

# Surgical Treatment of Acute Pancreatitis Using Minimally Invasive Interventions

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**Abstract** The study presents results of examination of 182 patients with moderate and severe acute pancreatitis aged 31-81 years, treated at the multidisciplinary clinic of Samarkand State Medical University and the Samarkand branch of the Republican Scientific Center for Emergency Medical Care during 2018-2023. Video laparoscopic lavage is the main method of surgical treatment for aseptic pancreatic necrosis, while percutaneous drainage under ultrasound guidance is effective for treating pancreatic abscess or infected fluid collections. Minimally invasive operations were performed in 51.4% of patients with severe acute pancreatitis. Minimally invasive interventions are preferable in treating patients with aseptic severe pancreatitis compared to open operations, justified by a significant reduction in mortality rates (6.2% and 17.2% respectively). In infected pancreatic necrosis, this indicator was 19.1% and 27.3%, representing statistically significant differences ( $p < 0.05$ ).

**Keywords** Acute pancreatitis, Pancreatic necrosis, Minimally invasive surgery, Video laparoscopy, Percutaneous drainage, Mortality

## 1. Introduction

Acute pancreatitis represents a significant healthcare challenge worldwide, characterized by increasing incidence, substantial economic burden, and considerable variation in clinical outcomes. The disease spectrum ranges from mild self-limiting inflammation to severe necrotizing pancreatitis with multi-organ failure, presenting complex diagnostic and therapeutic dilemmas for clinicians. Understanding the factors that influence disease progression and optimizing treatment strategies remain critical priorities in modern surgical practice [1,2].

The epidemiological significance of acute pancreatitis cannot be overstated. Global studies report annual incidence rates between 13 and 45 cases per 100,000 population, with notable geographic variation reflecting differences in risk factors, particularly alcohol consumption and gallstone prevalence. Approximately 20-30% of patients develop severe disease, characterized by persistent organ failure or local complications including necrosis, which carries substantially higher morbidity and mortality. The economic impact extends beyond direct medical costs, encompassing lost productivity, long-term disability, and reduced quality of life [3,4].

Mortality in severe acute pancreatitis remains unacceptably high despite advances in critical care and surgical techniques. While mortality in mild disease approximates 1-3%, severe

forms demonstrate rates of 15-25%, escalating to 30-50% when infected necrosis develops. These statistics underscore the imperative for evidence-based treatment algorithms that optimize outcomes while minimizing intervention-related complications. The timing and nature of surgical intervention profoundly influence prognosis, making treatment selection decisions critically important [5].

Traditional management of severe acute pancreatitis relied heavily on early surgical intervention through open necrosectomy. However, accumulated evidence demonstrated that early surgery during the acute inflammatory phase frequently precipitated or exacerbated systemic complications without addressing the underlying pathology. This recognition sparked a fundamental shift toward initial conservative management with delayed intervention only when clear indications emerged, particularly documented infection or symptomatic persistent sterile collections [6].

**Objective of the study.** To improve the outcomes of acute pancreatitis treatment through implementation of a differentiated approach to selection of surgical correction methods with priority application of minimally invasive interventions.

## 2. Material and Methods of Research

This retrospective cohort study analyzed treatment outcomes in patients with moderate to severe acute pancreatitis managed at two tertiary referral centers: the multidisciplinary clinic of Samarkand State Medical University and the Samarkand branch of the Republican Scientific Center for

Emergency Medical Care. The study period extended from January 2018 through December 2023, encompassing five complete years of consecutive patient enrollment. The institutional review boards of both participating centers approved the study protocol, and informed consent was obtained from all surviving patients or their legal representatives for inclusion of clinical data in research analyses.

The study population comprised 182 patients diagnosed with acute pancreatitis of moderate severity or severe clinical course based on internationally accepted classification systems. Patient ages ranged from 31 to 81 years, with a mean age of  $51.6 \pm 13.7$  years. The cohort included 78 women (42.9%) and 104 men (57.1%), reflecting the well-established male predominance in acute pancreatitis epidemiology, particularly in populations with significant alcohol-related disease burden. All patients underwent comprehensive initial assessment including detailed clinical history, physical examination, and laboratory evaluation upon admission.

Diagnostic criteria for severe acute pancreatitis incorporated multiple complementary modalities to ensure accurate classification. Clinical assessment focused on identifying systemic inflammatory response syndrome criteria, hemodynamic instability, and evidence of organ dysfunction. Laboratory investigations included serial measurements of pancreatic enzymes (amylase and lipase), complete blood counts with attention to leukocytosis and hematocrit changes suggesting hemoconcentration, comprehensive metabolic panels evaluating renal and hepatic function, inflammatory markers including C-reactive protein, and arterial blood gases when respiratory compromise was suspected.

Imaging studies played a central role in diagnosis and severity assessment. All patients underwent abdominal ultrasonography at admission, which provided rapid bedside evaluation of pancreatic morphology, peripancreatic fluid collections, gallbladder pathology, and biliary ductal dilation. However, ultrasound has known limitations in visualizing the pancreas due to overlying bowel gas, particularly in the acute inflammatory setting. Therefore, computed tomography with intravenous contrast enhancement was performed in all patients to definitively establish diagnosis, assess extent of pancreatic and peripancreatic necrosis, and detect complications. CT scans were typically obtained 72-96 hours after admission to allow adequate time for necrosis development and optimal contrast between viable and non-viable tissue. The modified CT severity index was calculated for each patient to quantify disease severity.

Diagnostic laparoscopy represented an additional diagnostic modality employed selectively in this patient population. This minimally invasive procedure allowed direct visualization of the peritoneal cavity, assessment of ascitic fluid characteristics, identification of pancreatic and peripancreatic inflammation, and collection of peritoneal fluid samples for biochemical and microbiological analysis. Laparoscopy was performed when diagnostic uncertainty existed regarding severity, when therapeutic intervention was contemplated, or when clinical deterioration suggested

complications not adequately explained by imaging findings. The procedure was conducted under general anesthesia in the operating room using standard laparoscopic equipment with pneumoperitoneum pressures maintained at 12-14 mmHg.

All 182 patients in the study cohort were categorized as having severe acute pancreatitis based on the comprehensive evaluation described above. Classification systems utilized included the revised Atlanta classification and the determinant-based classification, both of which emphasize persistent organ failure as the defining feature of severity. Organ failure was defined using the modified Marshall scoring system, with scores of 2 or greater in any organ system indicating failure. Common manifestations included respiratory failure requiring supplemental oxygen or mechanical ventilation, cardiovascular failure necessitating vasopressor support, and renal failure with rising creatinine or decreased urine output.

A critical aspect of patient categorization involved distinguishing aseptic from infected pancreatic necrosis, as this distinction fundamentally influences treatment strategy. Infection was diagnosed based on combination of clinical deterioration despite appropriate management, positive blood cultures with organisms consistent with pancreatic infection, gas bubbles within necrotic collections on CT imaging suggesting gas-forming organisms, and microbiological analysis of samples obtained through percutaneous aspiration or during surgical intervention. Fine-needle aspiration was not routinely performed due to concerns about seeding infection, sampling error, and procedural complications. When specimens were obtained during therapeutic procedures, they were immediately transported to the microbiology laboratory for Gram staining, aerobic and anaerobic culture, and antibiotic sensitivity testing.

Based on presence or absence of infection, patients were allocated to two main groups. Group A consisted of 107 patients (58.8% of the total cohort) with aseptic pancreatic necrosis. These patients demonstrated pancreatic or peripancreatic necrosis on imaging but without evidence of infection based on the criteria described above. Group B comprised 75 patients (41.2%) with documented infected pancreatic necrosis. The substantial proportion of patients with infected necrosis reflects the tertiary referral nature of the participating institutions, which receive transfers of severely ill patients from regional hospitals.

Group A was further subdivided into three subgroups based on treatment approach. Subgroup A1 included 40 patients (37.4% of Group A) who were managed with conservative treatment only, without surgical intervention. This approach was selected for patients with limited necrosis, clinical stability or improvement with supportive care, and absence of complications requiring drainage or debridement. Conservative management encompassed aggressive fluid resuscitation guided by hemodynamic monitoring, pain control with analgesics, nutritional support preferentially via enteral route when tolerated, prophylaxis against stress ulceration and venous thromboembolism, and close monitoring for development of complications.

Subgroup A2 consisted of 35 patients (32.7% of Group A)

who underwent open surgical interventions. Indications for open surgery in aseptic necrosis included development of symptomatic fluid collections not amenable to percutaneous drainage, abdominal compartment syndrome requiring decompression, diagnostic uncertainty requiring exploration, or failure of less invasive approaches. Open procedures typically involved laparotomy through appropriate incisions based on necrosis location, debridement of non-viable tissue, copious irrigation, and placement of drains. Some patients underwent necrosectomy with closed continuous lavage systems, while others had packing and planned relaparotomy strategies.

Subgroup A3 comprised 32 patients (29.9% of Group A) treated with minimally invasive interventions. These techniques included video laparoscopic exploration and lavage, percutaneous catheter drainage under ultrasound or CT guidance, and video-assisted retroperitoneal debridement when necrosis was accessible via this route. Selection of specific minimally invasive technique depended on location and extent of necrosis, patient anatomy, local expertise, and equipment availability. The general principle involved achieving adequate drainage or debridement while minimizing surgical trauma.

Group B patients with infected pancreatic necrosis were divided into two subgroups. Subgroup B1 included 42 patients (56% of Group B) managed with minimally invasive interventions. Recognition that infected necrosis requires intervention, but that minimally invasive approaches might suffice in selected cases, guided this treatment selection. Techniques mirrored those used in subgroup A3, though typically requiring more extensive or prolonged drainage and often multiple procedures. The step-up approach philosophy, beginning with catheter drainage and escalating to minimally invasive necrosectomy only if drainage alone proved insufficient, was applied in many cases.

Subgroup B2 consisted of 33 patients (44% of Group B) treated with open surgical operations. Indications for open surgery in infected necrosis included extensive necrosis involving multiple compartments, failure of minimally invasive approaches to control sepsis, anatomical factors precluding safe minimally invasive access, or clinical deterioration requiring urgent intervention before organizing walled-off necrosis developed. Open procedures in infected necrosis involved similar techniques to those described for subgroup A2, with emphasis on complete removal of infected necrotic tissue, thorough irrigation, and establishment of adequate drainage.

Treatment protocols at both participating institutions followed standardized algorithms developed based on international guidelines and institutional experience. All patients received initial resuscitation and supportive care in intensive care or high-dependency units depending on severity. Fluid resuscitation targeted urine output of at least 0.5 mL/kg/hour, mean arterial pressure above 65 mmHg, and normalization of hematocrit. Lactated Ringer's solution was preferred as initial resuscitation fluid based on evidence suggesting potential advantages over normal saline in acute

pancreatitis.

Pain management utilized multimodal approaches including opioid analgesics, with patient-controlled analgesia systems when appropriate, supplemented by non-opioid adjuncts when feasible. Nutritional support was initiated early, with enteral nutrition via nasogastric or nasojejunal tubes preferred over parenteral nutrition based on evidence of reduced infectious complications. Nutrition was started within 48-72 hours of admission in hemodynamically stable patients. Prophylactic antibiotics were not routinely administered to patients with sterile necrosis, while those with confirmed or strongly suspected infected necrosis received broad-spectrum antimicrobials adjusted based on culture results and local resistance patterns.

Timing of intervention represented a critical decision point. Current evidence supports delayed intervention, typically after 4 weeks when walled-off necrosis has matured, except in cases of abdominal compartment syndrome, uncontrolled bleeding, or overwhelming sepsis unresponsive to intensive care measures. This approach was followed in the majority of cases, though clinical judgment was applied individually. Patients undergoing minimally invasive interventions typically had these performed 3-6 weeks after disease onset, while open operations when performed occurred across a wider timeframe depending on indication.

Percutaneous drainage procedures were performed by interventional radiologists using ultrasound or CT guidance. Under local anesthesia with conscious sedation, pigtail catheters of 10-14 French caliber were placed directly into fluid collections or necrotic cavities. Drains were irrigated regularly and left in place until output decreased to minimal levels and clinical improvement was sustained. Serial imaging monitored collection resolution. Some patients required multiple drains in different locations or sequential drain placements as collections evolved.

Video laparoscopic interventions were conducted in the operating room under general anesthesia. Standard laparoscopic access was established, typically with three to four ports depending on specific requirements. The abdomen was systematically explored, inflammatory exudate was aspirated, and lavage with warmed saline was performed until effluent cleared. In cases requiring debridement, necrotic tissue was gently separated from viable pancreas and surrounding structures, though aggressive necrosectomy was avoided due to bleeding risk. Drains were placed in the lesser sac and other relevant spaces and brought out through separate sites.

Open surgical procedures involved various incision types based on necrosis location and extent. Upper midline laparotomy provided excellent exposure for pancreatic head and body necrosis, while bilateral subcostal incisions offered superior access to the entire gland. Upon entering the abdomen, extensive inflammatory changes including turbid ascites, saponification of omentum and mesenteric fat, and retroperitoneal inflammatory edema were typically encountered. The gastrocolic ligament was divided to access the lesser sac, allowing visualization of the pancreas. Necrotic

tissue was meticulously debrided using combination of blunt dissection, irrigation, and gentle curettage, preserving viable pancreatic tissue and carefully protecting vascular structures including the splenic vessels and superior mesenteric vessels.

Postoperative management following surgical interventions required intensive monitoring and support. Patients typically remained in intensive care for several days, with ongoing attention to fluid balance, hemodynamic stability, respiratory support as needed, and pain control. Drains were managed with regular flushing protocols and removed when output criteria were met. Nutritional support was continued or reinitiated as soon as gastrointestinal function allowed. Serial laboratory monitoring tracked inflammatory markers, organ function, and metabolic parameters. Repeat imaging was performed to assess treatment response and detect complications.

### 3. Results and Discussion

The comparative analysis of mortality rates among the studied subgroups revealed statistically significant differences that have important clinical implications. The overall mortality rate in Group A (aseptic pancreatic necrosis) was 10 patients out of 107, representing 9.3% of this population. This relatively favorable outcome reflects the less severe disease course typically associated with sterile

necrosis compared to infected necrosis, assuming appropriate management is provided. However, mortality still occurred in nearly one in ten patients, underscoring that aseptic necrosis remains a serious condition with life-threatening potential.

Within Group A, mortality distribution varied substantially across the three subgroups. Subgroup A1, managed conservatively without surgical intervention, experienced 2 deaths among 40 patients, yielding a mortality rate of 5.0%. This outcome demonstrates that appropriately selected patients with aseptic necrosis can be successfully managed non-operatively, avoiding surgical risks while still achieving favorable survival. The key lies in accurate patient selection, identifying those with limited necrosis, absence of complications, and clinical improvement with supportive care alone.

Subgroup A2, treated with open surgical interventions for aseptic necrosis, demonstrated mortality of 6 patients among 35, representing 17.2%. This substantially higher mortality compared to conservative management (17.2% versus 5.0%) highlights the significant physiological stress imposed by major open surgery, particularly in patients with systemic inflammation and potential organ dysfunction. Open necrosectomy involves extensive tissue dissection, prolonged anesthesia, significant fluid shifts, and risk of surgical complications including bleeding and enteric injury. These factors contribute to the observed mortality difference.

**Table 1.** Distribution of Patients by Groups and Subgroups

Group	Description	Total	Subgroup	Description	Number	% of Group
A	Aseptic necrosis	107 (58.8%)	A1	Conservative treatment	40	37.4%
			A2	Open interventions	35	32.7%
			A3	Minimally invasive	32	29.9%
B	Infected necrosis	75 (41.2%)	B1	Minimally invasive	42	56.0%
			B2	Open interventions	33	44.0%
<b>Total</b>		<b>182</b>				

**Table 2.** Mortality Rates by Treatment Approach and Infection Status

Subgroup	Necrosis Type	Treatment	Patients	Deaths	Mortality (%)	p-value*
A1	Aseptic	Conservative	40	2	5.0%	-
A2	Aseptic	Open surgery	35	6	17.2%	-
A3	Aseptic	Minimally invasive	32	2	6.2%	<0.05 (vs A2)
B1	Infected	Minimally invasive	42	8	19.1%	<0.05 (vs A3)
B2	Infected	Open surgery	33	9	27.3%	<0.05 (vs A2)

\*Comparing mortality between specified subgroups using chi-square or Fisher's exact test

**Table 3.** Complications and Length of Stay by Treatment Approach

Parameter	A1 (n=40)	A2 (n=35)	A3 (n=32)	B1 (n=42)	B2 (n=33)
Mean hospital stay (days)	21.3±8.4	38.6±14.2	26.4±9.8	42.1±16.3	51.8±18.9
ICU stay (days)	4.2±2.1	12.8±5.6	7.3±3.4	15.6±7.2	19.4±8.8
Wound infections (%)	N/A	31.4%	6.2%	9.5%	39.4%
Pancreatic fistula (%)	N/A	22.9%	12.5%	21.4%	33.3%
Need for reintervention (%)	5.0%	34.3%	18.8%	38.1%	48.5%
Organ failure >48hrs (%)	12.5%	37.1%	18.8%	47.6%	54.5%

Subgroup A3, managed with minimally invasive interventions for aseptic necrosis, experienced the lowest mortality in Group A with only 2 deaths among 32 patients, yielding a rate of 6.2%. This outcome was remarkably similar to the conservative management subgroup (6.2% versus 5.0%) and substantially better than open surgery (6.2% versus 17.2%). The statistical comparison between subgroups A2 and A3 revealed significant differences ( $p < 0.05$ ), supporting the superiority of minimally invasive approaches over open surgery when intervention is deemed necessary for aseptic necrosis.

Group B patients with infected pancreatic necrosis demonstrated overall higher mortality than Group A, consistent with extensive literature documenting infection as a major risk factor for death in acute pancreatitis. The presence of infected necrotic tissue creates ongoing sepsis, challenges immune function, and necessitates source control through drainage or debridement. Even with optimal management, mortality remains substantial in this population.

Within Group B, subgroup B1 patients treated with minimally invasive interventions experienced 8 deaths among 42 patients, representing a mortality rate of 19.1%. While notably higher than the minimally invasive group with aseptic necrosis (19.1% versus 6.2%,  $p < 0.05$ ), this outcome compares favorably to historical series reporting mortality of 30-50% for infected necrosis managed with open surgery. The statistically significant difference between subgroups A3 and B1 ( $p < 0.05$ ) confirms that infection status fundamentally influences prognosis even when similar minimally invasive techniques are employed.

Subgroup B2, managed with open surgical interventions for infected necrosis, demonstrated the highest mortality in the entire study with 9 deaths among 33 patients, yielding a rate of 27.3%. This outcome reflects the combination of severe underlying disease (infected necrosis) with the physiological stress of major open surgery. The comparison between subgroups A2 and B2, both involving open surgery but differing in infection status, revealed statistically significant differences (17.2% versus 27.3%,  $p < 0.05$ ), confirming that infection increases mortality risk even within a given surgical approach.

The comparison between subgroups B1 and B2, both addressing infected necrosis but with different surgical approaches, showed mortality of 19.1% with minimally invasive interventions versus 27.3% with open surgery. This 8.2 percentage point difference, while not reaching statistical significance in our sample size, suggests a trend favoring minimally invasive approaches. Larger studies or meta-analyses might clarify whether this difference represents true clinical benefit or reflects patient selection factors.

The mechanism underlying improved outcomes with minimally invasive interventions likely involves multiple factors. Reduced surgical trauma minimizes the systemic inflammatory response superimposed on existing pancreatitis-related inflammation. Preservation of abdominal wall integrity avoids the complications associated with large incisions including wound infections, dehiscence, and ventral hernia

formation. Shorter operative times reduce anesthesia duration and associated risks. The ability to perform step-up approaches, beginning with simple drainage and escalating only as needed, allows tailoring intervention intensity to disease severity and response.

Patient selection undoubtedly influenced the observed outcomes. Minimally invasive interventions were preferentially applied to patients with more favorable anatomy, limited necrosis extent, and sufficient hemodynamic stability to tolerate the procedures. Conversely, open surgery was more commonly performed in patients with extensive necrosis, hemodynamic instability, or anatomical factors precluding minimally invasive access. These selection factors may have contributed to outcome differences beyond the inherent effects of surgical technique itself.

The analysis of secondary outcomes including hospital length of stay, intensive care requirements, and complication rates provides additional context for interpreting mortality differences. Patients treated conservatively (subgroup A1) had the shortest hospitalizations, averaging  $21.3 \pm 8.4$  days, reflecting the less severe disease and absence of operative recovery. Those undergoing minimally invasive interventions (subgroups A3 and B1) had intermediate lengths of stay, while open surgery patients (subgroups A2 and B2) required the longest hospitalizations, often exceeding 40-50 days due to prolonged recovery and higher complication rates.

Intensive care utilization followed similar patterns. Conservative management required the least intensive care support ( $4.2 \pm 2.1$  days), minimally invasive interventions intermediate requirements (7.3-15.6 days depending on infection status), and open surgery the most prolonged intensive care stays (12.8-19.4 days). These differences reflect both the physiological stress of different interventions and the severity of complications when they occurred. The economic and resource implications of these differences are substantial, particularly in resource-limited settings.

Wound complications, particularly infections and dehiscence, occurred almost exclusively in open surgery patients, affecting approximately one-third of patients in subgroups A2 and B2. The large incisions required for open necrosectomy, combined with contamination from pancreatic contents and compromised healing in malnourished patients with systemic inflammation, create high risk for wound problems. Minimally invasive approaches virtually eliminate this complication category, as the small port sites rarely develop significant infections and healing is typically uncomplicated.

Pancreatic fistula, defined as persistent drain output with elevated amylase content, occurred across all intervention groups but with varying frequency. Open surgery patients demonstrated the highest rates (22.9-33.3%), likely reflecting more extensive pancreatic tissue manipulation and disruption. Minimally invasive approaches showed intermediate rates (12.5-21.4%), while conservative management by definition did not involve this complication. Most fistulas resolved with conservative management including drainage and nutritional support, though a small proportion required additional interventions.

The need for reintervention, defined as any additional procedure beyond the index operation, varied substantially between approaches. Conservative management required intervention in only 5.0% of cases, representing clinical deterioration necessitating surgical management. Minimally invasive interventions required additional procedures in 18.8-38.1% of cases, often involving drain repositioning, additional catheter placement, or conversion to open surgery. Open surgery patients required reintervention most frequently (34.3-48.5%), typically for complications including bleeding, abscess formation, or inadequate initial debridement.

Persistent organ failure, defined as dysfunction lasting more than 48 hours despite appropriate support, represented a major predictor of mortality. Conservative management patients rarely developed persistent organ failure (12.5%), consistent with the favorable disease course in this selected population. Minimally invasive interventions were associated with intermediate rates (18.8-47.6% depending on infection status), while open surgery demonstrated the highest incidence (37.1-54.5%). Whether organ failure prompted surgical intervention or resulted from it cannot be definitively determined from observational data, though likely both directions of causality operated.

The pattern of microorganisms isolated from infected necrosis provides insight into infection pathophysiology and antibiotic selection. Gram-negative enteric organisms predominated, including *Escherichia coli*, *Klebsiella* species, and *Enterobacter* species, supporting the theory of bacterial translocation from gut as a primary infection mechanism. Gram-positive organisms including *Enterococcus* species and coagulase-negative staphylococci were also common. Fungal infections, particularly *Candida* species, occurred in approximately 15% of infected cases, associated with particularly poor outcomes. Antimicrobial resistance was prevalent, with extended-spectrum beta-lactamase producing organisms in 28% of cases and carbapenem resistance in 7%.

The timing of intervention relative to disease onset influenced outcomes significantly. Early surgery, performed within 14 days, was associated with mortality of 42% in our series compared to 18% for surgery after 28 days. This dramatic difference supports current guidelines recommending delayed intervention whenever clinically feasible. The pathophysiological basis involves ongoing evolution of necrosis during the first 2-4 weeks, with indistinct tissue planes, friable structures prone to bleeding, and systemic inflammation peak. Delayed intervention allows demarcation of viable and non-viable tissue, encapsulation of necrotic collections, and resolution of acute-phase systemic inflammation.

The learning curve for minimally invasive techniques represents an important consideration for broader implementation. Analysis of outcomes stratified by time period revealed improvement over the five-year study duration, with mortality in minimally invasive cases decreasing from 15.8% in 2018-2019 to 8.3% in 2022-2023. This improvement likely reflects accumulating surgeon experience, refined patient selection, improved perioperative care protocols, and enhanced multidisciplinary collaboration.

Institutions beginning minimally invasive programs should anticipate a learning period with potentially suboptimal early results.

The economic analysis, though not the primary focus of this study, revealed substantial cost differences between approaches. Minimally invasive interventions incurred lower overall costs despite requiring specialized equipment, due to shorter hospitalizations, reduced intensive care utilization, and fewer complications. Open surgery generated the highest costs through prolonged hospitalization, extensive intensive care requirements, and management of complications. From a healthcare system perspective, these cost differences support investment in minimally invasive capabilities even when initial equipment costs appear substantial.

Geographic and cultural factors may have influenced our findings in ways relevant to interpretation and generalizability. The patient population in Central Asia may differ from Western populations in disease etiology, with alcohol-related pancreatitis relatively less common and biliary pancreatitis more frequent. Genetic factors might influence inflammatory responses and disease severity. Healthcare system characteristics including insurance coverage, referral patterns, and resource availability differ from high-income Western countries. Despite these differences, the fundamental biological principles underlying acute pancreatitis pathophysiology remain constant, suggesting that core findings should be applicable broadly.

The integration of interventional radiology, endoscopy, and surgery in a multidisciplinary team approach emerged as critical to optimal outcomes. Weekly conferences reviewing all patients with severe acute pancreatitis, attended by specialists from multiple disciplines, allowed individualized treatment planning incorporating diverse expertise. Interventional radiologists provided guidance on feasibility and optimal timing of percutaneous interventions. Surgeons contributed expertise regarding anatomical considerations and surgical options. Critical care physicians ensured appropriate timing relative to physiological stability. This collaborative model likely contributed to the favorable outcomes observed.

The role of nutritional support deserves emphasis. All patients received nutritional assessment within 48 hours of admission, with early initiation of enteral nutrition via nasogastric or nasojejunal tubes in hemodynamically stable patients. Enteral nutrition was possible in 87% of patients overall, with only those with complete ileus or severe hemodynamic instability requiring parenteral nutrition. The low rate of infectious complications compared to historical series may partly reflect this aggressive nutritional approach, as maintenance of gut barrier function reduces bacterial translocation and preserved nutritional status enhances immune function.

Long-term follow-up, available for 143 surviving patients (87%), revealed important sequelae. Endocrine insufficiency requiring insulin therapy developed in 31% of patients, particularly those with extensive necrosis involving pancreatic head and body. Exocrine insufficiency necessitating enzyme

supplementation occurred in 56%, manifesting as steatorrhea, weight loss, or fat-soluble vitamin deficiency. Chronic pain required ongoing management in 24%. Whether these long-term complications differ between minimally invasive and open approaches remains uncertain from our data, though some studies suggest preserved pancreatic parenchyma with less aggressive debridement might reduce endocrine and exocrine dysfunction.

Quality of life assessment using validated instruments was performed in a subset of 89 patients at one-year follow-up. Those treated with minimally invasive interventions reported significantly better physical function scores and less pain compared to open surgery patients. Body image and cosmetic satisfaction were substantially superior in the minimally invasive group, as expected given the absence of large abdominal scars. However, psychological distress including anxiety and depression occurred similarly across groups, suggesting that these mental health consequences relate more to the overall disease severity and life-threatening nature of the illness rather than surgical approach specifically.

The present study has several limitations warranting acknowledgment. The retrospective observational design precludes definitive causal inference, as treatment assignment was not randomized and patient selection influenced group composition. Surgeons preferentially applied minimally invasive techniques to patients with more favorable characteristics, potentially inflating apparent benefits. Confounding by indication represents a significant concern in any observational surgical study. Randomized controlled trials would provide stronger evidence, though ethical and practical challenges complicate such studies in severe acute pancreatitis.

Sample size, while substantial for a single-center series, limits statistical power for detecting smaller differences and for subgroup analyses. The confidence intervals around mortality estimates are relatively wide, particularly for subgroups with fewer patients. Multi-center studies with larger populations would allow more precise effect estimates and more robust conclusions. However, single-center studies offer advantages of protocol consistency and standardized outcome assessment that can be challenging in multi-center contexts.

The five-year study period encompassed evolution in management approaches, surgical techniques, and critical care practices. Changes over time may have confounded comparisons between groups if different time periods predominated in different subgroups. However, analysis stratified by time period did not reveal substantial differences in comparative outcomes, suggesting that temporal trends did not substantially bias results. The consistency of findings across the study duration actually strengthens confidence in the conclusions.

Outcome assessment focused primarily on short-term endpoints including in-hospital mortality and major complications. While these represent critically important outcomes, longer-term measures including quality of life, functional status, and chronic complications deserve more systematic evaluation. The follow-up data collected provide

some insight into these domains but were incomplete and not standardized across all patients. Future studies should incorporate comprehensive long-term outcome assessment as a core component.

The generalizability of findings to other settings requires consideration. The participating institutions are tertiary referral centers with specialized expertise in managing severe acute pancreatitis, including experienced interventional radiologists, therapeutic endoscopists, and surgeons familiar with both minimally invasive and open techniques. Community hospitals without these resources might not achieve similar outcomes. The development of referral networks directing patients to centers with appropriate expertise represents one approach to addressing this concern.

Cost analysis was limited to direct medical costs without considering indirect costs including lost productivity, caregiver burden, and long-term disability. Comprehensive economic evaluation incorporating all relevant costs and outcomes would provide better guidance for resource allocation decisions. Additionally, cost structures differ substantially across healthcare systems, limiting direct transferability of economic findings. Each healthcare system must evaluate cost-effectiveness within its own context.

The exclusion of patients with mild acute pancreatitis from this analysis focuses attention on the population most relevant to surgical decision-making but limits generalizability across the full pancreatitis severity spectrum. Patients with mild disease, representing approximately 80% of all acute pancreatitis cases, almost never require surgical intervention and have excellent prognosis with conservative management alone. The findings presented here apply specifically to the 20% with moderate or severe disease where surgical considerations arise.

Despite these limitations, the study provides valuable real-world evidence regarding outcomes with different management approaches in severe acute pancreatitis. The large consecutive series, comprehensive outcome assessment, and systematic comparison across multiple clinically relevant subgroups offer practical guidance for treatment selection. The consistency of findings with emerging international literature supports the validity and relevance of the conclusions.

## 4. Conclusions

1. Minimally invasive surgical interventions represent effective treatment options for severe acute pancreatitis, successfully implemented in 51.4% of patients in this series. Video laparoscopic lavage serves as the primary minimally invasive approach for aseptic pancreatic necrosis, while percutaneous drainage under ultrasound or computed tomography guidance provides effective treatment for pancreatic abscess and infected fluid collections. These techniques, when appropriately applied, achieve source control while minimizing surgical trauma and associated complications.

2. Minimally invasive interventions demonstrate clear advantages over open surgical operations in patients with aseptic severe acute pancreatitis, supported by statistically significant reduction in mortality rates (6.2% versus 17.2%,  $p < 0.05$ ). This substantial 11 percentage point difference in mortality, combined with additional benefits including shorter hospital stays, reduced intensive care requirements, and lower complication rates, establishes minimally invasive approaches as the preferred intervention when surgical management becomes necessary for aseptic pancreatic necrosis. Conservative management without surgical intervention remains appropriate for carefully selected patients with limited necrosis who demonstrate clinical improvement with supportive care, achieving favorable outcomes with 5.0% mortality in this series.
3. In infected pancreatic necrosis, minimally invasive interventions similarly provide superior outcomes compared to open surgical approaches, with mortality rates of 19.1% versus 27.3% respectively ( $p < 0.05$ ). While this 8.2 percentage point difference appears smaller than observed in aseptic necrosis, it remains clinically meaningful and statistically significant. The higher overall mortality in infected versus aseptic necrosis (19.1% versus 6.2% for minimally invasive approaches; 27.3% versus 17.2% for open surgery) confirms infection as a critical determinant of prognosis independent of surgical technique.

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