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Original Article

Minimally invasive step-up surgery demonstrates superior suitability over open surgery in severe acute pancreatitis

Qinliang Mo[1], Weilan Liu[2]

[1]Department of General Surgery, First Affiliated Hospital of Huzhou University, Huzhou 313000, Zhejiang, China;
[2]Department of Operation Room, First Affiliated Hospital of Huzhou University, Huzhou 313000, Zhejiang, China

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Abstract: Objective: To evaluate the clinical outcomes of minimally invasive step-up surgery in patients with severe acute pancreatitis (SAP). Methods: A retrospective cohort analysis was conducted, involving 96 consecutive SAP cases. The control group (n=46) underwent conventional open surgery, while the research group (n=50) received minimally invasive step-up procedures. Comparative assessments included operative parameters, recovery of intestinal function, nutritional markers, disease severity, immune function, serum inflammatory biomarkers, clinical safety, and prognostic outcomes. Results: Despite a markedly higher frequency of surgical interventions, the research group showed significantly reduced operative duration, shorter postoperative recovery time for intestinal function, and shorter hospitalization duration compared to the control group. Postoperatively, patients in the research group exhibited superior nutritional markers, enhanced immunological function, and notable alleviation of disease severity. Systemic infections were less frequent in the research group, with an obviously reduced fatality rate. Other complications and the total complication rate did not differ significantly between groups. Conclusion: Despite necessitating additional surgical interventions, the minimally invasive step-up approach for SAP features shorter surgical times, faster recovery of intestinal function, and a lower mortality rate.

Keywords: Severe acute pancreatitis, minimally invasive step-up procedures, operative parameters, intestinal function recovery, prognostic outcomes

Introduction

As a critical inflammatory condition affecting the exocrine pancreas, severe acute pancreatitis (SAP) is associated with high morbidity and mortality rates. Various predisposing factors, such as cigarette smoking, heavy alcohol consumption, obesity, diabetes mellitus, cholelithiasis, and dyslipidemia, contribute to the development of SAP [1, 2]. SAP often leads to serious adverse events, including endotoxemia, systemic inflammatory response syndrome (SIRS), and multiorgan dysfunction (MOD), with reported mortality approaching 40% [3]. Furthermore, SAP exhibits higher rates of adverse events and death compared to moderate acute pancreatitis [4, 5]. Research suggests that SAP triggers a cascade of pathophysiological mechanisms, including pancreatic necrosis, immune dysfunction, compromised intestinal barrier integrity, and sepsis, potentially leading to acute lung injury, which increases the mortality risk to 60% [6]. Therefore, optimizing therapeutic interventions to halt disease progression and improve survival is crucial.

Open surgical intervention has long been used in SAP management, directly addressing therapeutic objectives by excising necrotic tissues, relieving intra-abdominal pressure, and handling associated complications like biliary obstruction and digestive tract fistulas [7]. While this well-established technique enables operation under direct visualization and treatment in a single procedure, it is associated with considerable tissue damage, extended recovery, and higher complication rates [8]. In contrast, the minimally invasive step-up strategy employs a staged treatment protocol, involving initial laparoscopic irrigation to remove inflammatory mediators, followed by percutaneous catheter drainage for localized infection control, and concluding with targeted necrosectomy to address remaining pathological tissues [9]. This

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phased approach minimizes early surgical trauma through damage control, reduces physiological disturbances, maintains anatomical integrity, and accelerates rehabilitation with shorter hospital stays [10, 11]. Nevertheless, this technique requires advanced procedural skills, may involve repeated interventions, and relies on specialized tools such as computed tomography (CT) and laparoscopic instruments [12].

This study aims to compare the efficacy of these two surgical approaches in SAP patients, focusing on operative parameters, intestinal function recovery, and prognostic outcomes. The goal is to clarify the clinical benefits of the minimally invasive step-up technique and provide evidence-based benchmarks for therapeutic decision-making and the promotion of effective treatment approaches.

Clinical data

Study population

Clinical records of 96 SAP patients hospitalized at First Affiliated Hospital of Huzhou University (05/2012-01/2025) were retrospectively reviewed. Of these participants, 46 cases underwent conventional open surgery (control group), whereas 50 cases were managed with a minimally invasive step-up approach (research group). The study protocol was approved by the First Affiliated Hospital of Huzhou University Review Board.

Patient selection criteria

Inclusion criteria: (1) Diagnosis of SAP based on established criteria [13]; (2) Symptom onset within ≤ 48 hours prior to enrollment; (3) Clinically significant manifestations, including abdominal pain, distension, nausea/vomiting, peritoneal irritation, and diminished or absent bowel sounds; (4) Acute Physiology and Chronic Health Evaluation II (APACHE-II) score > 8 and CT severity grade ≥ II [14]; (5) First-time treatment for SAP; (6) No contraindications to the proposed therapy; (7) Availability of complete clinical records.

Exclusion criteria: (1) Pregnancy or lactation; (2) Concurrent hyperthyroidism; (3) Severe dysfunction of major organs (cardiac, hepatic, pulmonary, or renal); (4) Concurrent conditions, including active infections, trauma, or gastrointestinal hemorrhage; (5) Hematologic disorders; (6) Psychiatric illness or cognitive impairment; (7) Active malignancy; (8) Recent abdominal surgery unrelated to SAP; (9) Use of medications that may interfere with study outcomes within the preceding six months.

Treatment methods

The control group underwent open surgical intervention. Indications for surgery included: (1) failure of conservative treatment with persistent clinical deterioration; (2) biliary pancreatitis refractory to non-surgical management, accompanied by multiorgan dysfunction (MOD); (3) signs of severe systemic infection (persistent high-grade fever or sepsis); or (4) local pancreatic complications (infected necrosis or abscess formation). For biliary pancreatitis, surgical intervention was performed via laparotomy, which simultaneously addressed biliary obstruction through procedures such as common bile duct exploration with T-tube drainage. Other cases underwent comprehensive surgical management, including pancreatic tissue incision with necrosectomy for pancreatic necrosis, triple diversion procedures (gastrostomy, jejunostomy, and biliary drainage), and extensive multi-locational drainage of the abdominal cavity and peripancreatic spaces. Except for early fulminant pancreatitis (requiring surgical intervention within 72 hours of symptom onset), all procedures were performed following a delayed approach, typically 2-4 weeks after disease onset.

The research group was treated with a minimally invasive step-up approach. First Stage (Acute Response Phase: Within 1 Week of Onset): Indications: Early presentation of SIRS or multiple organ dysfunction syndrome (MODS), with abdominal CT or diagnostic puncture confirming peritoneal effusion but no evidence of peripancreatic fluid collection or necrotic tissue accumulation. Intervention: Diagnostic laparoscopic exploration with extensive peritoneal lavage, followed by placement of drainage tubes in the lesser omental sac and abdominal cavity (without peripancreatic incision or debridement). Drainage tubes were maintained until resolution of peritoneal effusion (typically removed after approximately 1 week).

Second Stage (Necrotic Accumulation Phase: 3-4 Weeks Post-Onset): Indications: Presence of acute necrotic collection or walled-off necrosis, accompanied by clinical signs such as fever, abdominal pain, elevated infection markers, or gastrointestinal obstruction. Intervention: CT-guided percutaneous catheter drainage, with subsequent adjustment of antibiotic therapy and supportive care based on drainage fluid analysis (including bacterial culture and amylase levels).

Third Stage (Infection Spread Phase: Late-Stage Disease): Indications: Persistent or spreading infection following the second stage, inadequate drainage, or abscess formation. Intervention: Laparoscopic or intraoperative ultrasound-guided abscess/cyst incision and drainage, with drain placement in the most dependent position. Additional percutaneous drainage or re-exploration was performed if clinically indicated.

Outcome measures

(1) Operative parameters: The number of surgeries and operative durations were recorded.

(2) Intestinal function recovery: Intestinal function recovery time and lengths of hospital stay were documented.

(3) Disease severity: Disease severity was assessed using the APACHE-II score (range: 0-71), where higher scores correlated with worsening conditions. Organ dysfunction was measured using the Sequential Organ Failure Assessment (SOFA) scale [15], which evaluates six vital organ systems. Each component is graded from 0 to 4, yielding a cumulative score of 0-24, with higher scores indicating more severe organ failure.

(4) Nutritional markers: Pre- and post-operative levels of prealbumin (PA), albumin (Alb), and transferrin (TRF) in serum samples were determined using immunoturbidimetric assays, following the manufacturer's instructions (Shanghai Yuduo Biotechnology, 4471; HePeng (Shanghai) Biotech, HPBIO-JM4329, HPBIO-JM4327).

(5) Immunological function: Pre- and postoperative fasting venous blood samples (3 mL) were collected for immunonephelometric quantification of serum immunoglobulin (IgG/A/M) levels. Assays were performed according to the kit instructions (Shanghai XuanYa Biological Technology, XY1152A, XY0210A, XY-SJH-1140).

(6) Inflammatory biomarkers: Serum concentrations of high-sensitivity C-reactive protein (hs-CRP), tumor necrosis factor-alpha (TNF-α), and interleukin-6 (IL-6) were measured using Enzyme-linked immunosorbent assays (ELISAs).

(7) Safety profile: Post-treatment adverse events, including pancreatic pseudocysts, peripancreatic cysts, hemorrhage, intestinal fistula, MOD, and systemic infections, were recorded. The overall incidence of adverse events was computed.

(8) Prognostic outcomes: Mortality following surgery was recorded to determine the fatality rate.

Primary endpoints included operative parameters, intestinal function recovery, disease severity, safety, and prognostic outcomes, whereas secondary measures involve nutritional markers, immunological function, and inflammatory biomarkers.

Statistical analysis

Data analysis was conducted using SPSS 20.0. Continuous variables were summarized as mean ± standard error of the mean (SEM), and inter-group differences were assessed using independent t-tests, while pre- and post-operative comparisons were analyzed using paired t-tests. Categorical data were reported as frequencies and percentages (n/%), and inter-group comparisons were made utilizing χ^2 tests. Statistical significance was defined as a p-value of < 0.05.

Results

Comparison of baseline characteristics between the two groups

Both cohorts exhibited similar baseline parameters, with no statistically significant differences in age, gender distribution, body mass index (BMI), disease duration, smoking status, alcohol consumption, or hyperlipidemia incidence ($P > 0.05$, **Table 1**).

Comparison of operative parameters between the two groups

The operative parameters, including the number of surgeries and operative duration, were compared between the two cohorts. The research group underwent significantly more surgeries and had notably shorter procedure

Table 1. Comparison of demographic and clinical characteristics between the two groups

Indicator	Control group (n=46)	Research group (n=50)	t/χ^2	P
Age (years)	45.74±8.91	47.64±6.61	1.193	0.236
Gender			0.560	0.454
Male	26 (56.52)	32 (64.00)		
Female	20 (43.48)	18 (36.00)		
Body mass index (kg/m^2)	24.59±3.43	23.72±3.31	1.264	0.209
Disease duration (d)	20.67±1.90	20.78±2.78	0.224	0.823
Smoking history			0.405	0.524
No	34 (73.91)	34 (68.00)		
Yes	12 (26.09)	16 (32.00)		
Alcohol use history			0.251	0.617
No	30 (65.22)	35 (70.00)		
Yes	16 (34.78)	15 (30.00)		
Hyperlipidaemia			0.596	0.440
No	24 (52.17)	30 (60.00)		
Yes	22 (47.83)	20 (40.00)		

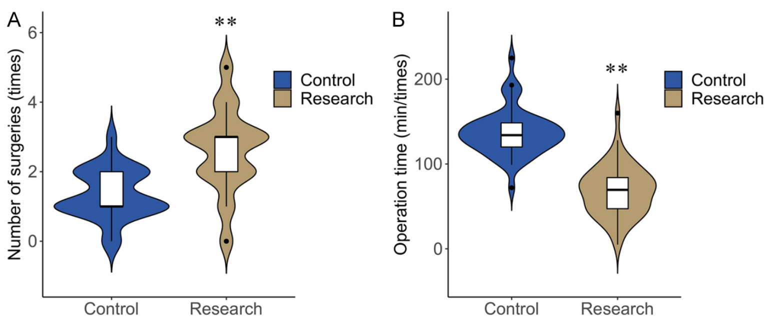

Figure 1. Comparison of operative parameters between the two groups. A. Number of surgeries. B. Operative duration. Note: **P < 0.01 versus control group.

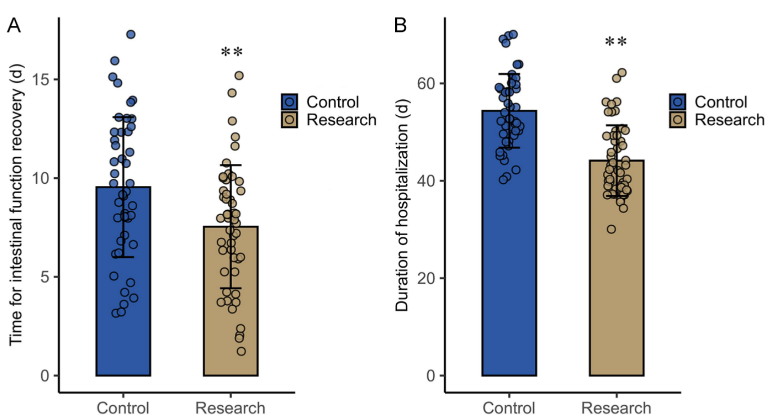

Figure 2. Comparison of intestinal function recovery metrics between the two groups. A. Time to intestinal function recovery. B. Duration of hospitalization. Note: **P < 0.01 versus control group.

durations compared to the control group (P < 0.05, **Figure 1**).

Comparison of intestinal function recovery between the two groups

The research group showed significantly accelerated intestinal function recovery and shorter hospitalization time than the control group (P < 0.01, **Figure 2**).

Comparison of nutritional markers between the two groups

Pre-operative evaluation of nutritional markers (PA, Alb, TRF) revealed no intergroup differences (P > 0.05). Post-intervention measurements demonstrated significant elevation in all markers, with the research group achieving superior improvements compared to the control group (P < 0.05, **Figure 3**).

Comparison of disease severity between the two groups

Disease severity was evaluated using the APACHE-II and SOFA scoring systems. Both groups had similar baseline scores (P > 0.05). Following treatment, significant decreases in APACHE-II and SOFA scores

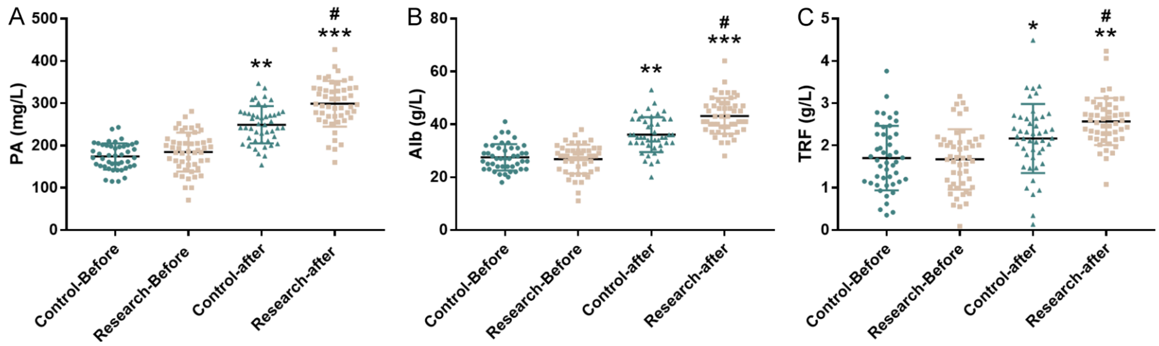

Figure 3. Comparison of nutritional markers between the two groups. A. Pre-post intervention PA levels. B. Pre-post intervention Alb levels. C. Pre-post intervention TRF levels. Note: PA, prealbumin; Alb, albumin; TRF, transferrin. **P < 0.01, ***P < 0.001 versus baseline; #P < 0.05 between groups.

Table 2. Comparison of disease severity between the two groups before and after surgery

Indicator	Control group (n=46)	Research group (n=50)	t	P
APACHE-II				
Preoperative	18.35±5.00	19.56±5.04	1.180	0.241
Postoperative	14.09±3.84**	9.78±3.10***	6.073	< 0.001
SOFA				
Preoperative	8.37±2.18	7.92±2.12	1.025	0.308
Postoperative	5.39±1.96*	3.44±1.40**	5.643	< 0.001

Note: *P < 0.05, **P < 0.01, ***P < 0.001 versus preoperative values.

Table 3. Comparison of immunological parameters between the two groups before and after surgery

Indicator	Control group (n=46)	Research group (n=50)	t	P
IgG (g/L)				
Preoperative	8.65±2.66	9.18±1.95	1.120	0.266
Postoperative	11.00±2.85**	13.16±3.87**	3.092	0.003
IgA (g/L)				
Preoperative	2.09±0.96	2.14±0.78	0.281	0.779
Postoperative	3.78±1.88**	7.00±3.02***	6.208	< 0.001
IgM (g/L)				
Preoperative	0.90±0.20	0.86±0.27	0.819	0.415
Postoperative	1.49±0.42*	2.02±0.79**	4.053	< 0.001

Note: *P < 0.05, **P < 0.01, ***P < 0.001 versus preoperative values.

were observed in both groups (P < 0.05). However, the research group achieved notably lower scores in both assessments compared to the control group (P < 0.05, **Table 2**).

Comparison of immunological function between the two groups

Immune status was assessed by measuring serum IgG, IgA, and IgM levels. Initial measurements showed no significant inter-group differences (P > 0.05). Postoperatively, both groups exhibited marked increases in all Ig levels (P < 0.05). Notably, the research group demonstrated superior improvements in IgG, IgA, and IgM compared to the control group (P < 0.05, **Table 3**).

Comparison of serum inflammatory biomarkers between the two groups

Serum levels of inflammatory biomarkers, including hs-CRP, TNF-α, and IL-6, were analyzed in both cohorts. Initial measurements demonstrated no significant intergroup differences at baseline (P > 0.05). Following intervention, both groups exhibited marked reductions in all measured inflammatory markers (P < 0.05). Notably, the research group achieved significantly greater reductions in these biomarkers compared to the control group (P < 0.05, **Table 4**).

Comparison of safety profile between the two groups

The incidence of pancreatic pseudocysts, peripancreatic cysts, hemorrhage, intestinal fistula, and MOD showed no significant variation between groups (P > 0.05). However, the res-

Table 4. Comparison of serum inflammatory biomarkers between the two groups before and after surgery

Indicator	Control group (n=46)	Research group (n=50)	t	P
hs-CRP (mg/L)				
Preoperative	80.89±9.79	80.16±12.41	0.318	0.751
Postoperative	59.57±6.50**	40.64±5.65***	15.260	< 0.001
TNF-α (μg/L)				
Preoperative	100.70±13.28	101.22±18.05	0.160	0.874
Postoperative	81.30±9.54**	65.22±5.88***	10.029	< 0.001
IL6 (μg/L)				
Preoperative	71.15±7.49	72.76±9.03	0.946	0.347
Postoperative	49.20±8.14**	38.74±7.09***	6.727	< 0.001

Note: hs-CRP, high-sensitivity C-reactive protein; TNF-α, tumor necrosis factor-alpha; IL-6, interleukin-6. **P < 0.01, ***P < 0.001 versus preoperative values.

Table 5. Comparison of safety profile between the two groups

Indicator	Control group (n=46)	Research group (n=50)	χ^2	P
Pancreatic pseudocysts	7 (15.22)	5 (10.00)	0.596	0.440
Peripancreatic cysts	6 (13.04)	4 (8.00)	0.653	0.419
Hemorrhage	5 (10.87)	3 (6.00)	0.744	0.389
Intestinal fistula	5 (10.87)	3 (6.00)	0.744	0.389
Multiorgan dysfunction	9 (19.57)	4 (8.00)	2.737	0.098
Systemic infections	14 (30.43)	5 (10.00)	6.302	0.012
Total	23 (50.00)	17 (34.00)	2.523	0.112

earch group demonstrated a significant reduction in the incidence of systemic infection compared to the control group (P < 0.05). The overall complication rate did not differ significantly between groups (P > 0.05) (**Table 5**).

Comparison of prognostic outcomes between the two groups

Mortality analysis revealed 7 fatalities (15.22%) in the control group, while no deaths occurred in the research group. This reduced mortality rate represented a statistically significant improvement in survival for the research group (P < 0.01).

Discussion

The minimally invasive step-up approach for SAP patients involves multiple procedures, yet each operation is significantly shorter in duration. This reflects the phased nature of the intervention and the inherent advantages of minimally invasive techniques. In contrast, open surgery for SAP patients typically requires fewer total interventions, but each procedure is more time-consuming, highlighting the ability of conventional open surgery to achieve definitive resolution in a single operation. Furthermore, the minimally invasive step-up strategy demonstrates clear superiority over open surgery in key recovery metrics, including intestinal function recovery, duration of hospitalization, and nutritional markers (PA, Alb, and TRF), suggesting that minimally invasive techniques cause less physiological trauma and more effectively ameliorate metabolic disturbances. As reported in the literature, this approach better preserves intestinal integrity and facilitates earlier initiation of enteral nutrition, thereby improving nutritional markers and accelerating overall patient recovery [16, 17].

In addition, both approaches were approved to effectively reduce APACHE-II and SOFA scores; however, the minimally invasive step-up approach demonstrated superior clinical improvements. By implementing targeted surgical interventions in the first and second stages, this approach effectively interrupts the cascade of pro-inflammatory factors while mitigating secondary inflammatory responses. Moreover, its phased treatment strategy provides comprehensive organ protection, collectively contributing to more effective disease progression control [18, 19]. Notably, SAP patients undergoing minimally invasive step-up procedures exhibited more substantial increases in immunoglobulins (IgG, IgA, IgM) and more marked reductions in inflammatory biomarkers (hs-CRP, TNF-α, IL-6), highlighting enhanced efficacy in both immunological function enhancement and systemic inflammation control. This clinical advantage likely stems from the approach's immunomodulatory properties, as it minimizes extensive tissue trauma compared to conventional open surgery. By reducing immune cell depletion and preserving Ig production capacity, this technique consequently strengthens anti-infection defenses in SAP patients [20].

Regarding local complications, there were no significant differences between the treatment groups in the incidence of pancreatic pseudocysts, peripancreatic cysts, hemorrhage, intestinal fistula, and MOD, or the total complication rate. However, SAP patients who underwent minimally invasive step-up procedures demonstrated significantly lower rates of systemic infection and mortality, highlighting its systemic advantages. The stepwise drainage approach in minimally invasive step-up surgery effectively modulates the inflammatory microenvironment in SAP patients. Additionally, percutaneous drainage minimizes bacterial translocation, which is more common in open abdominal procedures, thus actively regulating inflammation and substantially lowering systemic infection risk [21]. The absence of mortality in the research group may result from early intervention, which halted SIRS-to-sepsis progression, accurate debridement that minimized reinfections, and preservation of organ function reserves [22, 23]. Morató O et al. [24] demonstrated that SAP patients treated with a minimally invasive step-up surgery had statistically lower specific and overall mortality rates than those undergoing open surgery, which corroborates our results. Supporting our conclusions, Szeliga J et al. [25] reported superior clinical outcomes and improved patient safety with this technique compared to open surgery.

Several limitations should be noted: (1) The lack of in-depth analysis regarding prognostic determinants necessitates follow-up studies to develop more targeted clinical improvement strategies. (2) The absence of biomarkers, for stress and oxidative stress parameters, limits our ability to further elucidate the comparative therapeutic benefits. (3) The relative advantages of minimally invasive step-up approach surgery cannot be fully assessed without comparative studies against other minimally invasive techniques.

In summary, the minimally invasive step-up approach offers distinct advantages over conventional open surgery in SAP treatment. This strategy shows significant benefits in accelerating intestinal function recovery, ameliorating nutritional markers, alleviating disease severity, and enhancing immunity. Furthermore, it effectively reduces systemic infection and mortality risks. These findings not only offer SAP patients a safer and more effective therapeutic alternative but also provide a reliable reference and new insights for formulating individualized treatment plans in clinical practice.

Disclosure of conflict of interest

None.

Address correspondence to: Weilan Liu, Department of Operation Room, First Affiliated Hospital of Huzhou University, No. 158, Guangchang Hou Road, Huzhou 313000, Zhejiang, China. Tel: +86-0572-2051000; E-mail: lwllwl0000@163.com

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