

Contemporary Surgical Management of Pancreatic Necrosis

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IMPORTANCE For decades, infected or symptomatic pancreatic necrosis was managed by open surgical necrosectomy, an approach that has now been largely supplanted by an array of techniques referred to as the step-up approach.

OBSERVATIONS This review describes the evidence base behind the step-up approach, when to use the different techniques, and their technical basics. The most common treatment strategies are included: percutaneous drainage, video-assisted retroperitoneal debridement, sinus tract endoscopy, endoscopic transgastric necrosectomy, and surgical transgastric necrosectomy. Also included is the evidence base around management of common complications that can occur during step-up management, such as hemorrhage, intestinal fistula, and thrombosis, in addition to associated issues that can arise during step-up management, such as the need for cholecystectomy and disconnected pancreatic duct syndrome.

CONCLUSIONS AND RELEVANCE The treatment strategies highlighted in this review are those most commonly used during step-up management, and this review is designed as a guide to the evidence base underlying these strategies, as surgeons tailor their therapeutic approach to individual patients.

JAMA Surg. 2023;158(1):81-88. doi:10.1001/jamasurg.2022.5695
Published online November 16, 2022.

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For decades, infected or symptomatic pancreatic necrosis was managed by open surgical necrosectomy. This approach has been supplanted by an array of techniques that are used within a step-up approach. The aim of this review is to help surgeons understand the step-up approach to managing necrotizing pancreatitis (NP), when to use the different techniques, and their technical basics. Treatment strategies discussed include percutaneous drainage, video-assisted retroperitoneal debridement (VARD), sinus tract endoscopy (STE), endoscopic transgastric necrosectomy (ETN), and surgical transgastric necrosectomy (STN). Additional discussion includes how to address common complications and associated issues.

Indications for and Timing of Intervention

There are multiple types of fluid collections that can form around the pancreas, and terminology has varied over time. According to the most recent revised Atlanta classification,¹ there are 4 types of pancreatic collections defined, including acute peripancreatic fluid collection (APFC), pseudocyst, acute necrotic collection (ANC), and walled-off pancreatic necrosis (WOPN). The first 2 types, APFC and pseudocysts, occur in the setting of interstitial edematous pancreatitis (IEP) as distinct from NP, in which ANC and WOPN can develop. Occurring 4 weeks or less from symptom onset, APFC is extrapancreatic, is homogeneous, shows fluid attenuation, and has no surrounding wall. A pseudocyst is distinct in that it occurs more than 4 weeks from symptom onset, and while similarly fluid-filled and homogeneous, it is surrounded by a discrete wall. Among collections

associated with NP, an ANC occurs within 4 weeks of symptom onset, can be intrapancreatic or extrapancreatic, is heterogeneous, and has no surrounding wall. WOPN occurs 4 weeks or more from symptom onset and is similarly heterogeneous but is encapsulated with a wall.

Once WOPN is identified radiographically, the next question is whether and when to intervene. Intervention is generally only indicated for WOPN, in which the collection is clearly demarcated, typically after a minimum of 4 weeks.^{2,3} Figure 1 demonstrates examples of poorly vs well-demarcated necrosis that is ready for intervention. Infection of WOPN is the clearest indication for intervention, although the diagnosis of infection can be difficult to determine. On computed tomographic (CT) scan, any air in a collection is highly specific for infection; however, CT is only approximately 50% sensitive for infection.⁴ Percutaneous sampling of WOPN to determine the presence of infection was once common but has a false negative rate of around 20% and should be used selectively.⁵ Current guidelines recommend clinical judgment as the primary basis for diagnosing infection, initiating intervention, and starting antibiotic therapy.⁶ A recent randomized trial investigating the timing of interventions using a step-up approach in patients with infected necrosis demonstrated that delayed intervention results in similar outcomes and fewer interventions compared with earlier drainage.⁷ Furthermore, the patient's clinical status should also be factored into the decision. While there is no concrete literature studying this exact topic, our experience as a high-volume center is that a patient with sepsis and clearly infected but poorly demarcated necrosis may require earlier intervention, whereas a patient who is clinically improving should be allowed to continue doing so without interven-

Figure 1. Examples of Poorly Demarcated vs Well-Demarcated Necrosis and Readiness for Intervention

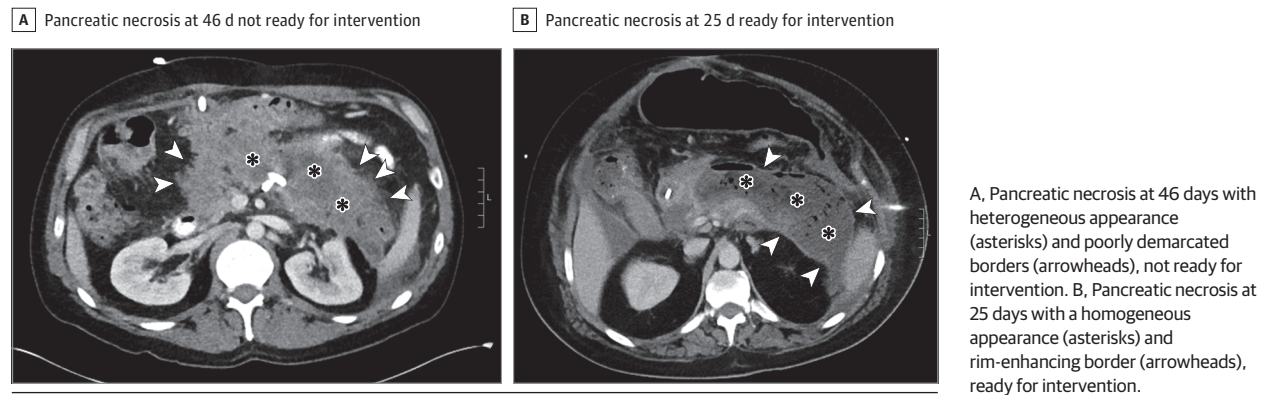
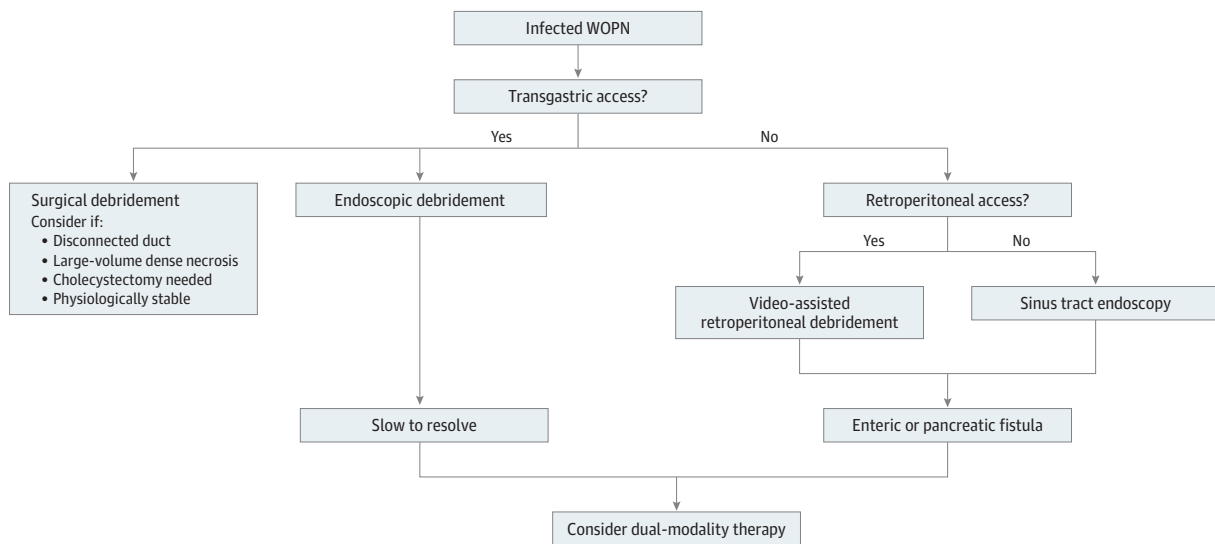


Figure 2. Treatment Algorithm for Infected Pancreatic Necrosis, Including Commonly Used Step-up Techniques



Before video-assisted retroperitoneal debridement or sinus tract endoscopy, a percutaneous drain needs to be placed as a critical first step to enable those procedures. In 30% to 40% of cases, that may be sufficient if the patient improves and the collection resolves, but in the majority of cases, additional

intervention as indicated here will need to be performed. Dual-modality therapy refers to a combination of percutaneous and transgastric techniques. WOPN indicates walled-off pancreatic necrosis. Adapted from Fong and Fagenholz.¹⁶

tion. Even in the absence of clear infection, gastric outlet obstruction, intestinal obstruction, and failure to thrive are also indications to intervene.⁸

In the absence of infection or these additional indications mentioned, it is possible to take a noninterventional approach to managing WOPN. In a prospective, multicenter study including 639 patients with NP, 62% of patients were managed without intervention, and among these patients the mortality rate was 7%.⁹ Carefully selected patients without evidence of infection or other indication for intervention as listed above can be considered for noninterventional management. According to the 2019 World Society of Emergency Surgery Guidelines, for patients being treated without intervention and with sterile necrosis, there is no indication for prophylactic antibiotics or other therapy unless the patient deteriorates clinically, at which point the question of infection and need for intervention should be revisited.¹⁰

Overview of the Step-up Approach

The step-up approach refers to initial percutaneous or endoscopic drainage, followed by “stepping up” to additional procedures in patients who do not improve. In at least 60% of cases, patients will require further intervention after initial drainage.^{6,11,12} Thus, the initial intervention should be undertaken with a plan for subsequent necrosectomy. The decision to step up should be made based on a combination of clinical and radiographic metrics, but in general, if there is residual necrosis and the patient has not improved clinically based on metrics such as inflammatory markers, hemodynamics, ability to come off antibiotics, and ability to tolerate enteral nutrition, the initial drainage should be stepped up. Additionally, having a multidisciplinary team to review these cases and plan progressive interventions is incredibly important.

Table. Table of Step-up Techniques With Indications, Benefits, Downsides, and Select References

Technique	Indications	Benefits	Risks and downsides	Source
Percutaneous drainage	Necrosis not accessible transluminally or inadequately walled off for transluminal drainage	Essential initial step for VARD or STE.	Subsequent interventions often needed.	van Baal et al, ¹³ 2011
		Can be effective as monotherapy in 30%-40% of patients.	Drains are painful.	Maatman et al, ¹¹ 2020
Endoscopic transgastric necrosectomy	Necrosis in the lesser sac opposed to the posterior wall of the stomach or duodenum	Avoids external drainage and with it the risk of pancreatic fistula.	Often requires multiple procedures. Necrosis extending laterally is difficult to treat.	Bakker et al, ¹⁴ 2012 Collet et al, ¹⁵ 2013
Video-assisted retroperitoneal debridement	Large-volume necrosis not accessible transgastrically but accessible via an RP percutaneous drainage route	Technique approachable for surgeons new to minimally invasive pancreatic debridement.	Requires RP drainage route. High risk of pancreatic fistula. Wound complications.	Fong and Fagenholz, ¹⁶ 2019 Fagenholz et al, ¹⁷ 2016
Sinus tract endoscopy	Percutaneous drain needed to access necrotic cavity, positioning and location flexible	Low rate of wound complications. Can use for WOPN only accessible via transperitoneal, intercostal, or very narrow RP routes.	High risk of pancreatic fistula. Equipment unfamiliar to most surgeons.	Fong and Fagenholz, ¹⁶ 2019
Surgical transgastric necrosectomy	Necrosis in the lesser sac, patient functional status adequate for open or laparoscopic surgical intervention	Avoids external drainage and associated pancreatic fistula.	Patient needs to be able to tolerate an operation.	Worhunsky et al, ¹⁸ 2014
		Can provide durable internal drainage for disconnected pancreatic duct syndrome.	Open approach is considerably more invasive than MIS or endoscopic techniques.	
		Cholecystectomy can be performed concurrently. Fewer interventions than endoscopic transgastric necrosectomy.	Necrosis extending laterally is difficult to treat.	Maatman and Zyromski, ¹⁹ 2020 Driedger et al, ²⁰ 2020
Open transperitoneal necrosectomy	Diffuse multifocal necrosis unable to be managed by MIS techniques	Can access diffuse areas of WOPN in a single procedure.	Higher mortality and morbidity than MIS approaches.	Madenci et al, ²¹ 2014
		Cholecystectomy can be performed concurrently.		Maatman et al, ²² 2021

Abbreviations: MIS, minimally invasive surgery; RP, retroperitoneal; STE, sinus tract endoscopy; VARD, video-assisted retroperitoneal debridement; WOPN, walled-off pancreatic necrosis.

Step-up Techniques

The anatomy of the patient's necrosis and their physiology determine the appropriate techniques for the step-up approach. The pros and cons of different techniques are described in the **Table**,^{11,13-22} and a general treatment algorithm for their use is depicted in **Figure 2**.¹⁶ There is no overarching evidence demonstrating that one technique is preferred over another in the step-up armamentarium, but instead, the sequence of interventions is guided by the particular circumstance of each individual.

Endoscopic Transgastric Necrosectomy

For patients with a necrosis cavity directly opposed to the posterior wall of the stomach, ETN can be an effective first option. This approach begins endoscopically and uses endoscopic ultrasound to locate the necrosis cavity, followed by needle and guidewire placement to access the cavity, creation of a tract to allow for mechanical debridement and irrigation, and then placement of plastic or lumen apposing covered metal stents to allow for continued drainage and reintervention.^{15,23} When compared with open surgical necrosectomy without preoperative drainage, the endoscopic approach had lower rates of organ failure and pancreatic fistula (as these patients have no external drain/tract to facilitate fistula development).^{14,24} Multiple interventions are often needed, particularly with dense necrosis, and about 20% of patients require additional modalities such as percutaneous drainage.^{14,24,25}

Percutaneous Drainage

Percutaneous drainage can also be the first intervention of a step-up approach. Importantly, this only works 30% to 40% of the time, and in the remainder of cases, further debridement is required.^{6,12,13,19} Studies suggest that patients with disconnected pancreatic ducts and those with less than 75% reduction in necrosis volume within the first 14 days after drain placement are more likely to require step-up.¹¹ Drain size has not been associated with differences in mortality among patients with NP.²⁶ Drains can be managed with differential flushing or irrigation strategies, including dependent drainage (often with intermittent flushing of small volumes of saline to maintain drain patency), continuous or intermittent large-volume lavage,^{27,28} or aggressive flushing to actively lavage debris.²⁹ Few data support one flushing or irrigation regimen over another.

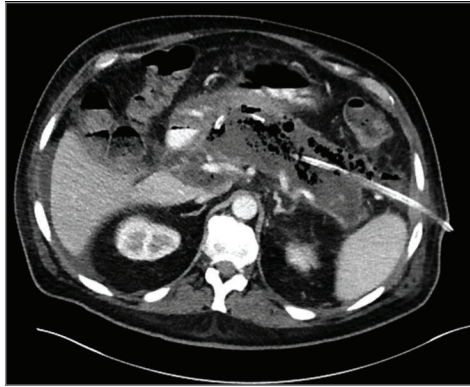
In most cases, percutaneous drainage is the pathway to other interventions, and decisions about location of drain placement determine the options for subsequent intervention. For example, if step-up to VARD is planned, a retroperitoneal drainage route should be chosen. Drains entering the WOPN at 1 or multiple points that allow access to the entire cavity best facilitate total debridement (**Figure 3**).

Video-Assisted Retroperitoneal Debridement

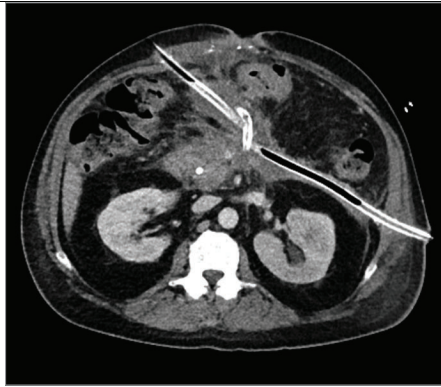
To enable VARD, the patient must have a retroperitoneal drain in place, which is most frequently positioned from the left flank between the perinephric fat and the descending colon, though

Figure 3. Examples of Optimal Drain Locations for Pancreatic Necrosis

A Intercostal, transperitoneal drainage route



B Example of crossing drains



A, An intercostal, transperitoneal drainage route that accesses the end of the walled-off necrosis and would allow debridement via sinus tract endoscopy. Accessing the end of the cavity as opposed to the middle allows access to the entire cavity. B, An example of "crossing" drains, in which the left-sided drain shows the typical retroperitoneal drainage route between the descending colon and the left kidney. The right anterior drain shows a typical transperitoneal drainage route that can be used for sinus tract endoscopy but not video-assisted retroperitoneal debridement.

right-sided collections can be drained via a similar approach, avoiding the duodenum. Initial drain placement that accounts for the possibility of VARD is ideal, as these windows can be narrow and can shrink or disappear if initial drainage via a transperitoneal route partially drains the WOPN. The technique for VARD has been previously described, including pertinent videos of the procedural steps and in-depth description.^{16,30} An overview of these steps is provided briefly here.

After positioning the patient in a partial lateral decubitus position, a 4- to 5-cm incision is made over the drain. Using electrocautery to dissect along its tract, the necrotic cavity is entered, avoiding the surrounding structures as visualized on the preoperative CT scan. The laparoscopic camera offers visualization of the cavity, and suction and irrigation are used to remove liquid necrotic contents. Ring forceps or laparoscopic graspers can be used to debride denser necrotic tissue. If adequate time has passed to allow the necrosis to demarcate, then the solid necrosis separates easily from the viable tissue of the cavity walls. Following debridement, drains are left in the cavity to allow egress of necrosis and fluid and to allow for irrigation or flushing. Independent incisions are made for the drains, rather than bringing them out through the incision to limit leakage, and the incision is closed in multiple layers.

For surgeons with less experience in these procedures, VARD is relatively accessible, because the equipment is familiar and it is essentially an open necrosectomy through a small flank incision. Additionally, debridement can often be accomplished with 1 intervention,¹² whereas many other debridement strategies routinely require multiple debridements. Limitations include the need for a retroperitoneal route sufficiently large to allow for safe cut-down all the way to the area of necrosis. In the early studies of VARD safety and efficacy, the most common reason for conversion to open was necrosis located more centrally and extending to the root of the mesentery.¹² With experience, central necrosis can often be reached, but VARD is best suited to lateral necrosis. Like any external debridement technique, VARD carries a relatively high risk of pancreatic fistula.

Sinus Tract Endoscopy

Sinus tract endoscopy is 1 of a variety of similar techniques that involve dilation of a percutaneous drain tract to debride WOPN.³¹ The

method for STE has previously been described in detail with video, which offers step-by-step instruction.^{16,32} In brief, under fluoroscopy, a guidewire is inserted through the preexisting drain into the area of necrosis, and a nephrostomy balloon dilator catheter is used to dilate the tract to permit insertion of a 30F working sheath. A rigid nephroscope is introduced through this sheath, and a grasper inserted through the working port allows debridement. It is particularly important to avoid any necrotic tissue that is not freely mobile, as this can cause bleeding, and even a small amount of bleeding can obscure the field and make further debridement difficult. Significant bleeding is difficult to control given limited access to the cavity. Adherent necrosis is better left behind and addressed, if needed, at a repeat procedure following irrigation of the cavity, at which point it has often sloughed and is safer to remove.

The main advantages of STE (and other dilational techniques) over VARD is that it allows the use of transperitoneal, intercostal, and very small drainage windows. The absence of an incision other than the drain tract also limits wound complications. The main disadvantage is that the relatively small instrumentation often leads to the need for more than 1 procedure to complete debridement. It also requires the use of potentially unfamiliar equipment (fluoroscopy, nephroscope), increasing the learning curve.¹⁶

Surgical Transgastric Necrosectomy

While not explicitly a minimally invasive procedure, STN can be used to treat WOPN abutting the posterior wall of the stomach. A step-by-step video of this procedure is portrayed by Maatman and Zyromski,¹⁹ and both the open and laparoscopic approach are described by Driedger et al.²⁰ In brief, this technique involves accessing and debriding necrosis through the posterior wall of the stomach, followed by creation of a cystgastrostomy into the necrosis cavity, allowing for internal drainage without any external drains. Compared with ETN, STN provides the opportunity to perform extensive debridement at the index operation and maintains the advantage of internal drainage of the necrosis cavity, while often avoiding the multiple procedures typically required with less invasive techniques.^{18,22} For patients with disconnected pancreatic tail segments, the surgical anastomosis to the necrosis cavity may provide more durable internal drainage than stent-

dependent endoscopic drainage. Compared with minimally invasive techniques, STN also allows for other intraabdominal procedures such as cholecystectomy and, like ETN, has a significantly lower risk of pancreatic fistula.

Like ETN, STN can only be applied to patients with necrosis abutting the stomach. Surgical transgastric necrosectomy is more invasive than ETN and carries inherent surgical risks that ETN avoids, such as wound infection. In theory, laparoscopic STN might reduce some of these risks, but a higher readmission rate with similar complication rates was seen in patients managed with laparoscopic compared with open STN in 1 series.²⁰ As with any open surgery, STN also requires grappling with a sometimes hostile intraperitoneal environment due to prior abdominal surgery, pancreatitis-induced inflammation, or other factors while the other techniques discussed here avoid those difficulties.

Transperitoneal Necrosectomy

Historically, open transperitoneal necrosectomy had mortality rates approaching 40%.² However, contemporary studies, incorporating such modern tenets of NP management as delaying intervention and using preoperative drainage, have shown mortality rates in the range of 2% to 10%.^{6,21,33} Open transperitoneal necrosectomy can be a valuable technique for multifocal necrosis that responds poorly to less invasive interventions or select cases of intestinal fistula. Transperitoneal necrosectomy can also be performed laparoscopically, although this technique has largely fallen out of favor as the less invasive techniques described above have become available. Laparoscopy may occasionally be the best option for small but symptomatic WOPN near the base of the mesentery that is not accessible via other means.³⁴

Complications During Step-up Management

A range of complications, including hemorrhage, thrombosis, intestinal fistula, biliary stricture, pancreatic fistulae, endocrine and exocrine insufficiency, and many other sequelae, can occur in patients with NP during the process of treatment.³⁵ This section will emphasize 3 frequently encountered complications during the step-up process, including hemorrhage, intestinal fistula, and thrombosis.

Hemorrhage

Recent series have shown a range of bleeding complication rates, from 0% to 15% of patients.^{6,14,36} The most feared bleeding complications result from erosion of necrosis into visceral arteries, most commonly the splenic or gastroduodenal. The great majority of these complications can be managed with angioembolization^{6,37}; however, mortality remains high at 10% to 20%.³⁷⁻⁴⁰ Any significant bleeding from a drain in WOPN or upper gastrointestinal bleed in a patient treated with ETN or STN should be considered a potential visceral artery bleed until proven otherwise. Depending on the scenario, this may mean performing a CT angiogram to evaluate for an underlying pseudoaneurysm or proceeding straight to angiography (in cases of major bleeding and hemodynamic instability). Given the potential for catastrophic hemorrhage, at our center, we take an aggressive approach toward incidentally identified arterial lesions (pseudoaneurysms or significant irregularities) in areas of WOPN and liberally prophylactically embolize.⁴¹ Intraoperative hemorrhage during minimally invasive approaches is less common but can

be difficult to manage. During VARD, bleeding can be controlled with packing or occasionally direct control with clips. "Blind" packing with strips of gauze through the sheath can be performed during STE. Balloon tamponade of the cavity in cases of major bleeding has also been described. In cases of major arterial bleeding, these would need to be bridges to other techniques such as angioembolization or conversion to open surgery.

Intestinal Fistula

Walled-off pancreatic necrosis can erode into nearby intestinal structures, most commonly the colon and the duodenum. In a study including more than 600 patients with NP at a single tertiary care center, 8% of patients developed an intestinal fistula.³⁵ Management of these fistulas depends on the location of the fistula, along with the patient's overall clinical picture. For instance, in a series of 119 patients who developed intestinal fistulas in the context of pancreatitis, all duodenal fistulas were managed nonoperatively, whereas 61% of colonic fistulas were managed via fecal diversion with ileostomy or colostomy.⁴² Our experience has been that the first step in management of intestinal fistulas that communicate with WOPN cavities is complete debridement of the WOPN. If that resolves sepsis, intervention on the fistula is usually not needed and certainly not needed acutely. Generally, if a patient is septic from a colonic fistula, this merits intervention, often with fecal diversion; whereas a radiographically identified fistula in a patient who is clinically stable and otherwise improving generally does not require intervention.

Thrombosis

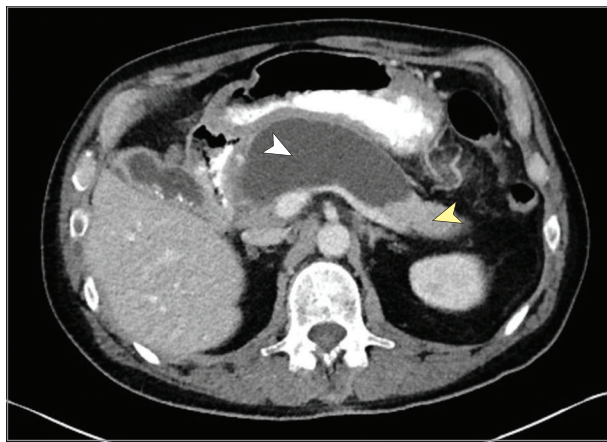
The development of NP has been associated with a 2 to 3 times higher rate of deep vein thrombosis and pulmonary embolism, respectively, than acute nonnecrotizing pancreatitis.⁴³ Standard dosing of unfractionated and low-molecular-weight heparin has been shown to be insufficient in more than 75% of patients with NP, and subprophylactic anti-factor Xa levels in this context were significantly associated with the development of deep vein thrombosis on screening ultrasound examinations.⁴⁴

Thrombosis of splanchnic veins is also frequently encountered in NP management. While some clinicians have explored the benefit of systemic anticoagulation to prevent splanchnic venous thrombosis,⁴⁵ this has not been studied in a randomized context. The decision to anticoagulate in cases of confirmed splanchnic vein thrombosis (most commonly portal, superior mesenteric, or splenic vein thrombosis) is made on a patient-by-patient basis, as evidence is limited and there is no clear consensus. A meta-analysis of 5 small case series of patients with splanchnic vein thromboses suggested that there was no significant difference in thrombosis resolution between patients who received anticoagulation and those who did not, but more than double the risk of bleeding in the anticoagulated group.⁴⁶ Ultimately, at our center, we decide case-by-case depending on the risk of bleeding weighed against indications of possible hepatic compromise with portal vein involvement.

Late Complications Following Step-up Management

The late complications of NP have previously been compared between open necrosectomy and step-up cohorts, with signifi-

Figure 4. Example of a Typical Computed Tomographic Scan for a Patient With a Disconnected Pancreatic Duct



The viable pancreatic tail can be seen (yellow arrowhead), enhancing normally, but there is an area of intervening pancreatic necrosis (white arrowhead) between the head of the pancreas and the tail. The apposition of the area of necrosis to the posterior wall of the stomach can also be seen. This patient was treated with surgical transgastric necrosectomy and simultaneous cholecystectomy.

cantly lower rates of incisional hernias (7%-23%), new-onset diabetes (16%-40%), and need for pancreatic enzymes (29%) in the step-up group, albeit with large ranges that vary by study cohort.^{47,48} Between different step-up techniques, literature is scant on long-term outcomes specifically associated with each methodology. In 1 meta-analysis of 3 randomized clinical trials with a total of 190 patients comparing endoscopic and surgical necrosectomy, the authors reported similar rates of incisional hernia and exocrine and endocrine insufficiency in both groups, with higher rates of pancreatic fistula in the surgical group.⁴⁹

Common Associated Issues

Two issues that commonly arise in patients with NP are the optimal timing and approach to cholecystectomy in patients with biliary pancreatitis and management strategies for patients with disconnected pancreatic duct syndrome (DPDS).

Management of the Gallbladder

Historically, it was safe and effective to perform cholecystectomy at the same time as open transperitoneal necrosectomy.⁵⁰ In patients managed with operative transgastric necrosectomy, as described above, this is still a viable option. In patients managed with a step-up approach, there is a substantial risk of gallstone-related complications in the delay before cholecystectomy if it is deferred until resolution of necrosis, as high as 20% in recent studies.⁵¹⁻⁵³ However, there is no evidence-based consensus on the optimal tim-

ing of cholecystectomy in step-up patients, and better evidence-based patient benchmarks are needed to determine this. We tend to proceed when the acute phase of inflammation and necessary debridement have been performed, the patient is nutritionally replete, and the period of critical illness has passed. Multiple series have now shown a laparoscopic approach to be feasible and safe in the vast majority of these patients.^{51,52} While often performed at tertiary care centers where these patients receive their NP care, there is no evidence that this is necessary.

Management of DPDS

Disconnected pancreatic duct syndrome arises when discontinuity of the pancreatic duct results in a functional distal pancreatic segment that is disconnected from the gastrointestinal tract.⁵⁴ Some radiographically disconnected pancreatic ducts do not cause any clinical problems, but DPDS refers to the adverse clinical manifestations of this anatomy. Suspicion for a disconnected duct usually arises early in the course of disease and is often easiest to recognize on early imaging studies when a large volume of necrosis intervenes between the viable proximal and distal pancreas (Figure 4). This should generally prompt a management strategy such as ETN or STN that involves internal drainage of the necrosis cavity so that drainage from the disconnected remnant can be internalized. If this cannot be done, or if it fails to provide adequate drainage, patients typically present with recurrent pancreatic fluid collection, recurrent pancreatitis involving the tail, or a persistent pancreatic fistula via old drain tracts. If necessary, the ductal anatomy can be defined by magnetic resonance cholangiopancreatography or endoscopic retrograde cholangiopancreatography.^{35,55}

Endoscopic options for treatment of DPDS include pancreatic duct stenting or transluminal drainage of the disconnected tail segment into the stomach.^{56,57} Surgical treatment involves either internal drainage by anastomosis to the stomach or a Roux limb of jejunum or distal pancreatectomy. Internal drainage is a less morbid operation and retains pancreatic function but is not always feasible and can fail with time.^{19,58,59} Distal pancreatectomy for DPDS is difficult, virtually always requires splenectomy, results in loss of functional pancreatic tissue, and is associated with more blood loss and complications than internal drainage, though once patients recover, their DPDS is resolved.⁵⁸

Conclusions

A variety of options are available to surgeons caring for patients with NP. The treatment strategies highlighted in this review are those most commonly used during step-up management, although a multitude of variations exist. The emphasis should be on tailoring the therapeutic approach to the specific clinical scenario, and this review is designed to be useful for surgeons taking care of these patients.

ARTICLE INFORMATION

Accepted for Publication: September 28, 2022.

Published Online: November 16, 2022.
doi:10.1001/jamasurg.2022.5695

Author Contributions: Drs Maurer and Fagenholz had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: Both authors.
Acquisition, analysis, or interpretation

of data: Maurer.
Drafting of the manuscript: Both authors.
Critical revision of the manuscript for important intellectual content: Maurer.
Administrative, technical, or material support: Maurer.

Supervision: Fagenholz.

Conflict of Interest Disclosures: None reported.

REFERENCES

- Banks PA, Bollen TL, Dervenis C, et al; Acute Pancreatitis Classification Working Group. Classification of acute pancreatitis–2012: revision of the Atlanta classification and definitions by international consensus. *Gut*. 2013;62(1):102-111. doi:10.1136/gutjnl-2012-302779
- Besselink MGH, Verwer TJ, Schoenmaeckers EJP, et al. Timing of surgical intervention in necrotizing pancreatitis. *Arch Surg*. 2007;142(12):1194-1201. doi:10.1001/archsurg.142.12.1194
- Thoeni RF. The revised Atlanta classification of acute pancreatitis: its importance for the radiologist and its effect on treatment. *Radiology*. 2012;262(3):751-764. doi:10.1148/radiol.11110947
- van Grinsven J, van Brunschot S, van Baal MC, et al; Dutch Pancreatitis Study Group. Natural history of gas configurations and encapsulation in necrotic collections during necrotizing pancreatitis. *J Gastrointest Surg*. 2018;22(9):1557-1564. doi:10.1007/s11605-018-3792-z
- van Baal MC, Bollen TL, Bakker OJ, et al; Dutch Pancreatitis Study Group. The role of routine fine-needle aspiration in the diagnosis of infected necrotizing pancreatitis. *Surgery*. 2014;155(3):442-448. doi:10.1016/j.surg.2013.10.001
- Luckhurst CM, el Hechi M, Elsharkawy AE, et al. Improved mortality in necrotizing pancreatitis with a multidisciplinary minimally invasive step-up approach: comparison with a modern open necrosectomy cohort. *J Am Coll Surg*. 2020;230(6):873-883. doi:10.1016/j.jamcollsurg.2020.01.038
- van Grinsven J, van Dijk SM, Dijkgraaf MG, et al; Dutch Pancreatitis Study Group. Postponed or immediate drainage of infected necrotizing pancreatitis (POINTER trial): study protocol for a randomized controlled trial. *Trials*. 2019;20(1):239. doi:10.1186/s13063-019-3315-6
- Working Group IAP/APA Acute Pancreatitis Guidelines. IAP/APA evidence-based guidelines for the management of acute pancreatitis. *Pancreatology*. 2013;13(4)(suppl 2):e1-e15. doi:10.1016/j.pan.2013.07.063
- van Santvoort HC, Bakker OJ, Bollen TL, et al; Dutch Pancreatitis Study Group. A conservative and minimally invasive approach to necrotizing pancreatitis improves outcome. *Gastroenterology*. 2011;141(4):1254-1263. doi:10.1053/j.gastro.2011.06.073
- Leppäniemi A, Tolonen M, Tarasconi A, et al. 2019 WSES guidelines for the management of severe acute pancreatitis. *World J Emerg Surg*. 2019;14:27. doi:10.1186/s13017-019-0247-0
- Maatman TK, Mahajan S, Roch AM, et al. Disconnected pancreatic duct syndrome predicts failure of percutaneous therapy in necrotizing pancreatitis. *Pancreatology*. 2020;20(3):362-368. doi:10.1016/j.pan.2020.01.014
- Horvath K, Freeny P, Escallon J, et al. Safety and efficacy of video-assisted retroperitoneal debridement for infected pancreatic collections: a multicenter, prospective, single-arm phase 2 study. *Arch Surg*. 2010;145(9):817-825. doi:10.1001/archsurg.2010.178
- van Baal MC, van Santvoort HC, Bollen TL, Bakker OJ, Besselink MG, Gooszen HG; Dutch Pancreatitis Study Group. Systematic review of percutaneous catheter drainage as primary treatment for necrotizing pancreatitis. *Br J Surg*. 2011;98(1):18-27. doi:10.1002/bjs.7304
- Bakker OJ, van Santvoort HC, van Brunschot S, et al; Dutch Pancreatitis Study Group. Endoscopic transgastric vs surgical necrosectomy for infected necrotizing pancreatitis: a randomized trial. *JAMA*. 2012;307(10):1053-1061. doi:10.1001/jama.2012.276
- Collet PH, Doppl W, Padberg W. Endoscopic transgastric necrosectomy in necrotizing pancreatitis. *Video J Encyclopedia GI Endosc*. 2013;1(2):548-550. doi:10.1016/S2212-0971(13)70239-5
- Fong ZV, Fagenholz PJ. Minimally invasive debridement for infected pancreatic necrosis. *J Gastrointest Surg*. 2019;23(1):185-191. doi:10.1007/s11605-018-3908-5
- Fagenholz PJ, Thabet A, Mueller PR, Forcione DG. Combined endoscopic transgastric drainage and video assisted retroperitoneal pancreatic debridement: the best of both worlds for extensive pancreatic necrosis with enteric fistulae. *Pancreatology*. 2016;16(5):788-790. doi:10.1016/j.pan.2016.06.009
- Worhunsky DJ, Qadan M, Dua MM, et al. Laparoscopic transgastric necrosectomy for the management of pancreatic necrosis. *J Am Coll Surg*. 2014;219(4):735-743. doi:10.1016/j.jamcollsurg.2014.04.012
- Maatman TK, Zyromski NJ. Transgastric pancreatic debridement: a step-by-step guide to a single-staged procedure for walled-off pancreatic necrosis. *J Gastrointest Surg*. 2020;24(7):1720. doi:10.1007/s11605-019-04375-x
- Driedger M, Zyromski NJ, Visser BC, et al. Surgical transgastric necrosectomy for necrotizing pancreatitis: a single-stage procedure for walled-off pancreatic necrosis. *Ann Surg*. 2020;271(1):163-168. doi:10.1097/SLA.0000000000003048
- Madenci AL, Michailidou M, Chiou G, Thabet A, Fernández-del Castillo C, Fagenholz PJ. A contemporary series of patients undergoing open debridement for necrotizing pancreatitis. *Am J Surg*. 2014;208(3):324-331. doi:10.1016/j.amjsurg.2013.11.004
- Maatman TK, McGuire SP, Flick KF, et al. Outcomes in endoscopic and operative transgastric pancreatic debridement. *Ann Surg*. 2021;274(3):516-523. doi:10.1097/SLA.0000000000004997
- Baron TH, Thaggard WG, Morgan DE, Stanley RJ. Endoscopic therapy for organized pancreatic necrosis. *Gastroenterology*. 1996;111(3):755-764. doi:10.1053/gast.1996.v111.pm8780582
- Baron TH, Kozarek RA. Endotherapy for organized pancreatic necrosis: perspectives after 20 years. *Clin Gastroenterol Hepatol*. 2012;10(11):1202-1207. doi:10.1016/j.cgh.2012.07.009
- Papachristou GI, Takahashi N, Chahal P, Sarr MG, Baron TH. Peroral endoscopic drainage/debridement of walled-off pancreatic necrosis. *Ann Surg*. 2007;245(6):943-951. doi:10.1097/01.sla.0000254366.19366.69
- Bruennler T, Laggartner J, Lang S, et al. Outcome of patients with acute, necrotizing pancreatitis requiring drainage: does drainage size matter? *World J Gastroenterol*. 2008;14(5):725-730. doi:10.3748/wjg.14.725
- Liu P, Song J, Ke HJ, et al. Double-catheter lavage combined with percutaneous flexible endoscopic debridement for infected pancreatic necrosis failed to percutaneous catheter drainage. *BMC Gastroenterol*. 2017;17(1):155. doi:10.1186/s12876-017-0717-3
- Kohli P, Gupta V, Kochhar R, Yadav TD, Sinha SK, Lal A. Lavage through percutaneous catheter drains in severe acute pancreatitis: does it help? a randomized control trial. *Pancreatology*. 2019;19(7):929-934. doi:10.1016/j.pan.2019.09.003
- Sleeman D, Levi DM, Cheung MC, et al. Percutaneous lavage as primary treatment for infected pancreatic necrosis. *J Am Coll Surg*. 2011;212(4):748-752. doi:10.1016/j.jamcollsurg.2010.12.019
- Fong ZV. Video assisted retroperitoneal debridement of pancreatic necrosis by Peter J Fagenholz, MD. YouTube. Posted December 22, 2017. Accessed October 17, 2021. <https://www.youtube.com/watch?v=9ErPBAnrOAU>
- Carter CR, McKay CJ, Imrie CW. Percutaneous necrosectomy and sinus tract endoscopy in the management of infected pancreatic necrosis: an initial experience. *Ann Surg*. 2000;232(2):175-180. doi:10.1097/0000658-200008000-00004
- Fong ZV. Sinus tract endoscopic debridement of pancreatic necrosis by Peter J Fagenholz, MD. YouTube. Posted December 11, 2017. Accessed October 24, 2021. <https://www.youtube.com/watch?v=eO5-SVI-7rA>
- Maatman TK, Flick KF, Roch AM, Zyromski NJ. Operative pancreatic debridement: contemporary outcomes in changing times. *Pancreatology*. 2020;20(5):968-975. doi:10.1016/j.pan.2020.05.024
- Parekh D. Laparoscopic-assisted pancreatic necrosectomy: a new surgical option for treatment of severe necrotizing pancreatitis. *Arch Surg*. 2006;141(9):895-902. doi:10.1001/archsurg.141.9.895
- Maatman TK, Roch AM, Ceppa EP, et al. The continuum of complications in survivors of necrotizing pancreatitis. *Surgery*. 2020;168(6):1032-1040. doi:10.1016/j.surg.2020.07.004
- Wei AL, Guo Q, Wang MJ, Hu WM, Zhang ZD. Early complications after interventions in patients with acute pancreatitis. *World J Gastroenterol*. 2016;22(9):2828-2836. doi:10.3748/wjg.v22.i9.2828
- Maatman TK, Heimberger MA, Lewellen KA, et al. Visceral artery pseudoaneurysm in necrotizing pancreatitis: incidence and outcomes. *Can J Surg*. 2020;63(3):E272-E277. doi:10.1503/cjs.009519
- Beattie GC, Hardman JG, Redhead D, Siriwardena AK. Evidence for a central role for selective mesenteric angiography in the management of the major vascular complications of pancreatitis. *Am J Surg*. 2003;185(2):96-102. doi:10.1016/S0002-9610(02)01199-6
- Bergert H, Hinterseher I, Kersting S, Leonhardt J, Bloomenthal A, Saeger HD. Management and outcome of hemorrhage due to arterial pseudoaneurysms in pancreatitis. *Surgery*. 2005;137(3):323-328. doi:10.1016/j.surg.2004.10.009
- Gambiez LP, Ernst OJ, Merlier OA, Porte HL, Chambon JPM, Quandalle PA. Arterial embolization for bleeding pseudocysts complicating chronic pancreatitis. *Arch Surg*. 1997;132(9):1016-1021. doi:10.1001/archsurg.1997.01430330082014
- Luckhurst CM, El Hechi M, Maurer LR, et al. Treatment and prevention of intraabdominal bleeding in necrotizing pancreatitis patients treated

- with a step-up approach. *Pancreas*. 2022;51(5):516-522. doi:10.1097/MPA.0000000000002067
42. Jiang W, Tong Z, Yang D, et al. Gastrointestinal fistulas in acute pancreatitis with infected pancreatic or peripancreatic necrosis: a 4-year single-center experience. *Medicine (Baltimore)*. 2016;95(14):e3318. doi:10.1097/MD.0000000000003318
43. Ahmad DS, Mansoor E, Alikhan MM, et al. Risk of venous thromboembolism in acute necrotizing pancreatitis: a large database study. *Pancreas*. 2021;50(1):71-76. doi:10.1097/MPA.0000000000001714
44. Maatman TK, McGuire SP, Lewellen KA, et al. Prospective analysis of the mechanisms underlying ineffective deep vein thrombosis prophylaxis in necrotizing pancreatitis. *J Am Coll Surg*. 2021;232(1):91-100. doi:10.1016/j.jamcollsurg.2020.08.774.
45. Zhou J, Zhang H, Mao W, et al. Efficacy and safety of early systemic anticoagulation for preventing splanchnic thrombosis in acute necrotizing pancreatitis. *Pancreas*. 2020;49(9):1220-1224. doi:10.1097/MPA.0000000000001661
46. Hajibandeh S, Hajibandeh S, Agrawal S, Irwin C, Obeidallah R, Subar D. Anticoagulation versus no anticoagulation for splanchnic venous thrombosis secondary to acute pancreatitis: do we really need to treat the incidental findings? *Pancreas*. 2020;49(9):e84-e85. doi:10.1097/MPA.0000000000001644
47. van Santvoort HC, Besselink MG, Bakker OJ, et al; Dutch Pancreatitis Study Group. A step-up approach or open necrosectomy for necrotizing pancreatitis. *N Engl J Med*. 2010;362(16):1491-1502. doi:10.1056/NEJMoA0908821
48. Hollemans RA, Bakker OJ, Boermeester MA, et al; Dutch Pancreatitis Study Group. Superiority of step-up approach vs open necrosectomy in long-term follow-up of patients with necrotizing pancreatitis. *Gastroenterology*. 2019;156(4):1016-1026. doi:10.1053/j.gastro.2018.10.045
49. Haney CM, Kowalewski KF, Schmidt MW, et al. Endoscopic versus surgical treatment for infected necrotizing pancreatitis: a systematic review and meta-analysis of randomized controlled trials. *Surg Endosc*. 2020;34(6):2429-2444. doi:10.1007/s00464-020-07469-9
50. Fong ZV, Peev M, Warshaw AL, et al. Single-stage cholecystectomy at the time of pancreatic necrosectomy is safe and prevents future biliary complications: a 20-year single institutional experience with 217 consecutive patients. *J Gastrointest Surg*. 2015;19(1):32-37. doi:10.1007/s11605-014-2650-x
51. Maurer LR, Maatman TK, Luckhurst CM, Horvath KD, Zyromski NJ, Fagenholz PJ. Risk of gallstone-related complications in necrotizing pancreatitis patients treated with a step-up approach: the experience of two tertiary care centers. *Surgery*. 2021;169(5):1086-1092. doi:10.1016/j.surg.2020.11.002
52. Ackermann TG, Cashin PA, Alwan M, et al. The role of laparoscopic cholecystectomy after severe and/or necrotic pancreatitis in the setting of modern minimally invasive management of pancreatic necrosis. *Pancreas*. 2020;49(7):935-940. doi:10.1097/MPA.0000000000001601
53. Hallensleben ND, Timmerhuis HC, Hollemans RA, et al; Dutch Pancreatitis Study Group. Optimal timing of cholecystectomy after necrotizing biliary pancreatitis. *Gut*. 2022;71(5):974-982. doi:10.1136/gutjnl-2021-324239
54. Fischer TD, Gutman DS, Hughes SJ, Trevino JG, Behrns KE. Disconnected pancreatic duct syndrome: disease classification and management strategies. *J Am Coll Surg*. 2014;219(4):704-712. doi:10.1016/j.jamcollsurg.2014.03.055
55. Sandrasegaran K, Tann M, Jennings SG, et al. Disconnection of the pancreatic duct: an important but overlooked complication of severe acute pancreatitis. *Radiographics*. 2007;27(5):1389-1400. doi:10.1148/rg.275065163
56. Chen Y, Jiang Y, Qian W, et al. Endoscopic transpapillary drainage in disconnected pancreatic duct syndrome after acute pancreatitis and trauma: long-term outcomes in 31 patients. *BMC Gastroenterol*. 2019;19(1):54. doi:10.1186/s12876-019-0977-1
57. Varadarajulu S, Noone TC, Tutuian R, Hawes RH, Cotton PB. Predictors of outcome in pancreatic duct disruption managed by endoscopic transpapillary stent placement. *Gastrointest Endosc*. 2005;61(4):568-575. doi:10.1016/S0016-5107(04)02832-9
58. Maatman TK, Roch AM, Lewellen KA, et al. Disconnected pancreatic duct syndrome: spectrum of operative management. *J Surg Res*. 2020;247:297-303. doi:10.1016/j.jss.2019.09.068
59. Howard TJ, Rhodes GJ, Selzer DJ, Sherman S, Fogel E, Lehman GA. Roux-en-Y internal drainage is the best surgical option to treat patients with disconnected duct syndrome after severe acute pancreatitis. *Surgery*. 2001;130(4):714-719. doi:10.1067/msy.2001.116675