

Endoscopic management of infected necrotizing pancreatitis: Advancing through standardization

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Abstract

Infected necrotizing pancreatitis (INP) remains a life-threatening complication of acute pancreatitis. Despite advancements such as endoscopic ultrasound (EUS)-guided drainage, lumen-apposing metal stents, and protocolized step-up strategies, the clinical practice remains heterogeneous, with variability in endoscopic strategies, procedural timing, device selection, and adjunctive techniques contributing to inconsistent outcomes. This review synthesizes current evidence to contribute to a structured framework integrating multidisciplinary team decision-making, advanced imaging (three-dimensional reconstruction, contrast-enhanced computed tomography/magnetic resonance imaging), EUS assessment, and biomarker-driven risk stratification (C-reactive protein, procalcitonin) to optimize patient selection, intervention timing, and complication management. Key standardization components include endoscopic assessment and procedural strategies, optimal timing of intervention, personalized approaches for complex pancreatic collections, and techniques to reduce the number of endoscopic debridements and mitigate complications. This work aims to enhance clinical outcomes, minimize practice heterogeneity, and establish a foundation for future research and guideline development in endoscopic management of INP.

Key Words: Infected necrotizing pancreatitis; Endoscopic management; Perioperative management; Standardized management; Multidisciplinary collaboration

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Core Tip: Endoscopic therapy serves as the first-line treatment for infected necrotizing pancreatitis (INP), effectively reducing mortality and complication rates. Standardizing INP endoscopic management relies on multidisciplinary collaboration, advanced imaging techniques (*e.g.*, three-dimensional reconstruction, endoscopic ultrasound-guided procedures), and biomarker-driven strategies (C-reactive protein, procalcitonin) to tailor interventions, optimize timing, and minimize complications. Addressing the heterogeneity in endoscopic management remains crucial, requiring clarification of optimal intervention windows, selection of appropriate stents, implementation of combined therapies for complex lesions, and strategies to reduce endoscopic debridement sessions and complication risks, thereby guaranteeing individualized therapeutic demands with clinical efficacy assurance.

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INTRODUCTION

Acute pancreatitis, a typical gastrointestinal emergency, progresses to necrotizing pancreatitis in approximately 20% of cases, with infection of necrotic tissue [infected necrotizing pancreatitis (INP)] occurring in 30%–70% of these patients[1-4]. INP carries a mortality rate of up to 30%, necessitating timely and effective intervention[5,6]. Traditional open surgical necrosectomy, while life-saving, is associated with significant morbidity, including organ failure, pancreaticocutaneous fistulas, and prolonged hospitalization[7].

The advent of minimally invasive endoscopic techniques, including endoscopic ultrasound (EUS)-guided transmural drainage, direct endoscopic necrosectomy, and lumen-apposing metal stents (LAMS), has revolutionized INP management[8]. These approaches leverage the natural transluminal route, mitigating systemic inflammation while improving healthcare efficiency through reduced hospitalization and costs[9,10]. Previous randomized trials have demonstrated non-inferiority of endoscopic step-up protocols compared to surgical or percutaneous strategies, with improved patient-centered outcomes[11,12].

Despite these advances, the clinical practice of INP management remains heterogeneous. Variability in procedural timing, choice of devices (*e.g.*, plastic stents *vs* LAMS), adjunctive irrigation methods, and antimicrobial protocols contributes to inconsistent success rates and complication profiles[13-15]. Additionally, the evolving evidence on the role of early *vs* delayed intervention, the utility of proactive necrosectomy, and the management of disconnected pancreatic duct syndrome (DPDS) underscores the urgent need for standardization in the field of INP management[16-18].

This review synthesizes advances in the endoscopic management of INP while incorporating real-world expertise from the authors' tertiary referral center, with the dual objectives of improving patient outcomes and promoting consistency across varied clinical environments.

DIAGNOSTIC PHASE

The 2012 Revised Atlanta Classification established standardized definitions for INP and categorized acute pancreatitis complications and severity. However, due to its publication timeline, this consensus did not address the evolving role of endoscopic management, particularly the application of EUS in treating INP[19]. Prioritizing computed tomography (CT) as the primary imaging modality demonstrates significant clinical utility for diagnosing INP in resource-limited settings, leading to widespread global adoption. While early contrast-enhanced CT (CECT) (performed within 72–96 hours) remains the gold standard for differentiating interstitial edematous pancreatitis from necrotizing pancreatitis, its specificity for detecting infected necrosis remains suboptimal[20,21]. Although the "gas within necrosis" sign on CT aids in identifying INP, it is detected in less than 50% of INP patients, rendering its sensitivity as a diagnostic marker suboptimal[22,23]. Furthermore, when selecting imaging modalities for serial monitoring and reassessment during INP treatment, the cumulative radiation exposure associated with relatively frequent CT examinations must be considered[24,25]. These limitations underscore the imperative to integrate endoscopic modalities into the diagnostic procedures of INP.

Endoscopic evaluation, especially EUS, should be considered in specific clinical scenarios[26]. Endoscopic techniques are pivotal in diagnosing pancreatitis, demonstrating superior diagnostic accuracy compared to magnetic resonance cholangiopancreatography (MRCP), particularly in patients with idiopathic or recurrent pancreatitis[27,28]. EUS and endoscopic retrograde cholangiopancreatography (ERCP) enable early identification of underlying etiologies that may evade detection by conventional imaging[29-31]. These include, but are not limited to, biliary sludge or microlithiasis (sub-5 mm stones), pancreaticobiliary maljunction, sphincter of Oddi dysfunction, small pancreatic cancers (less than 20 mm in size), and communication between pancreatic lesions and the main pancreatic duct (MPD) (Figure 1)[32-35]. Such findings are critical for guiding timely therapeutic interventions. For instance, EUS provides high-resolution imaging to confirm ductal continuity or identify DPDS, and ERCP allows direct therapeutic actions, such as biliary sphincterotomy or stent placement, to alleviate obstructions[36-38]. Furthermore, delineating ductal anatomy helps determine whether transpapillary drainage *via* the duodenal papilla should be integrated with conventional transmural drainage (transga-

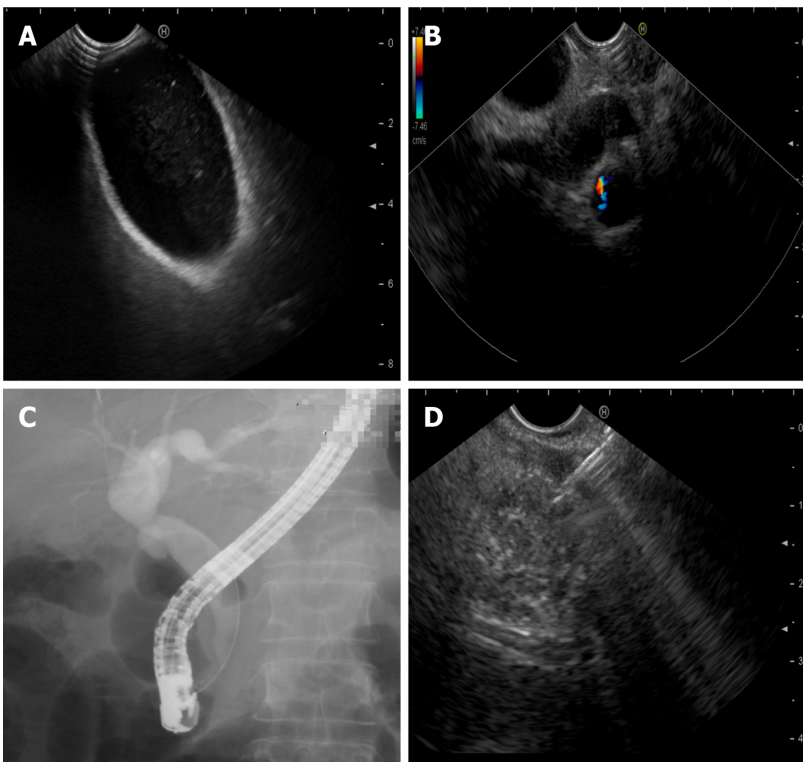


Figure 1 Endoscopically diagnosed etiology of pancreatitis. A: Cholecystic microlithiasis detected by endoscopic ultrasound (EUS); B: Biliary sludge detected by EUS; C: Sphincter of Oddi dysfunction detected by endoscopic retrograde cholangiopancreatography; D: Small pancreatic cancer confirmed by EUS-guided fine-needle aspiration.

stric/transduodenal) in INP[39]. This dual approach is particularly beneficial when imaging or procedural findings confirm direct communication between necrotic collections and the pancreatic duct, reducing the risk of recurrent fluid accumulation or persistent leaks[40].

Therefore, our team advocates for early EUS (within 72 hours of symptom onset) in patients with acute pancreatitis of unclear etiology in specialized endoscopy centers, aiming to identify underlying pathologies that may be missed by CT or MRCP. Furthermore, during EUS, assessing pancreatic cystic lesions adjacent to the MPD warrants evaluation for DPDS, a critical determinant of persistent leaks and recurrent collections that may influence endoscopic therapeutic planning [41]. While the diagnosis of INP relies on clinical manifestations (*e.g.*, fever, organ dysfunction) and imaging findings (*e.g.*, the "gas within necrosis" sign on CT), the necessity of obtaining microbiological evidence *via* EUS-guided fine-needle aspiration (EUS-FNA) remains debated[22,42-44]. Our team advocates that EUS-FNA, combined with culture or metagenomic next-generation sequencing of aspirated samples, should be considered for patients who remain unresponsive to empirical antibiotic therapy after 96 hours or those with diagnostic uncertainty[44,45]. Endoscopic intervention in such cases may facilitate tailored antimicrobial regimens and improve clinical outcomes. A tiered diagnostic strategy is critical to optimize resource utilization. Before performing EUS-FNA, pre-procedural triage using noninvasive biomarkers [*e.g.*, C-reactive protein (CRP), procalcitonin (PCT)] combined with cross-sectional imaging [CT/magnetic resonance imaging (MRI)] is imperative[46-48]. Emerging tools, such as radiomics and artificial intelligence (AI)-driven analysis of imaging data, alongside multiplex biomarker panels [interleukin (IL)-6, lactate], have demonstrated the potential to substantially enhance the diagnostic accuracy of INP by identifying quantitative radiomic signatures (*e.g.*, necrosis heterogeneity) and systemic inflammatory burden[49,50].

TREATMENT PHASE

While encouraged by the progress in the endoscopic treatment of INP, endoscopists should also confront the reality that surgical management of INP has already achieved a high degree of standardization, with minimal variability among research groups across major centers worldwide. In stark contrast, endoscopic treatment remains highly non-standardized, a factor that could significantly influence treatment outcomes[51-53]. Therefore, the subsequent sections will delve into the issues surrounding the standardization of endoscopic treatment for INP, focusing on aspects such as preoperative assessment, endoscopic techniques, and complication prevention and management.

Pre-procedural assessment

A structured pre-procedural evaluation is critical to optimize therapeutic outcomes and minimize risks (Figure 2). Key components include contrast-enhanced CT/MRI, biomarker-driven risk stratification, EUS reassessment, and multidiscip-

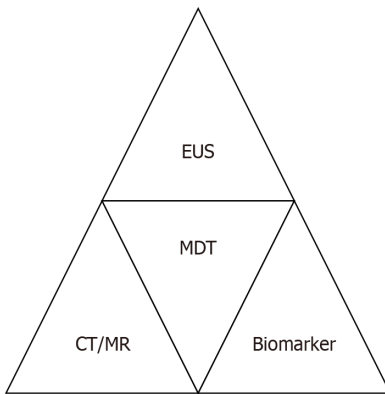


Figure 2 Structured pre-procedural evaluation for patients with infected necrotizing pancreatitis. CT: Computed tomography; EUS: Endoscopic ultrasound; MDT: Multidisciplinary team; MR: Magnetic resonance.

linery consensus.

First, contrast-enhanced CT/MRI and MRCP are frequently utilized in the preoperative assessment of endoscopic procedures for INP. The former is primarily used to assess the necrosis extent (*e.g.*, < 30% *vs* > 30%), identify local complications, and detect signs of infection (*e.g.*, air bubble signs)[23,54]. The latter is mainly used to evaluate biliary and pancreatic duct abnormalities and the potential connection between pancreatic pseudocysts and the MPD[55]. In most cases, imaging modalities, typically performed before EUS, confirm the presence of infection (*e.g.*, gas within necrosis), evaluate lesion size, and assess wall integrity and definition. These findings, integrated with clinical symptoms such as fever or persistent abdominal pain, guide the decision for endoscopic drainage and necrosectomy, ensuring adherence to evidence-based intervention criteria[43]. Our team has utilized contrast-enhanced CT imaging to construct three-dimensional (3D) reconstruction models of necrotic lesions in INP patients. This model has been applied to guide endoscopic debridement of walled-off necrosis (WON) in cases with extensive necrosis or complicated patients (Figure 3). Preliminary results have demonstrated promising clinical utility, and we anticipate sharing these data with the broader community soon. In addition to imaging modalities, widely used scoring systems (*e.g.*, the Ranson score, acute physiology and chronic health evaluation score, bedside index for severity in acute pancreatitis score), as well as AI technologies integrating extensive clinical and imaging data, have been applied and studied for severity prediction and prognostic evaluation in INP[20,56].

Second, biomarker-driven risk stratification is also integral. Elevated PCT (> 1.8 ng/mL) and IL-8 (> 112 pg/mL), and increased lactate (> 2 mmol/L) serve as robust indicators of severe infection necessitating prompt intervention[57,58]. These biomarkers enable noninvasive prediction of infected necrosis and inform perioperative strategies for endoscopic or surgical debridement[59,60]. Persistently elevated PCT and CRP levels beyond 72 hours post-onset exhibit greater diagnostic accuracy for INP compared to early-phase measurements, underscoring the need for serial biomarker monitoring in dynamic risk assessment[46]. Our team's single-center study revealed that the endoscopic debridement interval showed no significant correlation with the patient's biochemical markers (*e.g.*, white blood cell count, neutrophil percentage, CRP). In contrast, statistically significant associations were observed with pre-intervention modified CT severity index (MCTSI) and elevated CRP levels[61].

Third, EUS assessment is crucial to evaluate the wall thickness of the collection, the proximity of adjacent vessels, and the presence of solid necrotic debris content, guiding the selection of access routes and devices[62]. Notably, contrast-enhanced CT is less sensitive than EUS in identifying the proportion of solid necrosis within INP[42,63,64]. Thus, EUS evaluations were systematically performed to quantify the extent of solid necrotic debris and assess peripancreatic vasculature, including the splenic vein and collateral vessels. This approach aimed to minimize bleeding risks during transmural drainage by avoiding vascular structures, particularly in patients with sinistral portal hypertension[65]. Studies have demonstrated that more significant solid necrotic debris observed on EUS is associated with increased requirement for necrosectomy, higher rates of stent occlusion, and prolonged hospitalization[66]. Our team's research further revealed that while the location and size of WON on EUS showed no significant correlation with the interval between endoscopic debridement sessions, they were significantly associated with the solid necrosis ratio within WON during EUS evaluation[61]. Consequently, the quantification of solid necrosis content should be prioritized in EUS assessments. Moreover, under Doppler imaging guidance, EUS evaluates the presence of sinistral portal hypertension and gastric varices (GV) secondary to INP[67,68]. This evaluation informs the design of puncture pathways and drainage strategies to mitigate perioperative complications such as intraoperative and postoperative stent-related bleeding, thereby underscoring the dual diagnostic and therapeutic utility of EUS in this context. Data from multiple studies indicate that perioperative bleeding rates associated with EUS-guided drainage of pancreatic cystic lesions are higher than those of standard EUS examinations, with particular attention needed for the risk of delayed bleeding following LAMS placement [69,70]. However, in patients with preexisting GV, the perioperative bleeding rates of EUS-guided variceal therapies are comparable to those of conventional endoscopic variceal therapies[71]. Therefore, based on our institutional experience in a high-volume endoscopic center, GV should not preclude EUS-guided INP management but necessitate meticulous preprocedural planning, including Doppler evaluation and multidisciplinary consultation. During Doppler assessment, clinicians must evaluate vasculature adjacent to the intended puncture and drainage pathways and anticipate potential

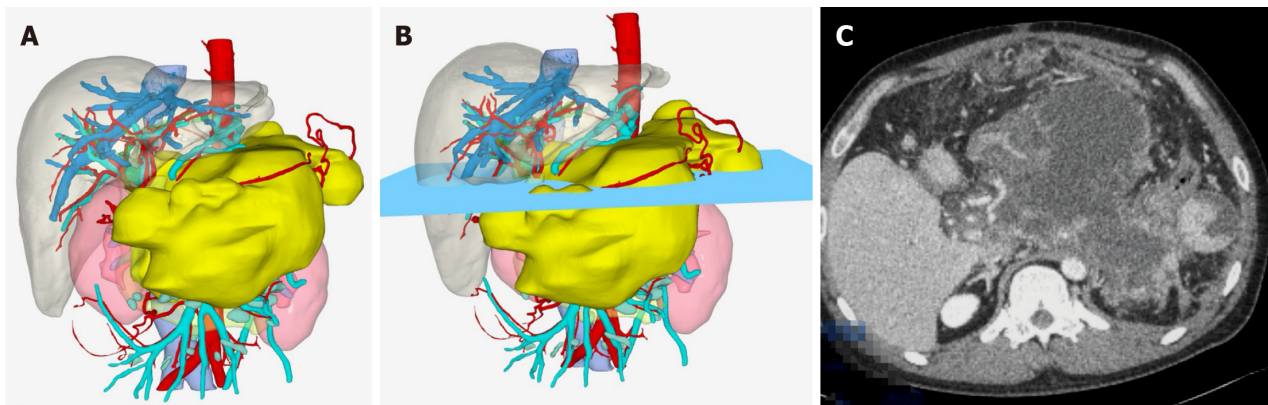


Figure 3 Three-dimensional reconstruction model of infected necrotizing pancreatitis. A: Three-dimensional reconstruction model of necrotic lesions; B: One transverse section of infected necrotizing pancreatitis; C: Transverse computed tomography section corresponding to Figure 2B.

vascular risks due to post-drainage changes in lesion size and vascular proximity along necrosectomy trajectories. This comprehensive vascular mapping minimizes bleeding risks and ensures endoscopic procedural safety, particularly in patients with sinistral portal hypertension.

Ultimately, while endoscopic management has been recommended as first-line treatment for INP patients meeting indications, the treatment plan and timing must be determined through multidisciplinary team (MDT) collaboration involving gastroenterologists, endoscopists, radiologists, intensivists, and surgeons to confirm the INP diagnosis, assess severity, and establish intervention timing[43,55,72]. The ongoing debate over early intervention (within 4 weeks of onset) *vs* delayed intervention (more than 4 weeks of onset) remains unresolved, primarily due to heterogeneity in patient conditions and institutional expertise[53,73,74]. Notably, studies have demonstrated that endoscopic interventions performed earlier than 4 weeks correlate with significantly higher mortality rates (13% *vs* 4%, $P = 0.02$) and an increased necessity for open necrosectomy (7% *vs* 1%, $P = 0.04$) compared to delayed approaches[73]. Most experts still consider early endoscopic intervention high-risk and believe that it should only be performed in experienced centers after MDT confirms that the benefits outweigh the risks[43,75]. Our institutional protocol emphasizes individualized decision-making. When weighing early *vs* delayed intervention, we prioritize a comprehensive evaluation integrating the patient's clinical symptoms (*e.g.*, persistent organ failure), EUS assessment findings (*e.g.*, solid necrosis ratio, vascular proximity), and anticipated outcomes of alternative therapies (*e.g.*, surgical mortality rates, conservative treatment efficacy rates), rather than relying solely on temporal criteria. Our approach aligns with recent research advocating for patient-tailored rather than time-driven strategies in INP management[76]. Complication prediction is also a critical component of preoperative assessment and communication. Recent advances include the integration of machine learning (ML) and deep learning (DL) models to analyze factors influencing pancreatic fistula rates and INP-related mortality, enhancing risk stratification and personalized management[56,77,78]. Recent advances in ML research have demonstrated that random forest-based models exhibit superior predictive performance for severe acute pancreatitis and have the potential to facilitate personalized therapeutic strategies[79]. Furthermore, ML models utilizing gradient boosting decision trees surpass conventional clinical scoring systems, including the systemic inflammatory response syndrome score and bedside index for severity in acute pancreatitis score, in predicting sepsis among acute pancreatitis patients, thereby may serve as an effective tool for early identification of high-risk patients and timely clinical intervention optimization[80]. However, these novel AI-driven technologies incorporating ML and DL models remain confined to limited institutions. A critical lack of comparative studies across different models/methodologies and multicenter validation data hinders their broader clinical adoption. To address this gap, we advocate for international academic consortia to spearhead multicenter comparative trials, which would establish standardized protocols for integrating these innovations into the clinical management of INP.

Endoscopic procedures

This review is based on the multidisciplinary clinical experience from our tertiary referral center with evidence-based analyses conducted using Reference Citation Analysis, a unique AI system for evaluating citations in biomedical literature. The selection of specific endoscopic techniques and strategies for INP remains the most debated and heterogeneous aspect of its management[76,81]. For example, while the step-up approach has become the mainstream recommendation for endoscopic intervention due to its cost-effectiveness advantages, recent studies suggest that one-step or step-jump (referring to bypassing intermediate steps such as percutaneous drainage or minimally invasive necrosectomy in the conventional step-up protocol, proceeding directly to the following therapeutic phase like minimally invasive necrosectomy or open necrosectomy) strategies may offer superior safety and efficacy[43,82,83]. Recent retrospective analyses revealed comparable mortality rates ($P = 0.239$) but significantly reduced incidences of multidrug-resistant organism infections ($P = 0.029$) and procedural complications ($P < 0.001$) in patients undergoing direct minimally invasive necrosectomy without preceding percutaneous catheter drainage (PCD), compared to conventional step-up approaches [82]. These endoscopic approaches significantly reduce the number of required procedures, shorten hospitalization duration, and lower overall costs without increasing composite endpoint events[84]. Another primary divergence lies in the approach to establishing drainage and debridement pathways, broadly categorized into methods based on

endoscopic submucosal dissection (ESD) *vs* EUS guidance—both fundamentally falling within the realm of natural orifice transluminal endoscopic surgery (NOTES)[85,86]. Our team maintains that while isolated ESD-based approaches for pathway creation have been sporadically reported, their inherent technical uncertainties and elevated vascular injury risks preclude routine clinical adoption[87]. Moreover, for a subset of INP cases where necrotic collections communicate with the MPD, ERCP-guided transpapillary drainage *via* the duodenal papilla has emerged as an effective therapeutic attempt[88,89]. However, this method is constrained by the limited diameter of the pancreatic duct drainage tract and, therefore, typically implemented in conjunction with the ESD-based or EUS-based NOTES technique in INP patients with solid necrosis exceeding 30%[37,90]. In addition to transpapillary drainage, early-stage ERCP (within 72 hours of onset) is recommended for biliary-induced INP to address underlying biliary pathologies in our center unless duodenal obstruction or patient intolerance precludes ERCP implementation, as this approach may shorten hospitalization[91]. However, ERCP in biliary pancreatitis remains challenging[92]. Studies suggest that premature urgent ERCP performed within 24 hours of onset increases the risk of adverse events[93]. Therefore, early ERCP within the first 24 hours should proceed after careful multidisciplinary discussion. When feasible, sequential ERCP and EUS-guided interventions in a hybrid operating room are also advised for comprehensive endoscopic management of INP patients[94,95].

An alternative non-endoscopic approach for drainage is PCD, typically employed in early disease stages or clinical settings lacking endoscopic expertise or equipment. PCD is also frequently utilized in critically ill INP patients requiring intensive care. However, our center's experience demonstrates that in patients with extensive necrotic lesions, percutaneous drainage—particularly multi-site drainage—may inadvertently partition a huge necrotic lesion into multiple smaller, isolated compartments that are subsequently challenging to manage endoscopically, ultimately compromising therapeutic efficacy and patients' quality of life (Figure 4). Furthermore, PCD and subsequent percutaneous endoscopic debridement have been associated with prolonged resolution of pancreatic lesions and adverse outcomes such as pancreatic fistula formation[96,97]. Therefore, PCD is not recommended as the first-line intervention for INP patients with a high solid necrosis ratio in our center unless the necrotic collections are located in regions inaccessible to endoscopic transmural drainage or necrosectomy[76]. For extensive necrosis involving retroperitoneal or pelvic areas, combined percutaneous and EUS-guided strategies may be employed, but clinicians should prioritize minimizing the interval between percutaneous and endoscopic procedures[98,99]. This recommendation stems from data in our center where delayed endoscopic intervention was associated with procedural failures secondary to cavity collapse following initial PCD. Moreover, endoscopic drainage remains a safe and feasible alternative for critically ill INP patients in the intensive care unit who meet the criteria for endoscopic intervention[100]. Our team has successfully performed multiple EUS-guided endoscopic drainage procedures in intensive care settings, achieving favorable therapeutic outcomes without new-onset procedure-related mortality.

When endoscopic management of INP is indicated, a debridement and drainage tract should ideally be created under EUS guidance[101]. A 19-gauge needle and 0.035-inch guidewire are commonly employed for initial access[76,102]. However, when using LAMS with a single-step deployment system, the need for a needle and guidewire may be obviated[103,104]. For needle-based access, subsequent tract dilation typically requires bougies, balloons, or cystotomes. Given that the needle trajectory may form an acute angle with the necrotic cavity surface, complicating bougie or cystotome advancement and increasing the risk of procedural failure, our center advocates for graded balloon dilation as the preferred and safer method for transmural tract creation (Figure 5)[105]. This approach facilitates controlled tract expansion and allows immediate hemostasis during transmural tract formation by balloon compression, minimizing the technical challenges and risks associated with repeated device exchanges for bleeding control[106,107].

Stent selection continues to generate debate, particularly between LAMS and plastic stents. LAMS, with their wide lumens (15–20 mm), are favored for large (> 6 cm) WON due to facilitated direct necrosectomy and reduced reintervention rates, albeit at the cost of higher bleeding risks as highlighted in recent studies[108–111]. However, comparative studies have demonstrated that LAMS does not reduce the need for endoscopic debridement in INP patients compared to double-pigtail plastic stents[112]. While some retrospective studies have found that plastic stents are associated with reduced overall bleeding events, including pseudoaneurysm bleeding, compared to LAMS, multicenter prospective cohort studies and meta-analyses have demonstrated comparable technical success rates [$P = 0.986$; relative risk (RR) = 1.00; 95% confidence interval (CI): 0.93–1.08], similar clinical success rates ($P = 0.139$; RR = 1.063; 95%CI: 0.98–1.15), lower complication rates in LAMS-treated patients ($P = 0.009$; RR = 0.746; 95%CI: 0.60–0.93], comparable mortality ($P = 0.640$), and similar odds of bleeding complications requiring reintervention (RR = 0.44; 95%CI: 0.16–1.17)[109,110,112]. Therefore, step-up staged approaches, including staged PCD-endoscopic strategies, along with single or multiple plastic stent drainage, remain practical and cost-effective treatment options for smaller INP lesions or in low-resource settings where limitations exist in EUS equipment availability, LAMS accessibility, procedural training resources, or EUS expertise. At the same time, in well-resourced settings, optimal stent configuration—such as single *vs* multiple plastic stents or hybrid LAMS-plastic combinations—lacks consensus[52,64]. While some studies suggest that coaxial plastic stent placement within LAMS may reduce stent occlusion rates, a recent systematic review and meta-analysis concluded that adjunctive stent placement does not significantly differ from LAMS alone in terms of adverse events, including infection, stent migration, occlusion, or reintervention rates[113–115]. Our team posits that for INP lesions with a solid necrosis content < 30%, the therapeutic efficacy of LAMS and multiple double-pigtail plastic stents is comparable in achieving drainage. However, we strongly advocate LAMS as the first-line option for lesions with solid necrosis content $\geq 30\%$. In resource-limited settings where plastic stents are utilized, we recommend deploying ≥ 3 double-pigtail plastic stents to facilitate subsequent endoscopic debridement, thereby eliminating the need for balloon dilation and reducing procedural complexity and costs. While hybrid approaches—such as coaxial placement of LAMS with plastic stents or nasocystic irrigation tubes—demonstrate efficacy in managing debris-predominant necrosis, they exhibit limited utility for lesions with bulky solid necrosis ($\geq 30\%$)[101]. These hybrid methods may still lead to LAMS occlusion, resulting in recurrent symptoms (*e.g.*, fever, abdominal pain) and suboptimal patient outcomes in real-world clinical practice. Therefore, for

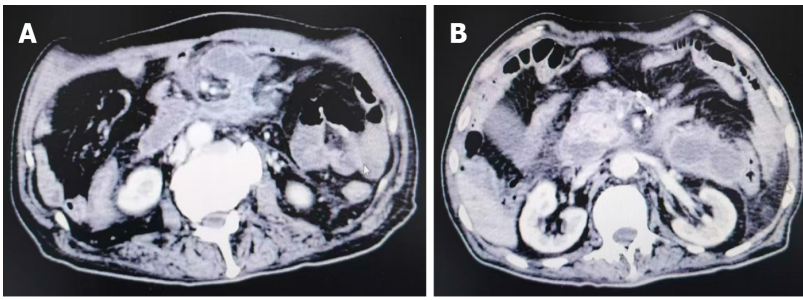


Figure 4 Post-percutaneous drainage fragmentations of necrotic collections. A: Cross-sectional view of an infected necrotizing pancreatitis lesion after percutaneous drainage; B: Another view from the same post-procedural patient.

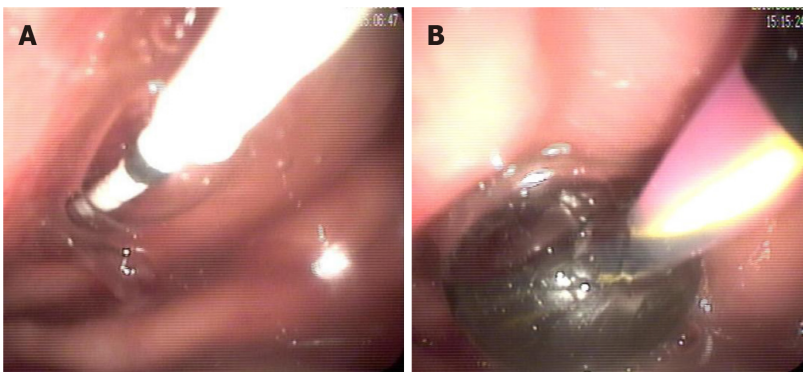


Figure 5 Graded balloon dilation. A: Initial balloon dilation with a small-diameter balloon; B: Subsequent dilation with a large-diameter balloon.

INP lesions with high solid necrosis content, our team emphasizes optimizing the interval between endoscopic debridement sessions over hybrid stent configurations alone.

The optimization of endoscopic debridement management in INP to improve procedural efficiency remains a dynamic and debated field. Early necrosectomy, though controversial, has demonstrated associations with improved clinical outcomes and reduced healthcare costs, necessitating careful patient selection under MDT guidance to balance risks and benefits[116]. Current recommendations for debridement intervals (mean 6.23 days \pm 4.71 days, range 3–21 days) are primarily based on aggregated global endoscopic expertise rather than standardized protocols[117]. Our single-center research identified five predictive parameters – EUS-measured solid necrosis ratio, MCTSI, postoperative fever, elevated CRP, and pre-interventional fever – as critical determinants of optimal timing for EUS-guided necrosectomy in WON [61]. At the same time, emerging ML and DL models show promise in refining intervention timing by integrating radiomic and clinical data. Retrospective analyses have demonstrated that ML models using support vector machines and random forest algorithms outperform conventional statistical models. ML models have also identified IL-6, infected necrosis, febrile episodes, and CRP as significant determinants for surgical intervention timing (< 4 weeks or \geq 4 weeks) in INP patients[118]. An individualized and rational endoscopic debridement schedule not only facilitates expedited recovery in INP patients but also enables optimized management of complications such as stent occlusion, migration, embedment, and stent-related bleeding, thus adhering to the principle that preventive strategies (early detection and intervention) yield superior outcomes with minimal poor prognosis impact compared to reactive measures (Figure 6). Innovations in endoscopic devices are also significantly enhancing debridement efficiency. Examples include the waterjet necrosectomy device, which has demonstrated preliminary efficacy and safety in preclinical animal studies, the powered endoscopic debridement system, capable of simultaneously resecting and removing solid necrotic debris, and the over-the-scope grasper, designed to remove large necrotic fragments that are challenging to extract with conventional tools [119–121]. Moreover, intracavitary irrigation strategies in INP have shown the potential to enhance debridement efficiency. Agents such as streptokinase, antibiotic solutions, and hydrogen peroxide have demonstrated utility in WON management by reducing the need for repeated necrosectomy, lowering mortality rates, and shortening hospitalization durations[122–124]. Our team has further validated the efficacy of anhydrous ethanol in real-world clinical settings, where its adjunctive use during transluminal necrosectomy significantly reduced the number of required endoscopic procedures without compromising safety[14]. Cumulatively, advancements in optimizing debridement intervals, adopting innovative devices, and implementing tailored irrigation protocols have markedly improved the efficacy of endoscopic INP management. However, future randomized controlled trials are imperative to validate these strategies and establish universally accepted guidelines, emphasizing the central role of MDT-driven personalized approaches in clinical practice to address the heterogeneity of INP presentations and optimize patient-centered outcomes.

While standardizing endoscopic management protocols for INP ensures consistent and high-quality care, it is equally important to recognize individual patients' unique clinical presentations and needs. Thus, pursuing standardized protocols must not eclipse the imperative for patient-specific adaptations. We propose a hybrid model integrating

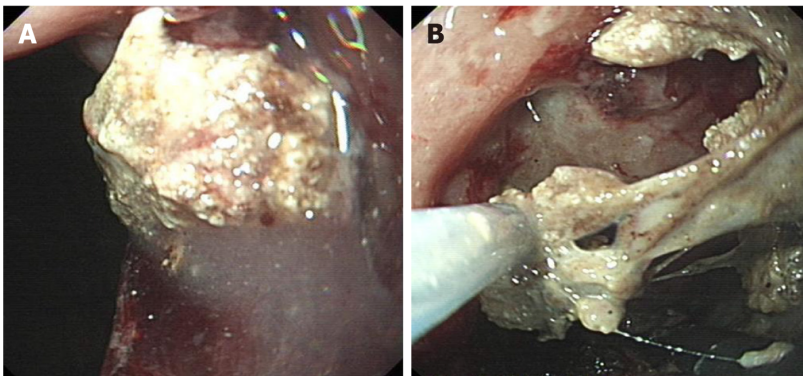


Figure 6 Endoscopic transgastric debridement of solid necrosis. A: Transgastric drainage tract obstructed by solid necrosis in infected necrotizing pancreatitis; B: Endoscopic transgastric debridement.

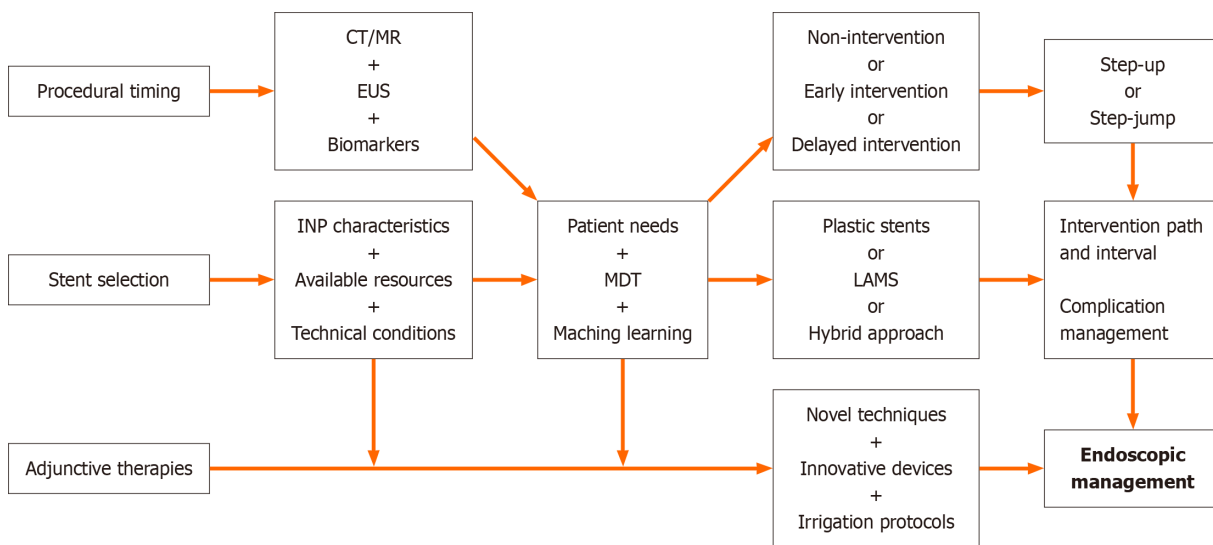


Figure 7 Endoscopic management flowchart of infected necrotizing pancreatitis. CT: Computed tomography; EUS: Endoscopic ultrasound; INP: Infected necrotizing pancreatitis; LAMS: Lumen-apposing metal stents; MDT: Multidisciplinary team; MR: Magnetic resonance.

standardized decision-making frameworks with MDT-adjusted flexibility to resolve this realistic dilemma. This approach would allow for applying evidence-based guidelines while accommodating patient-specific factors, such as comorbidities, prior treatment responses, and personal preferences. The cornerstone of this approach is to commence with a systematic pre-procedural assessment. At the same time, patient-specific strategies (*e.g.*, step-up *vs* step-jump), stent selection, debridement pathway establishment, debridement interval optimization, efficiency-enhancing adjuncts, and perioperative complication management require MDT evaluation to achieve patient-tailored adaptations within standardized therapeutic frameworks (Figure 7).

CONCLUSION

Endoscopic management of INP has transformed care by prioritizing minimally invasive, patient-centered strategies over traditional surgical approaches. Yet, persistent heterogeneity in endoscopic strategies, device selection, and adjunctive techniques underscores the urgent need for protocol standardization. Critical debates persist, including early *vs* delayed intervention, step-up *vs* step-jump, the role of hybrid strategies, personalized debridement intervals, and optimal irrigation agents, highlighting the necessity of balancing innovation with standardized, evidence-based protocols. Harmonizing endoscopic techniques through rigorous comparative studies and AI-driven algorithms will reduce future practice variability, optimize resource utilization, and ensure equitable access to high-quality INP care globally.

FOOTNOTES

Author contributions: Zeng Y and Yang J performed the literature search, analyzed the data, and wrote the original manuscript; Zhang JW and Yang J performed the endoscopic procedures, conceptualized and designed the research, and edited the final manuscript; all authors have read and approved the final manuscript.

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