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Impact of Early Surgical Debridement on Outcomes in ICU Patients With Sepsis-Associated Intra-Abdominal Infection: A Retrospective Analysis

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AIM: To investigate the impact of early surgical debridement, defined as a diagnosis-to-knife time (D-to-K time) ≤12 hours, on intensive care unit (ICU) outcomes in patients with sepsis-associated intra-abdominal infection.

METHODS: This single-center retrospective cohort study consecutively enrolled patients with sepsis-associated intra-abdominal infection who were admitted to the ICU and underwent surgical debridement between 1 January 2021 and 31 January 2025. Patients were stratified into an early surgery group (D-to-K time ≤12 hours, n = 65) and a delayed surgery group (D-to-K time >12 hours, n = 87). Baseline characteristics, ICU length of stay, duration of organ support, incidence of complications, mortality and other clinical outcomes were compared between the two groups. Multivariate logistic regression analysis was performed to evaluate the independent effect of early surgery on 28-day mortality.

RESULTS: The delayed surgery group demonstrated a higher prevalence of preoperative septic shock (66.7% vs. 33.8%) and diffuse peritonitis (50.6% vs. 32.3%), as well as a higher proportion of open surgical procedures (90.8% vs. 76.9%) compared with the early surgery group. The early surgery group exhibited significantly shorter ICU length of stay, total duration of mechanical ventilation, and duration of vasoactive drug use. The incidences of ICU-acquired weakness (ICU-AW), acute kidney injury (AKI), and 28-day ICU mortality were significantly lower in the early surgery group. Surgical timing and preoperative septic shock were significantly associated with mortality. After adjustment for preoperative septic shock, early surgery remained an independent protective factor for 28-day mortality.

CONCLUSIONS: In patients with sepsis-associated intra-abdominal infection, early surgical intervention (D-to-K time ≤12 hours) is associated with improved ICU outcomes, including shorter organ support duration, lower complication rates, and reduced 28-day mortality.

Keywords: sepsis; intra-abdominal infection; surgical debridement; 28-day mortality; intensive care unit outcomes

Introduction

Sepsis is a life-threatening condition characterized by organ dysfunction resulting from infection and remains one of the leading causes of mortality among patients admitted to the intensive care unit (ICU) [1]. Intra-abdominal infection is a common etiology of sepsis and is often difficult to control due to the continuous release of inflammatory mediators, frequently resulting in multiple organ failure. Timely source control is therefore crucial for improving outcomes in this population.

Surgical debridement represents the cornerstone of management for complicated intra-abdominal infections and is central to achieving effective source control. In recent years, the optimal timing of surgical intervention, particularly the distinct definition of "early" and "delayed" surgery, as well as its associated clinical impact, has become a major focus of debate in the fields of emergency surgery and critical care medicine. Guidelines issued by the World Society of Emergency Surgery (WSES) [2] recommend that, for patients with sepsis or septic shock, source control surgery should be performed as soon as possible after diagnosis, for example, within 12 hours. The theoretical rationale is that prompt mitigation of the infectious agents may limit systemic dissemination of pathogens and inflammatory mediators, thereby attenuating organ injury, shortening the duration of organ support, and ultimately improving clinical outcomes. However, in clinical practice, there is no universally accepted definition of "early" surgery (e.g., within 6, 12, or 24 hours), and existing evidence largely focuses on specific diseases (such as complicated appendicitis or diverticulitis) or includes heteroge-

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neous populations with varying infection severity, resulting in inconsistent conclusions [3]. Some studies suggest that early surgery reduces mortality and complication rates, whereas others indicate that "delayed" surgery performed after adequate preoperative resuscitation and physiological optimization may be equally safe or even beneficial [4,5].

At present, retrospective studies specifically targeting adult patients who meet the Third International Consensus Definitions for Sepsis and Septic Shock (Sepsis-3) criteria for sepsis [6], are admitted to the ICU due to secondary intra-abdominal infection, and undergo surgical debridement, remain limited. In particular, systematic evaluations of the interval between "confirmed diagnosis and surgical decision-making" and "skin incision", defined as the diagnosis-to-knife time (D-to-K time), and its impact on key ICU outcomes (including length of stay, organ support requirements, complication rates, and mortality) are scarce. Clarifying the potential benefits of early surgery (e.g., D-to-K time ≤12 hours) in this high-risk population is of substantial importance for guiding clinical decision-making and optimizing resource allocation.

Therefore, this retrospective cohort study aimed to investigate whether early surgery (D-to-K time ≤12 hours), compared with delayed surgery, improves ICU length of stay, duration of organ support, complication rates, and survival outcomes in patients with confirmed sepsis undergoing surgical debridement for secondary intra-abdominal infection. Multivariate analysis was performed to determine the independent effect of early surgical intervention, with the goal of providing evidence to inform clinical practice.

Methods

Study Population

In this single-center retrospective cohort study, eligible patients admitted to the ICU between 1 January 2021 and 31 January 2025 were consecutively identified through a systematic review of the hospital's electronic medical records, imaging data, as well as anesthesia and operative reports.

Inclusion criteria were as follows: (1) age ≥ 18years; (2) fulfillment of the diagnostic criteria for sepsis according to the Sepsis-3 [6], based on admission records and clinical evidence; (3) confirmed diagnosis of secondary intra-abdominal infection by abdominal computed tomography and/or emergency surgical exploration (etiologies including gastrointestinal perforation, acute appendicitis or diverticulitis with perforation, postoperative anastomotic leakage); (4) receipt of open or laparoscopic surgical debridement/source control during ICU stay for management of the infectious focus.

Exclusion criteria included: (1) death or withdrawal of active treatment within 24 hours after admission; (2) infection managed solely by percutaneous drainage without surgical intervention; (3) pregnancy; (4) emergency surgery for abdominal trauma, mesenteric ischemia, or other vascular or non-infectious etiologies; (5) missing key data (e.g., inability to determine the time of confirmed infection diagnosis, time of surgery, or primary study outcomes).

Patients were stratified according to the D-to-K time, which was explicitly defined as the interval between the first documented time point indicating "confirmed sepsis-associated intra-abdominal infection with a decision for surgery" (e.g., multidisciplinary consultation record or definitive imaging report) and the time of "skin incision" recorded in the operative note. The diagnosis time was defined as the earliest documented time point at which a definitive diagnosis was established, as recorded in either a multidisciplinary consultation note or a definitive imaging report. The D-to-K time was calculated in hours.

A cutoff value of 12 hours was selected based primarily on recommendations from the WSES guidelines and related clinical studies, which suggest that source control intervention for patients with sepsis requiring surgery should ideally be performed within 12 hours after diagnosis [1,3,6]. Accordingly, patients were divided into two groups: an early surgery group with a D-to-K time ≤12 hours, and a delayed surgery group with a D-to-K time >12 hours.

Data Collection and Variable Definitions

All data were independently extracted by two uniformly trained investigators through review of the electronic medical record (EMR) system, anesthesia and operative reports, ICU charts, and the laboratory information system. Discrepancies were resolved by consensus through discussion or, when necessary, adjudicated by a third senior investigator.

The collected variables included the following: (1) Demographic characteristics: age, sex, body mass index (BMI), and Charlson Comorbidity Index (CCI). The CCI was calculated according to standard methodology by assigning weighted scores (1, 2, 3, or 6 points) to specific comorbid conditions (e.g., myocardial infarction, congestive heart failure, diabetes mellitus, malignant tumors), with higher total scores indicating greater comorbidity burden [7]. (2) Disease severity and preoperative status: Sequential Organ Failure Assessment (SOFA) score, defined as the worst value within 24 hours after ICU admission, evaluating six organ systems with a total score ranging from 0 to 24 [8]. Appropriate preoperative antibiotic therapy was defined as the administration of empirically appropriate antibiotics targeting the suspected pathogens before skin incision. (3) Infection-related characteristics: source of intra-abdominal infection (colorectal vs. non-colorectal origin) and extent of peritonitis (diffuse vs. localized). (4) Surgery-related variables: Surgical approach (open vs. laparoscopic). (5) Hospitalization indicators: ICU length of stay, total duration of mechanical ventilation, and duration of vasoactive drug use.

Primary and secondary outcomes included: (1) ICU-acquired weakness (ICU-AW): assessed according to the clinical practice guidelines of the American Thoracic Society [9]. In cooperative and awake patients, the Medical Research Council (MRC) score was used, with a total score <48 defining ICU-AW. In patients not eligible for formal assessment, ICU-AW was defined by the presence of the following: (a) clear documentation of new-onset limb motor dysfunction; (b) exclusion of pre-existing neuromuscular disease prior to admission; (c) a dysfunction contributing to delayed weaning from mechanical ventilation or hindered early rehabilitation. (2) New-onset acute kidney injury (AKI) during ICU stay: diagnosed according to the Kidney Disease: Improving Global Outcomes (KDIGO) criteria [10]. (3) Reoperation rate: defined as any repeat surgical intervention during the same hospitalization due to recurrent infection, bleeding, fistula formation, or other complications following the initial debridement. (4) 28-day mortality: defined as death from any cause within 28 days of ICU admission. (5) In-hospital mortality: defined as death from any cause during the index hospitalization.

Statistical Analysis

All statistical analyses were performed using SPSS software (version 27.0, IBM, Chicago, IL, USA) and R software (version 4.3.1, The R Foundation for Statistical Computing, Vienna, Austria). Normality of continuous variables was assessed using the Shapiro–Wilk test. For categorical variables, the chi-square test was applied when expected frequencies were ≥5 in all cells; otherwise, Fisher's exact test was used. Normally distributed variables were expressed as mean ± standard deviation, whereas non-normally distributed variables were expressed as median (interquartile range). Categorical variables were presented as frequencies (percentages). Comparisons between groups were conducted using the independent samples *t*-test, Mann–Whitney *U* test, chi-square test, or Fisher's exact test, as appropriate.

To evaluate the independent effect of early surgery (D-to-K time ≤12 hours) on the primary outcome, univariable analyses were first performed. Only baseline characteristics and preoperative variables were included in the univariate analysis; post-admission or outcome-related variables (e.g., ICU length of stay, duration of organ support) were not considered as candidate predictors. This approach was adopted to avoid introducing post-treatment variables and potential mediators into the predictive model, thereby reducing the risk of bias and preserving the temporal relationship between predictors and outcomes. Variables significantly associated with 28-day mortality ($p < 0.05$) in univariable analysis were entered as candidate variables into a multivariate logistic regression model. Multicollinearity was assessed using the variance inflation factor (VIF), with VIF <10 indicating the absence of significant collinearity. Model calibration was evaluated using the Hosmer–Lemeshow goodness-of-fit test. All statistical tests were two-sided, and $p < 0.05$ was considered statistically significant.

Given the limited number of outcome events (26 deaths), we adhered to the principle of including approximately one predictor for every 10–15 events to minimize the risk of model overfitting. Accordingly, only variables with $p < 0.05$ in the univariate analysis were entered into the multivariate model.

To further address potential selection bias due to baseline imbalances between groups, propensity score matching (PSM) was performed as a sensitivity analysis. Propensity scores were estimated using a logistic regression model that included preoperative septic shock, extent of peritonitis, and surgical approach as covariates. Patients were matched using a 1:1 nearest-neighbor matching algorithm with a caliper width of 0.2 times the standard deviation of the propensity score. After matching, baseline characteristics were compared between the two groups using appropriate statistical tests, and outcome variables were re-analyzed in the matched cohort.

Results

Baseline Characteristics

A total of 152 patients with sepsis-associated intra-abdominal infection who met the inclusion criteria were included in this study. According to the actual D-to-K time, patients were stratified into an early surgery group (D-to-K time ≤12 hours, $n = 65$) and a delayed surgery group (D-to-K time >12 hours, $n = 87$). Significant differences were observed between the two groups in terms of disease severity and infection characteristics, and other baseline characteristics (Table 1). The delayed surgery group demonstrated a higher prevalence of preoperative septic shock (66.7% vs. 33.8%, $p < 0.001$) and diffuse peritonitis (50.6% vs. 32.3%, $p = 0.024$), as well as a higher proportion of open surgical procedures (90.8% vs. 76.9%, $p = 0.018$), compared with the early surgery group. The distribution of infection sources between groups approached statistical significance ($p = 0.078$). No significant differences were observed between groups regarding preoperative SOFA score, lactate levels, and the proportion of patients receiving appropriate preoperative antibiotic therapy (all $p > 0.05$). Demographic characteristics, including age, sex, BMI, and CCI, were also comparable between groups (all $p > 0.05$).

Comparison of ICU Outcomes

The early surgery group demonstrated superior outcomes across all key ICU indicators compared with the delayed surgery group (Table 2). Patients in the early surgery group had significantly shorter ICU length of stay, total duration of mechanical ventilation, and duration of vasoactive drug use (all $p < 0.001$). Regarding complications, the incidence of ICU-AW and AKI was significantly lower in the early surgery group (both $p < 0.05$), and the rate of reoperation showed a declining trend ($p = 0.060$). In terms of survival outcomes, the 28-day ICU mortality and overall in-hospital mortality were both significantly lower in the early surgery

Table 1. Comparison of baseline characteristics between groups.

Variables	Early surgery group (n = 65)	Delayed surgery group (n = 87)	$z/t/\chi^2$	p
Age (years)	60.00 (54.00, 65.00)	60.00 (58.00, 64.00)	−0.339	0.734
BMI (kg/m^2)	26.00 (24.00, 28.00)	25.90 (22.55, 29.45)	−0.948	0.343
Male, n (%)	44 (67.7%)	50 (57.5%)	1.647	0.199
CCI	2.00 (1.00, 3.00)	2.00 (1.00, 2.50)	−0.254	0.800
Preoperative SOFA score (points)	10.00 (8.00, 12.00)	10.00 (9.00, 11.00)	−0.382	0.702
Preoperative lactate (mmol/L)	3.64 ± 1.04	3.76 ± 1.35	−0.593	0.554
Preoperative septic shock, n (%)	22 (33.8%)	58 (66.7%)	16.075	<0.001
Appropriate preoperative antibiotic therapy, n (%)	52 (80.0%)	61 (70.1%)	1.906	0.167
Extent of peritonitis, n (%)			5.072	0.024
Diffuse	21 (32.3%)	44 (50.6%)		
Non-diffuse	44 (67.7%)	43 (49.4%)		
Infection source, n (%)			3.096	0.078
Colorectal origin	45 (69.2%)	48 (55.2%)		
Non-colorectal origin	20 (30.8%)	39 (44.8%)		
Surgical approach, n (%)			5.583	0.018
Open	50 (76.9%)	79 (90.8%)		
Non-open	15 (23.1%)	8 (9.2%)		

Note: BMI, body mass index; CCI, Charlson Comorbidity Index; SOFA, Sequential Organ Failure Assessment.

Table 2. Comparison of ICU outcome variables between groups.

Outcomes	Early surgery group (n = 65)	Delayed surgery group (n = 87)	z/χ^2	p
ICU length of stay (days)	9.00 (6.00, 11.00)	13.00 (8.50, 17.50)	−4.187	<0.001
Total duration of mechanical ventilation (hours)	80.00 (62.00, 96.00)	127 (94.00, 178.00)	−6.126	<0.001
Duration of vasoactive drug use (hours)	36.00 (21.00, 51.00)	88.00 (49.00, 105.00)	−6.110	<0.001
ICU-AW	14 (21.5%)	38 (43.7%)	8.102	0.004
AKI	21 (32.3%)	44 (50.6%)	5.072	0.024
Rate of reoperation	9 (13.8%)	23 (26.4%)	3.548	0.060
28-day ICU mortality	4 (6.2%)	22 (25.3%)	9.606	0.002
Overall in-hospital mortality	8 (12.3%)	25 (28.7%)	5.907	0.015

Note: AKI, acute kidney injury; ICU, intensive care unit; ICU-AW, ICU-acquired weakness.

group compared with the delayed surgery group (both $p <$ 0.05).

Univariate Analysis of Factors Associated With 28-Day Mortality

Univariate analysis of factors associated with 28-day mortality among all 152 patients (126 survivors, 26 non-survivors) showed that only surgical timing and preoperative septic shock were significantly associated with mortality (Table 3). Mortality was significantly lower in patients who underwent early surgery, whereas patients presenting with preoperative septic shock had significantly higher mortality. Other variables, including age, CCI, preoperative SOFA score, extent of peritonitis, infection source, surgical approach, and duration of organ support, were not significantly associated with 28-day mortality (all $p > 0.05$).

Multivariate Analysis of 28-Day Mortality

Multivariate logistic regression was performed to evaluate the independent effect of early surgery on 28-day mortality. Given the limited number of outcome events (26 deaths), the analysis adhered to the principle of "one predictor per 10–15 events" to ensure model stability. Based on univariate analysis results, two variables with $p < 0.05$, namely early surgery and preoperative septic shock, were included in the final model.

The results (Table 4) demonstrate that after adjustment for potential confounders like preoperative septic shock, early surgery (D-to-K time ≤12 hours) remained an independent protective factor for 28-day mortality (adjusted odds ratio [OR] = 0.270, 95% confidence interval [CI]: 0.085–0.860, p = 0.027). This indicates that, compared with delayed surgery, early surgery was associated with an approximately 73% reduction in the risk of 28-day mortality. Preoperative septic shock was identified as a strong independent risk factor for 28-day mortality (adjusted OR = 3.447, 95% CI: 1.180–10.070, p = 0.024).

The Hosmer–Lemeshow test indicated good model fit (χ^2 = 0.32, p = 0.853), and the variance inflation factor (VIF) values were low and identical (VIF = 1.118) for both variables included in the model, indicating no significant multicollinearity.

Table 3. Univariate analysis of factors associated with 28-day mortality in patients with sepsis-associated intra-abdominal infection.

Variables	Survivors (n = 126)	Non-survivors (n = 26)	$z/t/\chi^2$	p
Age (years)	59.81 ± 6.87	61.35 ± 4.44	−1.093	0.276
BMI (kg/m^2)	26.00 (23.00, 29.00)	25.30 (22.80, 30.20)	−0.017	0.986
Male, n (%)	77 (61.1%)	17 (65.4%)	0.167	0.683
CCI	2.00 (1.00, 3.00)	2.00 (2.00, 4.00)	−1.865	0.062
Preoperative SOFA score (points)	10.00 (9.00, 11.00)	10.00 (9.00, 11.00)	−0.261	0.794
Preoperative lactate (mmol/L)	3.65 (2.94, 4.55)	3.96 (2.63, 4.65)	−0.269	0.788
Preoperative septic shock, n (%)	59 (46.8%)	21 (80.8%)	9.961	0.002
Appropriate preoperative antibiotic therapy, n (%)	94 (74.6%)	19 (73.1%)	0.026	0.817
Extent of peritonitis, n (%)			0.147	0.701
Diffuse	53 (42.1%)	12 (46.2%)		
Non-diffuse	73 (57.9%)	14 (53.8%)		
Infection source, n (%)			2.984	0.084
Colorectal origin	81 (64.3%)	12 (46.2%)		
Non-colorectal origin	45 (35.7%)	14 (53.8%)		
Surgical approach, n (%)			0.410	0.522
Open	108 (85.7%)	21 (80.8%)		
Non-open	18 (14.3%)	5 (19.2%)		
Surgical timing, n (%)			9.606	0.002
Early surgery	61 (48.4%)	4 (15.4%)		
Delayed surgery	65 (51.6%)	22 (84.6%)		

Note: BMI, body mass index; CCI, Charlson Comorbidity Index; SOFA, Sequential Organ Failure Assessment.

Table 4. Multivariate analysis of factors associated with 28-day mortality in patients with sepsis-associated intra-abdominal infection.

Independent variables	β	S.E.	Waldχ^2	p	OR	95% CI	VIF
Surgery timing	−1.309	0.591	4.907	0.027	0.270	0.085–0.860	1.118
Preoperative shock	1.238	0.547	5.119	0.024	3.447	1.180–10.070	1.118
Constant	−1.994	0.508	15.436	<0.001	0.136	-	-

S.E., Standard Error; OR, odds ratio; CI, confidence interval; VIF, variance inflation factor.

Propensity Score Matching Analysis

To account for baseline imbalances between the early and delayed surgery groups, propensity score matching was performed. After 1:1 nearest-neighbor matching, 47 patients were included in each group. Baseline characteristics were well balanced between the matched groups, with no significant differences in preoperative septic shock (40.4% vs. 40.4%, p = 1.000), diffuse peritonitis (40.4% vs. 40.4%, p = 1.000), or open surgical approach (89.4% vs. 89.4%, p = 1.000).

Consistent with the primary analysis, the early surgery group demonstrated significantly better outcomes in the matched cohort. The 28-day ICU mortality rate was significantly lower in the early surgery group (6.4% vs. 21.3%, p = 0.037). In addition, the early surgery group had significantly shorter ICU length of stay (median 9.0 vs. 13.0 days, p < 0.001), total duration of mechanical ventilation (median 82.0 vs. 116.0 hours, p < 0.001), and duration of vasoactive drug use (median 35.0 vs. 93.0 hours, p < 0.001). The incidences of ICU-acquired weakness (23.4% vs. 42.6%, p = 0.048) and reoperation (12.8% vs. 29.8%, p = 0.044) were also significantly lower in the early surgery group, while the incidence of AKI was lower in the early surgery group, but did not reach statistical significance (29.8% vs. 46.8%, p = 0.090).

Multivariate logistic regression analysis in the matched cohort confirmed that delayed surgery was significantly associated with increased 28-day mortality (adjusted OR = 4.530, 95% CI: 1.199–22.488, p = 0.038) after adjusting for preoperative septic shock, consistent with the primary analysis.

Discussion

The core findings of this study indicate that early surgery, defined as D-to-K time ≤12 hours, significantly improves ICU resource utilization, reduces complication rates, and enhances survival outcomes. Following adjustment for the key confounding factor, namely the preoperative septic shock, early surgery remained an independent protective factor for 28-day mortality (adjusted OR = 0.270, 95% CI: 0.085–0.860). These results provide targeted clinical evidence to guide surgical timing decisions for high-risk patients with sepsis-associated intra-abdominal infection and reinforce the central role of timely source control in the management of critically ill patients.

Impact of Surgical Timing on Clinical Outcomes and Potential Mechanisms

The observed benefits in resource utilization are particularly noteworthy. Patients in the early surgery group had a median ICU stay that was 4 days shorter and required approximately 47 fewer hours of mechanical ventilation and 52 fewer hours of vasoactive support compared with the delayed surgery group. These differences likely reflect the interruption of the inflammatory cascade achieved by prompt source control. Early debridement removes the ongoing source of pathogen release and inflammatory mediators, thereby attenuating the progression of organ dysfunction and reducing the need for prolonged organ support [11]. In contrast, delayed surgery may allow persistent intra-abdominal contamination to drive sustained systemic inflammation, resulting in extended requirements for mechanical ventilation and vasoactive agents [12].

The significant reduction in ICU-AW in the early surgery group (21.5% vs. 43.7%) may be attributed to shorter durations of mechanical ventilation and sedation, as well as earlier mobilization. Similarly, the lower incidence of acute kidney injury (AKI) (32.3% vs. 50.6%) is consistent with shorter exposure to nephrotoxic insults and improved hemodynamic stability following timely source control. These findings suggest that the benefits of early surgery extend beyond mortality reduction to encompass meaningful improvements in organ function preservation and functional outcomes.

It is noteworthy that the delayed surgery group had higher rates of preoperative septic shock, diffuse peritonitis, and open procedures than the early surgery group. This baseline difference suggests that surgical timing in clinical practice may be influenced by disease severity: critically ill patients may experience delays due to preoperative resuscitation, multidisciplinary evaluation, or comorbidity management, and such patients inherently have a poorer prognosis [13]. The differences in surgical timing between the two groups likely reflect a complex clinical decision-making process influenced by disease severity. In the delayed surgery group, a higher proportion of patients presented with preoperative septic shock and diffuse peritonitis, which often necessitate initial resuscitation, hemodynamic optimization, and multidisciplinary consultation prior to surgical operation. While this approach may be appropriate in selected cases, our findings suggest that when feasible, earlier surgical intervention may confer additional benefits even in critically ill patients. It is important to acknowledge the potential presence of indication bias in this study. The higher prevalence of preoperative septic shock and diffuse peritonitis in the delayed surgery group may reflect a clinical scenario in which patients with more severe illness required preoperative stabilization before surgical intervention. This could have contributed to the observed differences in outcomes between groups. To address this concern, we performed propensity score matching to balance baseline characteristics, and the results remained consistent with the primary analysis. Nevertheless, residual confounding from unmeasured factors cannot be completely excluded.

The substantial difference in 28-day mortality between the early and delayed surgery groups (6.2% vs. 25.3%) warrants careful interpretation. While early surgery was associated with significantly lower mortality, it is important to note that the delayed surgery group had a higher baseline prevalence of preoperative septic shock (66.7% vs. 33.8%), a well-established predictor of poor outcomes. To address this imbalance, we included preoperative septic shock in the multivariate logistic regression model, and early surgery remained an independent protective factor after adjustment. Additionally, propensity score matching yielded consistent results, further supporting the robustness of this finding. However, the possibility of residual confounding from unmeasured factors cannot be entirely ruled out.

Nonetheless, after adjusting for preoperative septic shock in multivariate logistic regression analysis, early surgery still demonstrated an independent protective effect, indicating that timely source control can confer substantial benefit even in critically ill patients, rather than being merely a result of selection bias. The higher proportion of open procedures in the delayed surgery group may also reflect more extensive infection and adhesions, which potentially increase the risks of surgical trauma and postoperative complications, thereby further worsening outcomes [14].

Previous studies on surgical timing for sepsis-associated intra-abdominal infection have yielded inconsistent results. Some studies on complicated appendicitis or perforated diverticulitis support early surgery for reduced mortality, while others suggest that "delayed" surgery after adequate preoperative resuscitation may be equally safe [15,16]. This controversy may be attributed to population heterogeneity and ambiguity in defining the "early" concept. Regarding population heterogeneity, previous studies often included non-ICU or less severely ill patients, whereas our study focuses strictly on ICU patients with poor organ reserve, for whom timely source control is of greater importance. The dichotomy in pertinent research findings can also stem from the ambiguity in defining the "early" concept. In contrast to the prior thresholds that range from 6 to 24 hours—or sometimes measured from admission rather than confirmed diagnosis and surgical decision [17]—our study explicitly defines D-to-K time as the interval from "confirmed diagnosis and surgical decision" to "skin incision" and uses the guideline-recommended 12-hour cutoff, aiming to more accurately reflect the clinical decision-to-action timeframe and enhance comparability and guidance [18].

In univariate analysis, only surgical timing and preoperative shock were significantly associated with 28-day mortality, whereas traditional prognostic factors such as age, CCI, and SOFA score were not. This finding suggests that, in the ICU population studied, modifiable clinical factors, specifically timely surgical intervention, may have a greater influence on short-term survival than some non-modifiable baseline characteristics [19]. However, this result may also be influenced by sample size and warrants validation in larger cohorts.

The absence of a significant difference in SOFA scores between survivors and non-survivors may be attributed to the limited number of deaths (n = 26), which reduced statistical power, as well as the use of a single time-point measurement (within 24 hours of ICU admission). In contrast, dynamic changes in SOFA scores over time may provide a more accurate prediction of outcomes.

Clinical Implications and Practical Considerations

Our findings have clear clinical implications. For ICU patients with sepsis-associated intra-abdominal infection, once surgical contraindications are excluded, a prompt multidisciplinary approach should be implemented to facilitate timely diagnosis, optimize preoperative preparation, and achieve definitive source control surgery within 12 hours of diagnosis. This strategy aligns with both our study results and the pathophysiological rationale of intervening early in the course of infection progression.

The study also underscores the importance of appropriate preoperative antibiotics and adequate resuscitation as the foundation for surgical safety. Although the proportions of patients receiving appropriate preoperative antibiotic therapy were not significantly different between groups, the high treatment rate in the early surgery group (80.0%) likely contributed to surgical success and improved outcomes, highlighting that optimizing surgical timing must be accompanied by robust infection control and supportive care. While our findings support the principle of early intervention, the definition of “early” should be applied judiciously with clinical judgement. In particular, “early” should not be interpreted as rigidly adhering to a fixed time window. For patients with extreme hemodynamic instability (e.g., requiring high-dose vasoactive agents) or severe coagulopathy, it is clinically more appropriate to carry out “damage control surgery” [20]. This involves performing a brief life-saving procedure (e.g., hemorrhage control, source isolation), followed by targeted resuscitation in the ICU, with definitive debridement planned once physiological status stabilizes (usually within 24–48 hours). Optimal clinical decision-making requires balancing the urgency of source control with the patient’s physiological tolerance, thereby avoiding overly expedited or incomplete interventions in physiologically unstable patients.

In addition, the modality and quality of intervention are critical. Percutaneous drainage may be adequate for localized abscesses, whereas open surgery remains standard for diffuse peritonitis or confirmed visceral perforation. Effective source control requires accomplishing the triad of drainage, debridement, and cessation of ongoing contamination. In the present study, the delayed surgery group showed a higher trend toward reoperation, suggesting that incomplete initial debridement may represent another adverse consequence of delayed intervention.

Limitations and Future Directions

As a single-center retrospective observational study, this work has several inherent limitations. First, although multivariate analysis and propensity score matching were performed to address baseline imbalances, residual confounding from unmeasured factors (e.g., surgeon experience, specific resuscitation details, family decision-making time) cannot be completely excluded. Second, while D-to-K time was clearly defined, retrospective documentation may still be subject to recording inaccuracies. Third, the single-center design limits the generalizability of the findings, as institutional differences in workflows and resource availability may influence both surgical timing and outcomes. Fourth, due to the retrospective nature of this study, data on certain potentially important confounders, such as preoperative fluid resuscitation volume, vasopressor dosage, and the exact timing and selection of antibiotic therapy, were not consistently available for all patients. Fifth, the limited number of outcome events (26 deaths) restricted the number of covariates that could be included in the multivariate model and may have contributed to the lack of statistical significance for some traditional prognostic factors (e.g., SOFA score, lactate level) in the univariate analysis. Sixth, due to the limited sample size, we were unable to perform further stratified analyses based on key variables such as surgical approach or infection source. We also acknowledge that this study does not provide novel mechanistic insights or a refined risk stratification tool, because our primary aim was to evaluate the association between surgical timing and clinical outcomes in a well-defined cohort of ICU patients with sepsis-associated intra-abdominal infection.

Future research should be conducted at multiple levels and in an interdisciplinary manner: (1) validation and generalization of these findings through prospective multicenter studies; (2) development of individualized risk stratification tools integrating real-time physiological parameters, imaging features, and biomarkers; and (3) elucidation of molecular mechanisms underlying the improved clinical outcomes in patients receiving early surgery, alongside the development of technical innovations aimed at improving debridement efficacy while minimizing surgical trauma.

Conclusions

For ICU patients with sepsis-associated intra-abdominal infection, early surgery (D-to-K time ≤12 hours) is associated with significantly improved clinical outcomes, including shorter ICU length of stay, reduced duration of organ support, lower complication rates, and reduced 28-day mortality rate. Clinical practice should prioritize timely surgical debridement, alongside coordinated preoperative resuscitation and administration of appropriate antimicrobial therapy. Prospective multicenter studies are warranted to validate these findings and to explore individualized strategies for optimizing surgical timing based on patient characteristics. In addition, dynamic biomarker monitoring may further refine the assessment of treatment efficacy and guide clinical decision-making.

Availability of Data and Materials

The data used and analyzed during the current study are available from the corresponding author.

Author Contributions

JLH: Conceptualization, Methodology, Formal analysis, Project administration, Supervision, Writing–original draft. WJL: Conceptualization, Data curation, Investigation, Validation, Visualization, Writing–original draft. HDW: Investigation, Data curation, Validation, Visualization. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Ethics Committee of First Affiliated Hospital of Jishou University (Approval No. EC-LCKY2026009). Given the retrospective nature of the study and the use of anonymized patient data, the requirement for individual informed consent was waived by the ethics committee. All patient data were handled confidentially and used solely for research purposes.

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Conflict of Interest

The authors declare no conflict of interest.

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