complexity.

Resuscitation strategies for polytrauma patients with abdominal injuries include using "open treatment" to prevent and alleviate post-traumatic abdominal compartment syndrome, followed by delayed abdominal wall closure [55]. Surgeons often delay fracture surgery due to perceived surgical risks, subjecting patients to preventable complications associated with prolonged immobilization. In polytrauma, the timing of fracture fixation should not be based solely on concerns about an open abdomen. Instead, primary consideration should be given to the patient's physiological stability (e.g., hemodynamics, coagulation, inflammatory response, and infection) in polytrauma patients with fractures and abdominal injuries. When physiological status is stable, attention should focus on the risk of cross-infection between the fracture site and the open abdominal wound. Maintaining sufficient distance between the fracture incision and abdominal or other contaminated wounds allows for early fracture stabilization, promoting recovery while preventing cross-infection. Currently, no reports identify thoracic injuries as absolute contraindications to fracture reconstruction, so emphasis should remain on the patient's physiological stability.

The primary reason for delayed fracture treatment often stems from the trauma surgeon's judgment [56]. In cases of severe head or abdominal injury, surgeons may choose to delay treatment even when patients meet resuscitation standards based on inflammatory markers.

Literature suggests that patients with delayed fracture fixation have a significantly higher incidence of sepsis [57]. In these patients, immune system imbalance and increased intestinal permeability make bacterial translocation more likely. Prolonged bed rest and mechanical ventilation due to delayed fixation further extend the risk period, increasing the likelihood of bacterial translocation and infection. Additionally, in patients with open wounds or surgical sites near infected tissue or abscesses, even timely debridement may compromise healing and elevate the risk of sepsis. A reduction in complications is also associated with critical care monitoring and ventilation strategies, which vary according to hospital resuscitation standards. In our study, the limited number of patients with concurrent sepsis and bacteremia prevented us from conclusively determining the relationship between fracture fixation timing and the incidence of sepsis and bacteremia.

We advocate for early surgical intervention; however, China's triage system is underdeveloped, and the in-hospital emergency care model lacks standardized protocols, leading to considerable variability in treatment timing and approaches across regions. Consequently, the Damage Control Orthopedics (DCO) strategy is commonly adopted. Considering China's healthcare context, our study assesses patient resuscitation levels and physiological status, recommending surgery as soon as surgical criteria are met to reduce complications and enhance the approach's applicability.

This study provides only a preliminary investigation into surgical timing based on clinical experience, and many questions in this area require further exploration. Several limitations should be noted. Our reliance on retrospective data may result in omissions and inaccuracies when assessing postoperative outcomes, such as wound healing classification. To gain a more complete understanding of postoperative infection outcomes, additional prospective research and comprehensive statistical analysis are needed. We included postoperative inflammatory markers and changes in vital signs to assess the "second hit" effect of surgery; however, this approach may not fully capture the impact of the second hit, underscoring the need to establish evaluation criteria for this effect. Additionally, factors associated with deep vein thrombosis warrant further study.

Conclusions

For polytrauma patients with fractures, those who underwent fracture surgery after meeting the study's surgical criteria experienced fewer early postoperative pulmonary complications, faster recovery of consciousness, lower incision infection rates, shorter overall and ICU stays, reduced costs, and improved postoperative outcomes compared to those who did not meet the criteria. Our protocol is safe and effective for most polytrauma patients with mechanically unstable femoral, pelvic, acetabular, or spinal fractures requiring fixation.

Acknowledgements
The authors would like to thank all individuals who contributed to this work but do not meet the criteria for authorship, including those who provided professional writing assistance or supplied materials.

Author contributions
Conceptualization: Dr. SangMethodology: Dr. Sang and Dr. DingFormal analysis: Dr. DingInvestigation**: Dr. Jia and Dr. HanData Curation: Dr. DingWriting: Original Draft: Dr. Ding and Dr. ZhangWriting—Review & Editing: Dr. Zhao and Dr. ZhangSupervision: Dr. Sang Project Administration: Dr. SangAll authors reviewed the manuscript.

Funding
This research received no external funding.

Data availability
The data supporting the findings of this study were collected by the authors. Due to privacy, the data are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee of Qilu Hospital of Shandong University (approval number: KYLL-202405-044.), Jinan, Shandong, China.

Conflicts of interest
The authors declare no competing interests.

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Received: 4 November 2024 / Accepted: 7 April 2025
Published online: 16 April 2025

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