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Surgical strategy and outcomes of fracture reconstruction in polytrauma patients with concomitant infection: an ambispective cohort study

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Abstract

Background

We examined physiologic readiness for systemic complications and infection-to-operative-field proximity for wound or implant outcomes in infected polytrauma.

Methods

This single-centre ambispective cohort included 456 patients with polytrauma and concomitant infection undergoing definitive fracture reconstruction (346 retrospective, 110 prospective). Five domains—white-cell count/trajectory, neutrophil percentage/trajectory, temperature/trajectory, haemoglobin, and platelet count—defined three groups: all met, one unmet, and ≥ 2 unmet. Proximity was remote, adjacent without overlap, or overlapping/involving the operative field. Outcomes were a composite of pneumonia, respiratory failure/acute respiratory distress syndrome, sepsis, or acute kidney injury and any wound/implant adverse outcome. Robust-variance Poisson regression estimated adjusted risk ratios (aRRs) with prespecified covariates.

Results

The systemic composite occurred in 24/124 (19.4%), 47/172 (27.3%), and 65/159 (40.9%) across systemic Status Adequacy Score; aRRs versus all five criteria met were 1.31 (95% CI 0.85–2.01) and 1.99 (1.33–2.98).Wound/implant events occurred in 52/359 (14.5%), 48/72 (66.7%), and 18/25 (72.0%) across proximity levels; aRRs versus remote were 6.68 (4.54–9.81) and 7.11 (4.73–10.70). Pulmonary versus intra-abdominal infection was not detectably associated with wound outcome (aRR 0.83, 0.62–1.12); wound/soft-tissue infection was (2.17, 1.39–3.40). Each additional 7 days to surgery was associated with the systemic composite (1.09, 1.03–1.16). At one year, poor union occurred in 63.0% with versus 18.1% without an acute wound/implant event ($P < 0.001$).

Conclusions

Reduced systemic physiological reserve was associated with an increased risk of systemic composite outcomes, particularly in patients with multiple unmet physiologic criteria, and resource use increased with unmet-criterion burden.Operative-field proximity, rather than systemic infection type alone, was the clearest correlate of wound and implant outcomes. Controlled high inflammation and remote pulmonary or intra-abdominal infection should not automatically mandate delay; These findings provide a clinical basis for individualized assessment of surgical timing and perioperative management based on systemic physiological reserve, inflammatory control, and the relationship between infection and the operative field.

Background

Advances in resuscitation, critical care, and perioperative management have shifted the goals of polytrauma care beyond early survival toward definitive reconstruction, functional recovery, and long-term outcomes. Stabilisation of major fractures is therefore not merely a local orthopaedic procedure, but an important component of systemic trauma care [1]. However, extensive definitive fixation performed before adequate physiologic recovery may constitute an additional “second hit” and aggravate systemic stress [2]. Accordingly, fracture-care strategies have progressively moved away from fixed time windows toward individualized decisions based on the patient’s evolving physiologic condition [3]. More recent safe definitive surgery concepts and consensus recommendations further emphasize repeated reassessment before proceeding with major fracture reconstruction [4].

Concomitant infection makes this decision substantially more complex. Trauma itself induces a systemic inflammatory and immune response [5], while infection and subsequent surgical stress may further amplify inflammation and contribute to organ dysfunction [6]. In clinical practice, persistent leukocytosis, neutrophilia, fever, or the presence of pulmonary or intra-abdominal infection may therefore raise concern about proceeding with definitive fixation. Yet an isolated abnormal value does not necessarily reflect overall operative tolerance. The multidimensional nature of polytrauma also supports evaluating systemic physiological reserve in the context of injury burden and physiologic derangement rather than relying on a single marker [7]. In this setting, trends in inflammation together with hematologic and haemostatic reserve may provide a more clinically meaningful picture of readiness for reconstruction.

A second consideration is that systemic and local infection-related hazards may represent different dimensions of perioperative risk. Systemic physiological reserve may primarily influence susceptibility to postoperative systemic complications, whereas the local relationship between infected or compromised tissue and the planned operative field may more directly determine wound healing and implant-related outcomes. Our previous work focused on surgical timing and a multivariable decision framework [8], but did not specifically separate these two pathways. Locally contaminated or devitalized soft tissue is a recognized determinant of surgical-site complications [9]. Morel-Lavallée lesions may create a similarly high-risk environment despite an apparently intact skin surface [10], and their proximity to fracture fixation has been associated with increased surgical-site infection risk [11]. Contemporary fracture-related infection guidance likewise emphasizes soft-tissue viability, adequate debridement, and coverage as central determinants of successful reconstruction [12, 13].

In contrast, evidence remains limited on whether an infection remote from the operative field should carry the same implications for fracture reconstruction as infection adjacent to or directly involving the surgical corridor. Existing evidence is sparse and largely indirect [14, 15]. We therefore examined two complementary questions in polytrauma patients with concomitant infection: whether systemic physiological reserve, assessed through five preoperative physiologic domains, was associated with postoperative systemic complications; and whether the spatial relationship between infection and the operative field was associated with wound or implant outcomes independently of infection type and systemic status. We further explored whether controlled high inflammation and time from injury to definitive surgery provided clinically relevant signals.

Methods

Study design and setting

We conducted a single-centre ambispective observational cohort study in the Department of Emergency Surgery, Qilu Hospital of Shandong University. The retrospective phase comprised 346 consecutive patients treated from January 2019 through April 2024, for whom data were abstracted from existing records. The prospective phase comprised 110 consecutive patients treated from May 2024 through August 2025, for whom exposures, covariates, acute outcomes, and planned follow-up variables were collected forward using a study form. The prospective phase did not randomise treatment, mandate operation according to the study thresholds, or serve as an external validation cohort. Acute analyses therefore combined both phases and adjusted for collection phase; phase-stratified estimates and exposure-by-phase interactions assessed consistency. Reporting follows STROBE guidance [22].

Participants

Eligible patients met the New Berlin definition of polytrauma [7], had at least one fracture requiring definitive reconstruction, had a documented intra-abdominal, pulmonary, or wound/soft-tissue infection, and underwent definitive reconstruction during the index admission. Intra-abdominal infection required compatible clinical, laboratory, and imaging findings and was classified in accordance with international pathways [16]. Pulmonary infection required compatible symptoms, new or progressive imaging abnormalities, and inflammatory or microbiological support. Wound/soft-tissue infection required local inflammatory or purulent findings with imaging or microbiological corroboration when available.

Exclusion criteria were terminal organ failure or another condition precluding reconstruction, marked immunosuppression, non-reconstructable extensive bone or soft-tissue loss, pregnancy or lactation, and an immediately fatal condition. Refractory shock and uncontrolled severe sepsis at the time of planned fixation were excluded. Transient or reversible shock that was responsive to resuscitation or vasoactive support was not an automatic exclusion, but all included patients had achieved clinically correctable haemodynamic control before definitive surgery. All patients had negative preoperative blood cultures and no documented bacteraemia before fixation. The eligible cohort was analysed without post hoc sample-size calculation.

Five-domain systemic Status Adequacy Score

Five preoperative domains were evaluated on the day before surgery: white blood cell count (WBC), neutrophil percentage (NEUT%), temperature, haemoglobin, and platelet count. The inflammatory domains deliberately combined an absolute ceiling with evidence of a non-rising trajectory when the value remained high (Table 1). The thresholds were taken from the pre-existing clinical framework and were not selected by maximising association with the outcomes in this dataset [8].

Table 1
Five-domain systemic Status Adequacy Score criteria

Domain	Criterion met when	Interpretation
WBC	$WBC_1d < 22\times10^9$/L; if $WBC_1d > 15\times10^9$/L, $WBC_1d/WBC_3d < 1$	Absolute ceiling plus conditional decline
NEUT%	$NEUT_1d < 90\%$; if $NEUT_1d > 85\%$, $NEUT_1d/NEUT_3d < 1$	Absolute ceiling plus conditional decline
Temperature	$T_1d < 38.5$°C; if $T_1d > 38.0$°C, $T_1d - T_3d < 0$	Absolute ceiling plus conditional decline
Haemoglobin	> 90 g/L	Haematologic reserve
Platelets	$> 50\times10^9$/L	Haemostatic reserve

WBC, white blood cell count; NEUT%, neutrophil percentage; 1d and 3d denote the measurements 1 and 3 days before surgery.

For each patient, unmet domains were counted and classified as all five criteria met, one criterion unmet, or two or more criteria unmet. High inflammation was defined as at least one of WBC > 15×10^9/L, NEUT% >85%, or temperature > 38.0°C. An inflammation trajectory was considered controlled only when all three inflammatory domains met both their upper limit and conditional trend requirement. The controlled-high-inflammation comparison was restricted to patients with a controlled trajectory and contrasted those still above at least one high-inflammation trigger with those below all three.

Infection-to-operative-field spatial relationship

The spatial exposure was assessed separately from infection type. Level 0 (remote) meant that the infection focus, wound, closed degloving lesion, or compromised tissue was outside the planned incision, fracture exposure, fixation corridor, and soft-tissue coverage zone, and did not require a change in approach. Level 1 (adjacent without overlap) meant that local pathology did not enter the planned operative corridor but was sufficiently close to influence incision placement, exposure, fixation route, or coverage. Level 2 (overlapping/involving) meant that the planned operation traversed or directly involved infected, contaminated, degloved, devitalised, or poorly perfused tissue, or that infection control and reconstruction had to be managed as one local problem.

Two trauma surgeons independently classified the spatial relationship from examination records, preoperative photographs, imaging, and the operative plan. A senior trauma surgeon adjudicated disagreements. Main analyses retained all three levels with level 0 as reference. A secondary phase-consistency analysis combined levels 1 and 2 because the prospective phase contained no level-2 patients.

Outcomes

The systemic outcome was the occurrence of at least one postoperative pneumonia, respiratory failure/acute respiratory distress syndrome (ARDS), sepsis, or acute kidney injury (AKI). Only new or clearly worsened postoperative events were counted. Sepsis was adjudicated according to Sepsis-3 principles [18], AKI according to KDIGO criteria [19], and ARDS according to the Berlin definition [20]. Deep-vein thrombosis was excluded from the revised composite. Patients could contribute more than one component, but only once to the binary composite.

The local outcome was coded as 0, uncomplicated primary healing without implant infection; 1, a non-severe adverse incision outcome (institutional grade-II healing or grade-III healing managed without surgical debridement); or 2, a severe adverse outcome (grade-III healing requiring debridement or fracture-fixation/implant infection). The institutional grade was distinct from the CDC wound-class category: grade II denoted delayed or inflamed healing without purulence, whereas grade III denoted purulent drainage, dehiscence, or a clinically documented surgical-site infection. Fracture-related infection was adjudicated using international confirmatory criteria where applicable [13]. The primary local analysis used any adverse outcome (code ≥ 1); code 2 was described separately. Events were ascertained through the index admission and prespecified postoperative surveillance (30 days for superficial incisional events and 90 days for implant-related events) [17].

Secondary resource-use outcomes were total hospital length of stay, intensive care unit (ICU) length of stay, and total hospital charge in 10,000 Chinese yuan. One impossible zero-day hospital-stay record was treated as invalid, and four charge values were missing. ICU stays of zero days were retained as valid non-ICU use.

Prospective one-year follow-up subcohort

The prospective phase included a separate descriptive one-year follow-up subcohort. Follow-up was intended to characterise recovery rather than to validate the acute models. Fracture union was assessed from clinical examination and site-appropriate orthogonal radiographs (with computed tomography when clinically required) by two experienced orthopaedic trauma surgeons. For long-bone fractures, union required bridging callus or cortical continuity across at least three of four cortices, no progressive implant failure or displacement, and no clinically important fracture-site pain, tenderness, or pathological motion; disagreements were adjudicated by a third senior surgeon [34, 35]. Site-specific criteria were used for pelvis, acetabulum, and spine.

Functional outcomes were termed site-specific function rather than joint range of motion. The aggregate unfavourable-function outcome was defined by the instrument appropriate to the injured region: Harris Hip Score < 70 for the hip [26], absolute Constant–Murley score < 70 for the shoulder [27, 28], Knee injury and Osteoarthritis Outcome Score quality-of-life (KOOS-QoL) subscale < 44 for the knee [29, 30], or Oswestry Disability Index > 40% for the spine [31]. Constant scores vary by age and sex, and the KOOS-QoL threshold was developed mainly in anterior cruciate ligament populations; these binary applications were therefore prespecified as exploratory. Poor SF-36 health status was defined as PCS ≤ 43 or MCS ≤ 44. These are study-specified rather than universal failure thresholds, and orthopaedic interpretation of component scores requires caution [32, 33]. The supplied workbook contained the aggregate binary classifications but not instrument-specific denominators or continuous scores.

Covariates and confounding control

Adjustment variables were prespecified from clinical knowledge and availability before multivariable modelling; they were not selected by univariable P values or automated variable selection. The systemic-complication model included physiologic group, age per 10 years, sex, Injury Severity Score (ISS) per 10 points, fracture distribution (pelvis, spine, extremity, or multiple regions), infection type, time from injury to definitive surgery per 7 days, and retrospective versus prospective phase. These variables represented baseline reserve, injury burden and anatomy, infection context, treatment opportunity, and the change in data-collection direction.

The wound/implant model included spatial level, infection type, physiologic group, ISS per 10 points, time to surgery per 7 days, and phase. Infection type and spatial level were entered together so that an infection source was not used as a proxy for

local geometry. Covariate adjustment estimates the exposure–outcome association among patients with comparable measured characteristics; it does not remove unmeasured confounding, correct treatment indication, or create a causal effect. Postoperative variables were not used as confounders.

Statistical analysis

Continuous variables are reported as medians and interquartile ranges (IQRs), and categorical variables as counts and percentages. Because both binary outcomes were common, robust-variance Poisson regression with a log link was used to estimate adjusted risk ratios (aRRs) and 95% confidence intervals (CIs) [21]. Two indicator terms represented the three physiologic groups, and their joint robust Wald test provided the overall group P value. The wound model used separate indicators for levels 1 and 2. Severe wound events were not modelled because level 0 contained no events, producing complete separation.

Prespecified secondary analyses examined infection type within the full wound model; infection type within level 0; controlled high inflammation; time to surgery in the full cohort and physiologically stable subsets; descriptive phase-stratified effects; and exposure-by-phase interaction. Resource-use distributions were compared with Kruskal–Wallis tests. Adjusted length-of-stay and ICU ratios used robust Poisson log-link models; positive right-skewed charge data used a gamma model with log link and robust standard errors. Resource models used the same measured baseline covariates as the systemic model. Calendar year was unavailable; phase adjustment was not treated as inflation correction.

Analyses used complete available records for each outcome. Tests were two-sided with $P < 0.05$. Secondary and exploratory analyses were not adjusted for multiplicity and were interpreted as associations, not causal effects or evidence of equivalence. One-year follow-up was available only as aggregate 2×2 counts. We therefore reported crude risks, risk ratios with log-Wald 95% CIs, and Pearson chi-square P values without multivariable adjustment when the supplied cell counts and P values were internally consistent; affected comparisons were withheld pending author verification.

Ethics and consent

The study complied with the Declaration of Helsinki and was approved by the Ethics Committee of Qilu Hospital of Shandong University (approval no. [KYLL-202405-044]). Written informed consent was obtained from all prospectively enrolled patients or their authorised representatives. The requirement for individual consent in the retrospective phase was waived by the ethics committee. Consent included permission for one-year follow-up in the prospective phase.

Results

Cohort characteristics

The cohort comprised 456 patients: 346 in the retrospective phase and 110 in the prospective phase. Median age was 48.0 years (IQR 36.0–57.3), median ISS was 34 (27–41), and median time from injury to definitive surgery was 11.0 days (6.0–19.3). There were 186 intra-abdominal infections (40.8%), 151 pulmonary infections (33.1%), and 119 wound/soft-tissue infections (26.1%). Spatial levels 0, 1, and 2 comprised 359 (78.7%), 72 (15.8%), and 25 (5.5%) patients, respectively. All five physiologic criteria were met in 124 patients (27.2%); 173 (37.9%) had one unmet criterion and 159 (34.9%) had two or more unmet criteria (Table 2).

Table 2
Cohort characteristics by physiologic readiness

Characteristic	Overall (n = 456)	All five met (n = 124)	One unmet (n = 173)	≥ 2 unmet (n = 159)
Age, years	48.0 (36.0–57.3)	48.0 (35.0–56.3)	48.0 (39.0–58.0)	45.0 (36.5–57.0)
Male sex	315 (69.1)	92 (74.2)	115 (66.5)	108 (67.9)
ISS	34 (27–41)	32 (25–36.5)	34 (27–41)	34 (27–43)
Injury-to-surgery, days	11.0 (6.0–19.3)	10.0 (6.0–18.3)	12.0 (6.0–20.0)	11.0 (7.0–18.0)
Pelvic fracture	149 (32.7)	32 (25.8)	63 (36.4)	54 (34.0)
Spinal fracture	68 (14.9)	17 (13.7)	29 (16.8)	22 (13.8)
Extremity fracture	134 (29.4)	45 (36.3)	46 (26.6)	43 (27.0)
Multiple fracture regions	105 (23.0)	30 (24.2)	35 (20.2)	40 (25.2)
Intra-abdominal infection	186 (40.8)	47 (37.9)	68 (39.3)	71 (44.7)
Pulmonary infection	151 (33.1)	42 (33.9)	60 (34.7)	49 (30.8)
Wound/soft-tissue infection	119 (26.1)	35 (28.2)	45 (26.0)	39 (24.5)
Spatial level 0	359 (78.7)	92 (74.2)	145 (83.8)	122 (76.7)
Spatial level 1	72 (15.8)	24 (19.4)	20 (11.6)	28 (17.6)
Spatial level 2	25 (5.5)	8 (6.5)	8 (4.6)	9 (5.7)
Prospective phase	110 (24.1)	31 (25.0)	32 (18.5)	47 (29.6)

Data are median (IQR) or n (%). Baseline P values were not used to select model covariates. ISS, Injury Severity Score.

Systemic Status Adequacy Score and systemic complications

The systemic composite occurred in 136 patients (29.9%). Rates were 19.4% (24/124) when all five criteria were met, 27.3% (47/172) with one unmet criterion, and 40.9% (65/159) with two or more unmet criteria. Relative to all criteria met, the adjusted risk was not significantly increased for one unmet criterion (aRR 1.31, 95% CI 0.85–2.01; P = 0.222), but was significantly higher for two or more unmet criteria (aRR 1.99, 95% CI 1.33–2.98; P < 0.001). Bonferroni-adjusted pairwise comparisons showed no significant difference between the all-five-met and one-unmet groups (P ≈ 0.112), but significant differences between the one-unmet and ≥ 2-unmet groups (P ≈ 0.009) and between the all-five-met and ≥ 2-unmet groups (P ≈ 0.0001)(Table 3).

Table 3
Systemic Status Adequacy Score and postoperative complications

Analysis	Events/N (%)	Adjusted comparison	aRR (95% CI)	P value
All five met	24/124 (19.4)	Reference	1.00	—
One unmet	47/173 (27.2)	vs all five met	1.31 (0.85–2.01)	0.222
≥ 2 unmet	65/159 (40.9%)	vs all five met	1.99 (1.33–2.98)	<0.001
Group overall	136/456 (29.8)	Joint robust Wald test	—	0.228
Pneumonia	89 component events	Retrospective/prospective	72/17	—
Sepsis	35 component events	Retrospective/prospective	32/3	—
AKI	34 component events	Retrospective/prospective	26/8	—
Respiratory failure/ARDS	35 component events	Retrospective/prospective	28/7	—

Robust-variance Poisson model adjusted for time to surgery, age, sex, ISS, fracture distribution, infection type, and collection phase. Component events are not mutually exclusive; only one event per patient contributes to the binary composite. aRR, adjusted risk ratio; AKI, acute kidney injury; ARDS, acute respiratory distress syndrome.

Component events included pneumonia in 89 patients, sepsis in 35, AKI in 34, and respiratory failure/ARDS in 35; components were not mutually exclusive. No significant interaction was observed between study phase and systemic physiological reserve group (P = 0.441).

Operative-field proximity and wound or implant outcomes

Any wound/implant adverse outcome occurred in 118 patients (25.9%), comprising 96 code-1 outcomes (21.1%) and 22 severe code-2 outcomes (4.8%). Any-event rates were 14.5% (52/359), 66.7% (48/72), and 72.0% (18/25) across spatial levels 0, 1, and 2. Severe outcomes occurred in 0/359, 6/72 (8.3%), and 16/25 (64.0%), respectively; all 22 severe outcomes occurred at levels 1 or 2 (Fisher exact P < 0.001).

In the adjusted model, compared with level 0, the aRR was 6.68 (95% CI 4.54–9.81; P < 0.001) for level 1 and 7.11 (4.73–10.70; P < 0.001) for level 2 (joint P < 0.001). Pulmonary versus intra-abdominal infection was not detectably associated with the local outcome (aRR 0.83, 0.62–1.12; P = 0.215), whereas wound/soft-tissue infection was associated with higher risk (aRR 2.17, 1.39–3.40; P < 0.001). The Systemic Status Adequacy Score was not associated with the local outcome in this model (joint P = 0.967) (Table 4).

Table 4
Operative-field proximity and wound outcomes

Spatial level/variable	N	Any adverse outcome	Severe outcome	Adjusted result for any outcome
Level 0: remote	359	52 (14.5)	0 (0.0)	Reference
Level 1: adjacent	72	48 (66.7)	6 (8.3)	aRR 6.68 (4.54–9.81)
Level 2: overlapping/involving	25	18 (72.0)	16 (64.0)	aRR 7.11 (4.73–10.70)
Pulmonary infection	151	—	—	aRR 0.83 (0.62–1.12)
Wound/soft-tissue infection	119	—	—	aRR 2.17 (1.39–3.40)
One physiologic criterion unmet	173	—	—	aRR 1.03 (0.72–1.46)
≥ 2 physiologic criteria unmet	159	—	—	aRR 1.05 (0.74–1.47)

Any adverse outcome was code ≥ 1; severe outcome was code 2. Model n = 456, 118 events; adjusted for infection type, physiologic group, ISS, time to surgery, and phase. Infection-type reference was intra-abdominal infection. Severe outcomes were not modelled because level 0 had zero events. All proximity P values were < 0.001; pulmonary P = 0.215; wound/soft-tissue P < 0.001. aRR, adjusted risk ratio.

Within level 0, pulmonary versus intra-abdominal infection remained unassociated with detectable excess risk (aRR 0.92, 95% CI 0.37–2.26; P = 0.856), whereas wound/soft-tissue infection remained associated with higher risk (aRR 2.92, 1.60–5.32; P < 0.001). Thus, the data do not support treating every remote local wound infection as risk-neutral. The crude effect of levels 1–2 versus level 0 was similar in the retrospective phase (RR 4.61) and prospective phase (RR 5.00); the adjusted proximity-by-phase interaction was P = 0.765.

Controlled high inflammation and surgical timing

Among 235 patients whose inflammatory trajectory met all three control rules, 40 still met at least one high-inflammation trigger. Controlled high inflammation was not detectably associated with the systemic composite (aRR 1.03, 95% CI 0.61–1.74; P = 0.902) or the wound/implant outcome (aRR 0.58, 0.30–1.09; P = 0.092). These findings suggest that persistently elevated inflammatory markers may not indicate additional postoperative risk when the inflammatory trajectory is controlled.

Across the full cohort, each additional 7 days from injury to definitive surgery was associated with a 9% higher adjusted risk of the systemic composite (aRR 1.09, 95% CI 1.03–1.16; P = 0.003). This association was not statistically significant in the exploratory core-stable subset with a controlled inflammatory trajectory and haemodynamic stability (aRR 1.06, 0.96–1.17). These findings suggest that the association between surgical delay and systemic complications may partly reflect underlying physiologic instability, supporting interpretation of surgical timing in conjunction with physiologic reserve and inflammatory trajectory rather than elapsed time alone. (Table 5).

Table 5
Secondary and exploratory adjusted analyses

Analysis	Population	aRR (95% CI)	P value	Interpretation
Controlled high inflammation → systemic composite	Controlled trajectory (n = 235)	1.03 (0.61–1.74)	0.902	No detectable signal; imprecise
Controlled high inflammation → local outcome	Controlled trajectory (n = 235)	0.58 (0.30–1.09)	0.092	Not an equivalence test
Each 7-day surgical delay → systemic composite	Full cohort	1.09 (1.03–1.16)	0.003	Association; no causal inference
Pulmonary vs abdominal infection → local outcome	Spatial level 0 (n = 359)	0.92 (0.37–2.26)	0.856	No detectable difference
Wound vs abdominal infection → local outcome	Spatial level 0 (n = 359)	2.92 (1.60–5.32)	< 0.001	Remote wound infection not risk-neutral
Proximity × phase interaction	Full cohort	0.90 (0.43–1.85)	0.765	No detectable phase heterogeneity
Physiologic group × phase interaction	Full cohort	—	0.441	No detectable phase heterogeneity

Exploratory analyses were not corrected for multiplicity. Controlled high inflammation was assessed only among patients who met all three inflammatory ceiling-and-trend rules.

Medical resource use

Median total hospital stay, ICU stay, and total charge increased across the three physiologic groups (unadjusted P = 0.003, < 0.001, and < 0.001, respectively). Compared with all five criteria met, adjusted ratios for two or more unmet criteria were 1.14 (95% CI 1.05–1.25) for total stay, 1.22 (1.06–1.39) for ICU stay, and 1.39 (1.15–1.68) for total charge. Associations for one unmet criterion were smaller (Table 6). These findings suggest that lower systemic physiological reserve is associated with greater healthcare resource utilization.

Table 6
Medical resource use by physiologic group

Outcome	All five met	One unmet	≥ 2 unmet	Adjusted ratios vs all five met
Hospital stay, days	28.0 (21.0–41.0)	31.0 (25.0–46.0)	34.0 (27.0–48.0)	1.11 (1.01–1.22); 1.14 (1.05–1.25)
ICU stay, days	16.0 (10.0–24.3)	19.0 (13.0–32.0)	23.0 (15.5–32.0)	1.14 (0.99–1.31); 1.22 (1.06–1.39)
Total charge, 10,000 CNY	15.95 (10.68–23.30)	18.20 (13.60–28.40)	21.30 (14.10–32.70)	1.20 (1.04–1.38); 1.39 (1.15–1.68)

Values are median (IQR). Ratios are listed for one unmet and ≥ 2 unmet, respectively. Hospital stay n = 455; ICU stay n = 456; total charge n = 452. Time outcomes used robust Poisson log-link models; charge used a gamma log-link model with robust standard errors. Models adjusted for time to surgery, age, sex, ISS, fracture distribution, infection type, and phase. Calendar-year price adjustment was unavailable. CNY, Chinese yuan; ICU, intensive care unit.

One-year prospective follow-up

All 110 prospectively enrolled patients completed one-year follow-up. Overall, 47 (42.7%) had poor quality of life, 34 (30.9%) had limited site-specific function, and 32 (29.1%) had poor fracture union. Compared with patients without systemic complications, those with complications more frequently had poor quality of life (64.5% vs 34.2%; P = 0.004) and limited function (45.2% vs 25.3%; P = 0.043), whereas poor union did not differ significantly (29.3% vs 29.0%; P = 0.975). Patients with wound-healing adverse outcomes or implant infection had substantially more poor fracture union (63.0% vs 18.1%; P < 0.001),

while differences in quality of life and function were not statistically significant (Table 7). These findings suggest that systemic complications are associated with poorer long-term quality of life and functional recovery, whereas wound/implant adverse outcomes are closely associated with impaired fracture healing.

Table 7
One-year outcomes in the prospective subcohort

Outcome	No systemic complication	Systemic complication	RR (95% CI)	P value	No wound/implant-related event	Wound/implant-related event	RR (95% CI)	P value
Poor SF-36 health status	27/79 (34.2%)	20/31 (64.5%)	1.89 (1.26–2.82)	0.004	32/83 (38.6%)	15/27 (55.6%)	1.44 (0.93–2.22)	0.121
Poor fracture union	20/69 (29.0%)	12/41 (29.3%)	1.01 (0.55–1.84)	0.975	15/83 (18.1%)	17/27 (63.0%)	3.48 (2.03–5.99)	< 0.001
Unfavorable site-specific function	20/79 (25.3%)	14/31 (45.2%)	1.78 (1.04–3.07)	0.043	22/83 (26.5%)	12/27 (44.4%)	1.68 (0.96–2.92)	0.080

Values are n/N (%). RRs compare the event group with the corresponding no-event group. P values are Pearson chi-square tests from aggregate counts. Poor health status was the supplied aggregate of PCS ≤ 43 or MCS ≤ 44; unfavourable function used the site-specific threshold. Union status was available for 100 patients; other outcomes for 110. Two systemic-complication comparisons were withheld because the source summary was internally inconsistent; verify against patient-level one-year scores before submission. RR, crude risk ratio; PCS/MCS, physical/mental component summary.

Discussion

Principal findings

This study evaluated fracture-reconstruction risk in polytrauma patients with concomitant infection from two complementary dimensions: systemic physiological reserve and the spatial relationship between infection and the operative field. The risk of systemic complications increased with a greater number of unmet physiologic criteria, and patients with ≥ 2 unmet criteria had nearly twice the adjusted risk compared with those meeting all five criteria, suggesting that cumulative physiologic abnormalities may better reflect reduced systemic reserve than any single abnormal parameter. In parallel, wound and implant-related adverse outcomes increased markedly when infection was adjacent to or involved the operative field, and all severe local events occurred in these two groups. These findings support separate assessment of systemic and local risk rather than basing surgical decisions solely on an isolated inflammatory abnormality or infection type.

Clinical interpretation

Controlled high inflammation was not associated with an evident increase in postoperative systemic or local adverse outcomes. This suggests that, when inflammatory trajectories are stable and overall physiology is acceptable, persistent leukocytosis, neutrophilia, or fever should not by itself preclude definitive fracture reconstruction.

Similarly, after accounting for operative-field proximity and other covariates, pulmonary infection did not confer greater wound risk than intra-abdominal infection. Thus, a controlled infection remote from the operative field should not automatically delay surgery; local tissue condition and the spatial relationship between infection and the planned surgical corridor may be more relevant to operative decision-making.

Longer injury-to-surgery time was associated with a higher risk of systemic complications, with attenuation in physiologically stable patients. Taken together, these findings support an individualized early-surgery approach: once systemic physiology and inflammatory activity are adequately controlled and local infection is sufficiently separated from the operative field, definitive reconstruction should proceed without unnecessary additional delay.The goal of individualized treatment is not simply to

operate as early as possible, but to avoid unnecessary delay once acceptable systemic and local conditions have been achieved.

Strengths and limitations

The A major strength of this study is its focus on the clinically complex population of polytrauma patients with concomitant infection, with separate evaluation of systemic physiological reserve and local operative-field risk. The use of adjusted risk ratios also improves the clinical interpretability of the findings.

Several limitations should be acknowledged. This was a single-center observational study and remains subject to residual and confounding by indication. Some potentially important covariates were unavailable, the number of severe local events was limited, and the prospective cohort was relatively small and included no patients in the highest spatial-risk category. One-year follow-up and several exploratory analyses were not fully adjusted for covariates. These findings therefore warrant further confirmation in larger multicenter cohorts.

Conclusions

In polytrauma patients with concomitant infection, the spatial relationship between infection and the operative field was an important determinant of wound and implant-related outcomes, whereas infection type alone did not fully capture local risk. Pulmonary and intra-abdominal infections showed no detectable difference in local risk, while wound or soft-tissue infections adjacent to or involving the operative field were associated with greater local adverse outcomes. Meanwhile, reduced systemic physiological reserve, particularly the accumulation of multiple unmet physiologic criteria, was associated with increased risk of the systemic composite and greater healthcare resource utilization. These findings support dynamic, individualized assessment based on systemic physiology, inflammatory trajectory, and infection-to-operative-field relationship to identify appropriate conditions for reconstruction and avoid unnecessary surgical delay.

Abbreviations

AKI
acute kidney injury
ARDS
acute respiratory distress syndrome
aRR
adjusted risk ratio
CI
confidence interval
ICU
intensive care unit
IQR
interquartile range
ISS
Injury Severity Score
KOOS-QoL
Knee injury and Osteoarthritis Outcome Score quality-of-life subscale
MCS
mental component summary
NEUT%
neutrophil percentage
ODI
Oswestry Disability Index

PCS
physical component summary
SF-36
36-Item Short Form Health Survey
WBC
white blood cell count.

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Qilu Hospital of Shandong University (approval no. KYLL-202405-044). Prospective participants or authorised representatives provided written informed consent. The requirement for informed consent for the retrospective phase was waived by the Ethics Committee of Qilu Hospital of Shandong University.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

CD and XZ conceived the study. CD, MJ, XH, and JZ contributed to data acquisition and curation. CD and XH performed the formal analysis. ZW and XS supervised the project and clinical interpretation. CD drafted the manuscript. All authors critically revised the manuscript and must approve the final submitted version.

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Data Availability

Availability of data and materialsDe-identified data may be available from the corresponding author on reasonable request, subject to ethics approval, institutional requirements, and protection of participant privacy.

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