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Necrosectomy in the Management of Necrotizing Pancreatitis

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Keywords

- Necrotizing pancreatitis • Walled-off pancreatic necrosis
- Pancreatic debridement • Necrosectomy • Step-up approach
- Video assisted retroperitoneal debridement (VARD)
- Minimally invasive retroperitoneal pancreatectomy (MIRP)
- Transgastric necrosectomy (TGN)

Key points

- Percutaneous or endoscopic drainage can be performed to bridge critically ill patients to definitive debridement (surgical and endoscopic step-up approaches).
- Anatomic location of walled-off pancreatic necrosis can dictate treatment:
  - Retrogastric collections are amenable to transgastric interventions (endoscopic or surgical drainage/debridement).
  - Collections located in the paracolic gutter are appropriate for retroperitoneal percutaneous drainage and/or debridement.
- Surgical transgastric necrosectomy is an effective single-stage debridement procedure, with creation of a large cystgastrostomy that allows ongoing internal auto-debridement.

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INTRODUCTION

Necrotizing pancreatitis and walled-off pancreatic necrosis (WOPN) is a devastating condition, occurring in approximately 20% of patients diagnosed with pancreatitis [1–3]. Infected necrosis confers an associated mortality reported as high as 30% to 40% [1,2]. Management of this disease process has evolved substantially over the past three decades, and multidisciplinary decision-making for WOPN is an essential element in the modern care of pancreatitis [1].

Owing to varying patterns of disease, there is no single ideal approach for management of WOPN. Instead, interventions are tailored individually to each patient based on clinical status, anatomy, and nature of WOPN contents [2,4,5]. The purpose of this review is to provide an overview on the evolution of surgical debridement as well as the latest practices and techniques for the management of pancreatic necrosis.

BACKGROUND AND DEFINITIONS

Necrotizing pancreatitis is a disease spectrum with respect to the maturity, quality, and sterility of any given collection [6,7]. These characteristics vary from patient to patient in the development of WOPN, necessitating a variable approach to management. It is critical that the vocabulary used to describe necrotizing pancreatitis be precisely defined because the terminology impacts clinical data interpretation and, therefore, management. If a collection is erroneously labeled a "pseudocyst" on an imaging report but is in fact semi-solid necrosis, this error may have substantial clinical significance.

The most recent revision of the Atlanta classification for acute pancreatitis defines four major categories of acute pancreatitis based on clinical symptoms, severity, and radiographic findings [6] (Fig. 1). *Acute peripancreatic fluid collection* is defined as peripancreatic fluid present in the early stage of acute (<4 weeks) interstitial edematous pancreatitis, without evidence of necrosis, pseudocyst, or pancreatic extension. This peripancreatic fluid is described as homogenous fluid density without a defined wall on computed tomography (CT) imaging. When the peripancreatic fluid collection persists beyond 4 weeks and develops a well-defined mature wall, the well-circumscribed homogenous fluid collection is now called a pancreatic pseudocyst. These collections are predominantly comprised of fluid, without a solid component and associated with minimal necrosis [6].

A heterogenous collection of fluid and solid pancreatic and/or peripancreatic necrosis is an *acute necrotic collection*. These collections develop early (<4 weeks) in the course of necrotizing pancreatitis and have not yet matured a well-defined wall. The major distinction between acute peripancreatic fluid collection and acute necrotic collection is the presence of pancreatic and/or

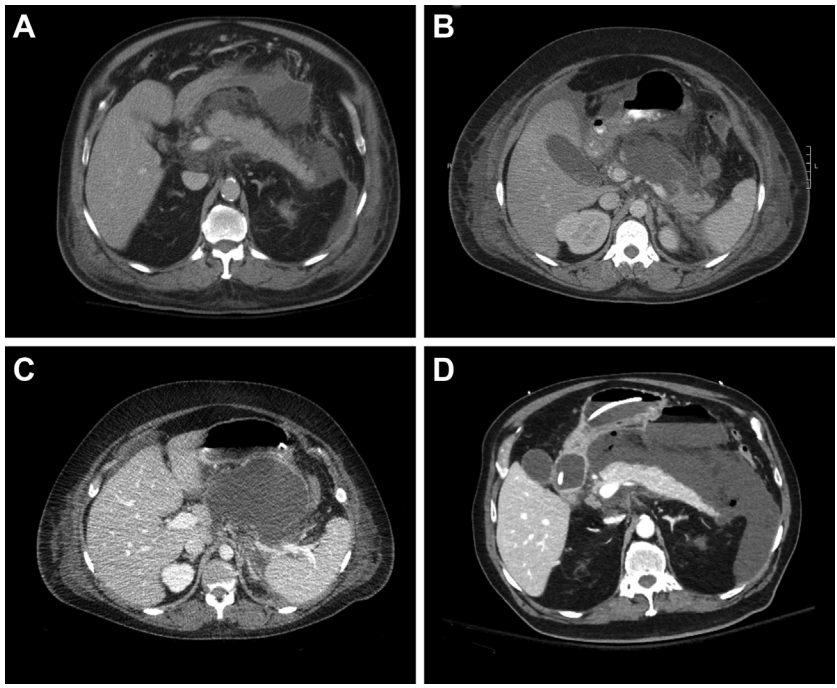

Fig. 1. Stages of necrotizing pancreatitis. Computed tomography (CT) imaging depicting the stages of necrotizing pancreatitis. (*A*) Acute pancreatitis with *peripancreatic fluid collection*; (*B*) necrotizing pancreatitis with an *acute necrotic collection* and a viable pancreatic tail; (*C*) necrotizing pancreatitis with *walled-off necrosis* abutting the posterior wall of the stomach; (*D*) necrotizing pancreatitis with gas bubbles throughout the collection, indicative of *infected necrosis*.

peripancreatic necrosis that is absent in the former [6]. An acute necrotic collection that persists beyond 4 weeks develops into *walled-off necrosis*, after maturation of a well-defined enhancing wall that encapsulates the pancreatic and/or peripancreatic necrosis. The presence of gas within necrotizing pancreatitis on imaging or clinical deterioration can be used to diagnose *infected necrosis* [6]. While CT is widely used in the diagnosis, staging and treatment of necrotizing pancreatitis, MRI is superior in evaluating walled-off necrosis for the quantity for solid debris versus liquid contents as well as pancreatic duct integrity [4,8–11] (Fig. 2). Because of MRI's advantage in detecting solid debris, unstable anatomy, and extent of pancreatic necrosis over CT imaging, MRI is a tool that can aid in directing treatment toward debridement over percutaneous drainage for a collection with solid necrosis [10,11].

INDICATIONS AND TIMING FOR NECROSECTOMY

Confirmed infected pancreatic necrosis usually requires intervention, in the form of drainage and/or pancreatic debridement [1,4,5]. Necrosectomy is

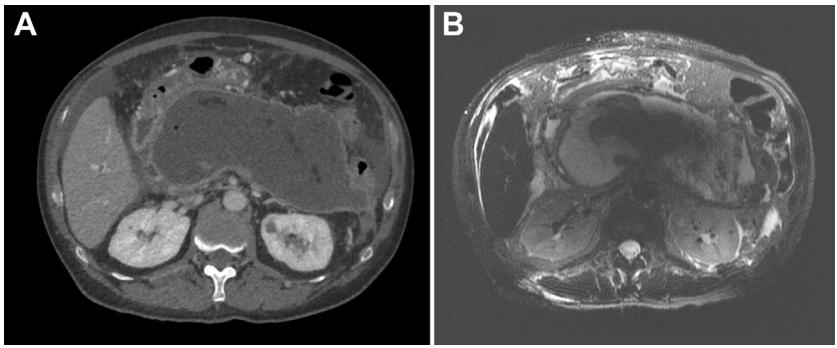

Fig. 2. Necrotizing pancreatitis CT versus MRI. Comparison of (*A*) computed tomography imaging, in contrast to (*B*) MRI. The MRI T2 weighted phase is the best modality for visualizing the heterogeneity of solid debris and liquid necrosis present in walled-off pancreatic necrosis.

recommended for cases with clinical suspicion of infected necrosis as well as necrotizing pancreatitis with deteriorating or persistent organ failure in the absence confirmed infection [1,4,12]. Routine fine needle aspiration is rarely required for diagnosis of infected necrosis, as clinical symptoms of deterioration or persistent sepsis and radiologic findings are generally adequate [1,4,5,12–14].

Additional indications for necrosectomy include:

- ''Persistent unwellness,'' a constellation of symptoms first described by Andrew Warshaw [15], consisting of persistent pain, inability to tolerate diet resulting in weight loss/nutritional failure, and/or low-grade systemic illness [1,4,5].
- Unstable anatomy (disconnected duct syndrome), a phenomenon that manifests when necrosis occurs in the pancreatic neck or body, disrupting the pancreatic duct. This results in complete transection and discontinuity of the pancreatic duct, with a persistent pancreatic fistula at the pancreatic remnant [1,4,5,16].
- In rare cases, WOPN (infected or sterile) may be associated with abdominal compartment syndrome, acute bleeding, bowel ischemia, and obstructive symptoms due to mass effect, requiring urgent or emergent intervention [1,4].

A small number of patients will have limited infected necrosis that is not anatomically accessible through percutaneous, endoscopic or surgical means for drainage and/or debridement. In these cases, antibiotics alone may be adequate in management of infected WOPN in clinically stable patients [1,12,17–20]. This typically requires a prolonged recovery period with long duration of antibiotic therapy. The mean duration of antibiotics ranges from 27 to 56 days across multiple retrospective studies [19,20]. In addition, intervention is not required for asymptomatic WOPN, as these collections will typically resolve without intervention. Prior studies have noted that 45% to 70% of patients will remain asymptomatic, and complete regression can be expected in 30% to 68% after a mean period of 6 months [21–23].

There is consensus that intervention should be delayed until approximately 4 weeks after the onset of pancreatitis whenever possible [1,4,5,12]. This allows for liquification of the necrotic collection and development of a mature wall [6,24]. Occasionally, intervention may be necessary within 4 weeks, such as the emergency scenarios outlined previously or early infected necrosis with clinical deterioration despite optimized medical therapy. Early intervention is associated with worse clinical outcomes, specifically for open necrosectomy [1,5,25–27]. However, earlier intervention by percutaneous or endoscopic means may be acceptable source control [28], and there is currently a prospective trial evaluating early drainage of WOPN [29].

The Dutch Pancreatitis Study Group is currently conducting the POINTER trial to better define the ideal timing of intervention by randomizing patients to immediate (early) versus delayed percutaneous drainage of necrotizing pancreatitis [29]. The authors recruited 104 patients (55 immediate, 49 delayed drainage). There was approximately 1-day delay between randomization and drainage in the immediate drainage arm, as opposed 9 days in the delayed drainage cohort. Preliminary results noted no significant difference in new-onset organ failure, morbidity, and mortality between the two cohorts. However, 39% of patients in the postponed cohort did not require any drainage intervention, and patients who underwent immediate drainage required an increased number of interventions [30]. This study supports the notion that delayed intervention is preferred, but if early intervention is absolutely necessary, drainage is feasible.

APPROACHES TO NECROSECTOMY

While open necrosectomy has traditionally been considered the "gold standard," the approach to interventional management of WOPN has evolved

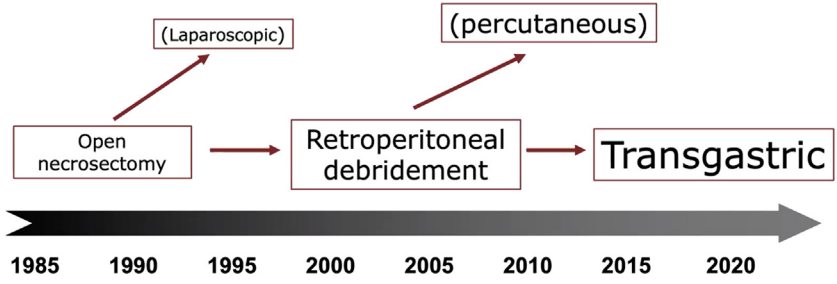

Fig. 3. Timeline and evolution of necrosectomy. Open necrosectomy was the traditional gold standard for debridement of walled-off pancreatic necrosis. Laparoscopic debridement was explored as an alternative technique that resulted in less surgical trauma, but this technique was limited. Attention turned to retroperitoneal debridement, combining percutaneous drainage and surgical debridement into the step-up approach for retroperitoneal collections. The transgastric approach, surgical debridement in particular, gained recognition as a single-stage procedure for retrogastric collections and circumvents the need for percutaneous drains.

Box 1: Anatomic considerations

Location of pancreatic necrosis is a key factor in guiding management:

- Collections involving the pancreatic tail that extend into the paracolic gutter would most benefit from retroperitoneal approach, with percutaneous drainage, followed by minimally invasive retroperitoneal pancreatic debridement (MIRP) or video-assisted retroperitoneal debridement (VARD) if necessary.
- Collections contained within the lesser sac that interface with the posterior gastric wall can be approached in a transgastric fashion – either open, laparoscopic or endoscopic.
- Collections isolated to the root of the mesentery may not be accessible percutaneously and instead, may require traditional open necrosectomy or laparoscopic transperitoneal approach
- Patients with limited collections should be considered for antibiotics alone. While this commits the patient to a prolonged course of antibiotics, this would potentially avoid the high risk of morbidity associated with formal necrosectomy.
- Patients with isolated tail remnants are best managed by surgical as opposed to endoscopic methods.

considerably over time [12] (Fig. 3). Percutaneous, endoscopic, and laparoscopic approaches have been explored as minimally invasive options with the objective of reducing morbidity and mortality associated with open necrosectomy [1,4,5]. Owing to the heterogeneity of the disease process, there is no "one-size fits all" treatment. Treatment should be tailored toward each individual patient, based on clinical status, anatomic location (Box 1), as well as quality (solid vs liquid) of pancreatic necrosum [2,4,5] (Fig. 4). The remainder of this review will focus on the approaches and evolution of necrosectomy for walled-off pancreatic necrosis.

Open necrosectomy

A variety of open necrosectomy techniques have been described, usually including repeated trips to the operating room and complex irrigation/drainage systems [31–33]. However, these approaches were associated with significant physiologic stress and subsequent morbidity including pancreatic insufficiency, pancreatic fistula, and incisional hernia [1,34–36]. Historically, the rate of morbidity after open necrosectomy approached 60% to 90%, while mortality has previously ranged from 25% to 60% [25,35–38]. Modern series have demonstrated improvement in mortality, now ranging from 4% to 18% [36,39,40]. A large contemporary series from University of Indiana reported outcomes of 116 patients who underwent open necrosectomy between 2006 and 2018, including 74% open debridement and 26% open transgastric necrosectomy. Morbidity ranged from 48% to 88% (for elective and urgent/emergent cases, respectively), and mortality was approximately 2%. The authors

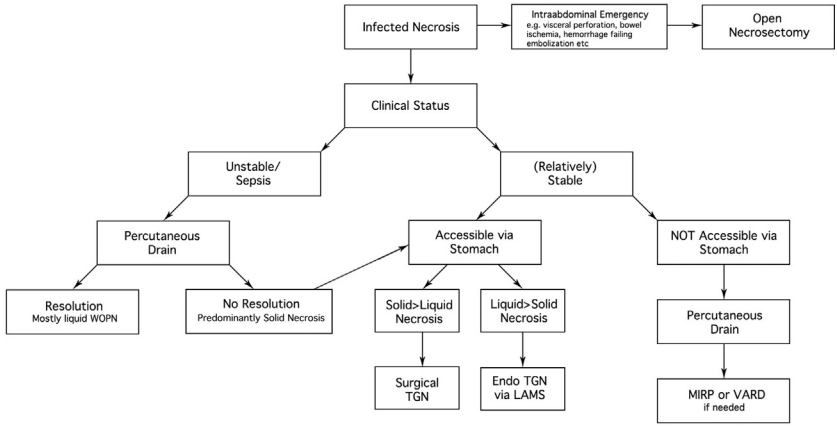

Fig. 4. Algorithm of Treatment Management for Walled-off Pancreatic Necrosis. Management is tailored individually to each patient based on clinical status, anatomic location of necrosis (accessible via the stomach or not), the maturity of the necrosis, quality of contents (from largely liquid to largely solid) and the state of infection (from sterile to profound sepsis). *Abbreviations:* LAMS, lumen-apposing metal stent; MIRP, minimally invasive retroperitoneal pancreatectomy; TGN, transgastric necrosectomy; VARD, video-assisted retroperitoneal debridement.

cited better understanding of the disease process and improvements in critical care of severe disease leading to decreased mortality [36].

With technological advances in laparoscopic and endoscopic techniques, open debridement has faded into the background. While minimally invasive techniques have largely replaced open surgery, there remain instances where open surgery is unavoidable. Laparotomy may be required in cases of associated intraabdominal emergencies, such as abdominal compartment syndrome, perforation of a visceral organ, and hemorrhage that cannot be controlled with angiography [24]. In addition, there is a small subset of patients who fail minimally invasive management and thus require a "salvage" open debridement for ongoing organ failure and infection [36].

Laparoscopic necrosectomy

It has been established that less invasive approaches result in less profound inflammatory response and decreased physiologic stress [1,5]. Laparoscopic transperitoneal debridement of WOPN was explored as a minimally invasive alternative in an effort to mitigate the postoperative morbidity and mortality associated with open necrosectomy [41]. The components of this strategy are described in the following steps [41–46]:

1. Pneumoperitoneum is established, and diagnostic laparoscopy is performed.
2. An additional 2 to 3 trocars are placed under direct vision.
3. For WOPN involving the head and/or body of the pancreas, the gastrocolic ligament is opened, and the retroperitoneum is exposed to access the necrosum.

4. For collections located in the tail of the pancreas, the mesocolon is opened at the root of the mesentery, to the left of the middle colic artery adjacent to the ligament of Treitz.
5. The necrotic collection is bluntly debrided with laparoscopic graspers or spoon forceps and the necrosum evacuated in an endoscopic specimen bag.
6. The pancreatic cavity is irrigated, and drains are left for postoperative lavage.

Retrospective cohort studies report morbidity of approximately 20% and mortality from 4% to 18% [12,42,44,45,47,48]. Among the largest series published, Tan and colleagues compared laparoscopic approach (n = 25) to a historical cohort (n = 51) and found that although operative time was significantly longer (157 min vs 127 min), there was less morbidity in the laparoscopic cohort [45]. The literature supporting this technique is limited to retrospective case series.

Laparoscopic necrosectomy is limited by several factors: the rigidity of laparoscopic instruments which is difficult working with in a cavity; the size of laparoscopic spoon forceps can make debriding solid necrosis tedious; laparoscopic suction devices are susceptible to obstruction when evacuating semi-solid and/or viscous liquid necrosis; and inability to control bleeding or hemorrhage. In addition, laparoscopic transperitoneal debridement risks potentially ''un-walling off'' (unroofing) the previously walled-off necrosis and an inadequate debridement would potentially disseminate the infection into the abdominal cavity [24,46]. In addition, this approach commits the patient to several weeks to months of multiple drains and irrigations, impacting patient quality of life.

This technique has largely fallen out of favor. Nonetheless, there may occasionally be a patient with infected necrosis that is not accessible via the gastric lumen or percutaneously (very centrally in the root of the mesentery) for which selecting this approach may be most appropriate [24].

Retroperitoneal debridement

Around the same time in the 2000s, transcutaneous retroperitoneal surgical debridement was explored as an alternative minimally invasive approach. Several techniques arose from this period, which all follow similar basic

Box 2: Surgical pearls for retroperitoneal debridement

Principles of performing retroperitoneal debridement:

- This technique targets retroperitoneal collections involving the tail, localized in between the spleen and kidney, as well as right sided collections, located behind the pancreatic head.
- Preoperative percutaneous drain placement creates a tract that is serially dilated or upsized for surgical instruments to traverse during surgical debridement.
- Patients may require multiple trips to the operating room for repeat debridements. Drains remain in place until complete resolution (clearance) of walled-off necrosis.

principles of establishing and performing debridement through a percutaneous tract into the WOPN [12] (Box 2). These techniques vary based on entry into the retroperitoneum:

- *Minimally invasive retroperitoneal pancreatectomy* (MIRP) first involved percutaneous drain placement into the collection of pancreatic necrosis. This tract is then serially dilated under radiologic guidance—typically to 30 Fr, which allows the use of an operating nephroscope through a 30 Fr Amplatz sheath. The nephroscope contains two channels, which allows debridement with small forceps and irrigation [24,49–51] (Fig. 5). However, debridement is slow because of the size limitations imposed by the nephroscopic instruments and the sheath. For very large collections, we use a two-trocar technique. This requires two percutaneous drains placed under radiographic guidance with insertion sites separated by approximately 3 to 4 cm. One drain is dilated to 30 Fr to allow the use of a nephroscope, similar to MIRP, while a wire is placed through the other. Using fluoroscopy and water irrigation via the nephroscope, a tract is created connecting to the wire. Under direct vision of the nephroscope, the drains are replaced with Versastep (Medtronic) trocars along the wire to ensure trocar placement into the collection. The nephroscope is then switched out for a laparoscope, the cavity is insufflated with carbon dioxide, and debridement can proceed more efficiently with 10-mm laparoscopic stone forceps [24,52,53].
- *Video-assisted retroperitoneal debridement* (VARD) similarly requires percutaneous drain placement that is upsized to 18 Fr. A 3- to 5-cm flank incision is created over the drain insertion site, and the drain tract is followed into the walled-off necrosis, guided by a laparoscope. Renal vein retractors can be used for exposure. Debridement is performed using ring forceps and suction [54,55].

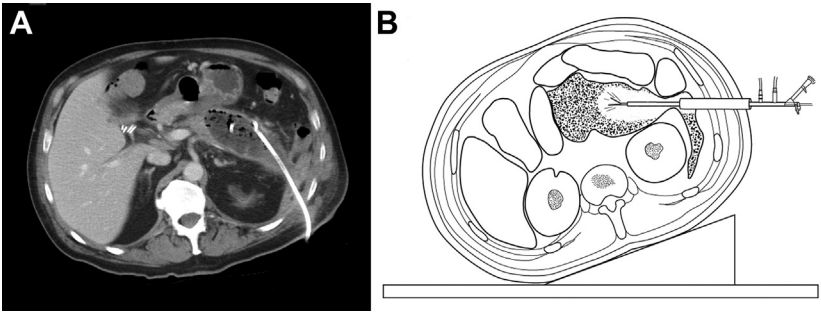

Fig. 5. Minimally invasive retroperitoneal pancreatectomy. (*A*) Computed tomographic axial imaging of walled-off pancreatic collection that does not have any contact with the stomach. There is a percutaneous drain entering the collection from the retroperitoneum. (*B*) During a minimally invasive retroperitoneal pancreatic necrosectomy (MIRP), the drain is replaced with a sheath, through which a nephroscope with two working channels (light source and forceps) can be placed for debridement.

These techniques generally require multiple trips to the operating room for repeat debridement, with several cohort studies reporting an average of 3 interventions. In addition, these studies found that retroperitoneal debridement seemingly resulted in decreased morbidity (10%–20%) and mortality (0%–20%, and even as high as 40% in one series) compared with historic series of open debridement [35,49,54,56–59].

In 2010, the Dutch Pancreatitis Study Group published the landmark PANTER study comparing their "Step-Up" approach (percutaneous drainage, followed by VARD as necessary) versus open necrosectomy. In this trial, 378 patients were enrolled, and 88 underwent randomization, of which 45 patients underwent primary open necrosectomy, while 43 patients were treated with the step-up approach. While neither mortality nor length of stay differed between groups, morbidity was reduced in the step-up arm, specifically incisional hernia and new-onset diabetes. Notably, 35% of patients who underwent initial percutaneous drainage improved without requiring any surgical intervention.

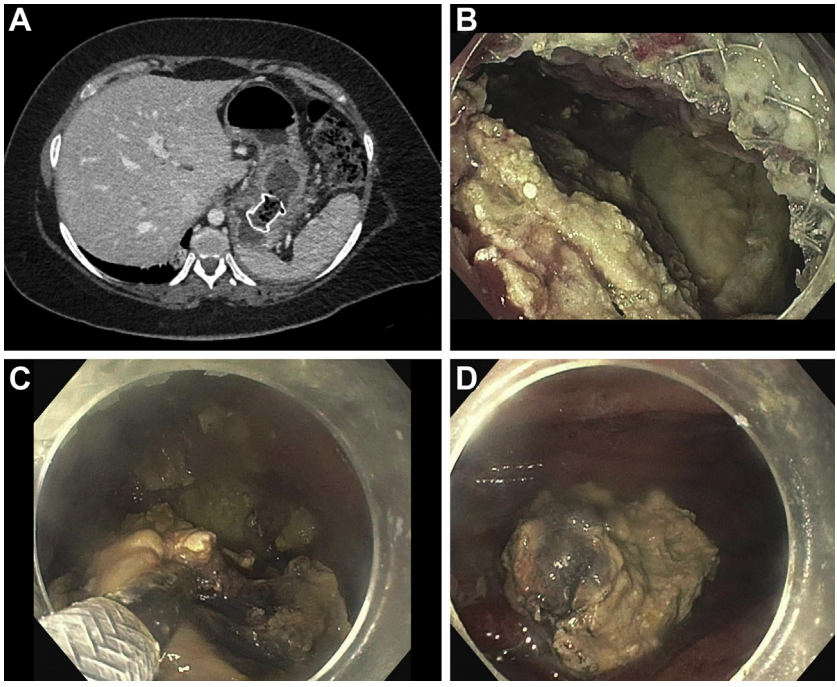

Fig. 6. Endoscopic transgastric necrosectomy. (*A*) Computed tomographic imaging of an AXIOS (Boston Scientific) lumen-apposing metal stent (LAMS) placed transmurally across the posterior gastric wall into the walled-off pancreatic necrosis. (*B*) Endoscopic view of the walled-off pancreatic necrosis through the LAMS. (*C,D*) Debridement of the white necrotic pancreatic tissue and evacuation of purulence is performed through the stent.

Overall, given the reduced morbidity of the step-up approach, this strategy was considered to be superior to traditional open necrosectomy [54].

Endoscopic transgastric drainage and necrosectomy

Shortly thereafter, endoscopic (transluminal) drainage gained recognition as an alternative minimally invasive nonsurgical approach for retrogastric WOPN. This technique entails endoscopic access to the stomach and transmural intervention into the necrotic collection through the posterior stomach or duodenal wall (under ultrasound assistance) [12,24]. The tract is dilated so pigtail drains or lumen-apposing metal stents (LAMS) can be placed to create a cystgastrostomy [60,61] (Fig. 6). Through this channel, debridement and lavage can be carried out with a variety of endoscopic instruments, such as forceps, balloons, baskets, irrigation, and suction catheters [12,24].

Then, the Dutch Pancreatitis Study Group evaluated an endoscopic step-up approach (initial endoscopic catheter drainage with two 7 Fr pigtail stents and one nasocystic drain, followed by endoscopic transluminal necrosectomy if no clinical improvement) head-to-head with the surgical step-up approach (percutaneous drainage, followed by VARD, if necessary) in the TENSION trial. Of the 418 patients screened, 98 patients were enrolled into the study, of which 47 were assigned to the previously established step-up arm, and the remaining 51 patients were randomized to the endoscopic step-up approach. Only 1 of 4 patients screened were enrolled, indicating that this is a highly selected group of patients with WOPN that was anatomically feasible for both endoscopic and retroperitoneal approaches [55].

The authors found no difference in major morbidity, mortality, or number of interventions. However, there was a lower rate of pancreatic fistula and shorter postoperative hospital stay (by 16 days, 53 vs 69 days) in the endoscopic cohort. Similar to the PANTER trial, there was a subset of patients within each cohort that did not require additional necrosectomy after initial drainage (51%). This randomized controlled trial confirmed prior observational studies' findings that endoscopic transgastric drainage resulted in fewer complications (namely, pancreatic fistula) and shorter hospitalizations than surgical and step-up approaches [55].

It should be noted that pigtail drains are limited in their ability to fully drain thick, viscous fluid or solid debris, and stents are susceptible to solid debris clogging the channel lumen. However, the technology is improving. Presently, 20 mm is the largest lumen size for the current existing AXIOS (Boston Scientific) LAMS approved for endoscopic transgastric necrosectomy [62]. In addition to traditional endoscopic instruments, the EndoRotor (Interscope Medical) is a novel mechanical instrument that combines the use of a rotating cutting blade and suction for tissue dissection and resection [63,64]. However, endoscopic debridement typically requires multiple sessions to achieve complete debridement if there is a significant quantity of true solid necrosis (rather than largely liquid contents with a limited solid component). While the clinical trials found a median of 3 (IQR 2–6 in both series) interventions necessary, a

systematic review found an average of 4 interventions from 14 retrospective studies, which ranged from as low as 1 intervention to as high as 15 endoscopic reinterventions [65]. It should be noted that patients who undergo endoscopic LAMS placement must undergo at least one additional endoscopy for stent removal. Currently, the European Society of Gastrointestinal Endoscopy recommends LAMS retrieval within 4 weeks [14,66], but there is limited evidence on optimal timing as removal timing ranges between 1 to 20 weeks across multiple studies [66]. While endoscopic drainage is an appealing approach that allows internal debridement without requiring a drain or risk of pancreatic fistula, this technique remains limited in its ability to resolve large, solid collections and the necessity for multiple endoscopic interventions.

Surgical transgastric necrosectomy

A solution to the limitations of endoscopic necrosectomy is surgical transgastric debridement with the creation of a larger cystgastrostomy, allowing for a more efficient debridement. Surgical transgastric necrosectomy (TGN) can be performed via laparoscopy or laparotomy, with the same fundamental principles of debridement [67–69] (Box 3).

Open transgastric necrosectomy is performed through a short upper midline laparotomy. Intraoperative ultrasound remains a critical component in identifying the extent of necrosis and planning gastrotomy. Anterior and posterior gastrostomies are created with electrocautery or ultrasonic shears. Debridement is performed with a combination gentle, blunt dissection, and irrigation. It is worth noting that debridement should be focused on necrosis that is loose and can be easily freed. The anterior gastrostomy is sutured closed. If indicated, a cholecystectomy can be performed before or after the debridement [67,68].

Box 3: Surgical pearls for transgastric debridement

Principles of performing transgastric necrosectomy:

- This technique requires a large area of contact between the collection of walled-off pancreatic necrosis and the posterior gastric wall.
- Use intraoperative ultrasound against the posterior wall of the stomach to localize the area of walled-off pancreatic necrosis. Confirmation of necrosum can be performed with needle aspiration prior to creation of cystgastrostomy.
- Cystgastrostomy can be performed with the LigaSure (Covidien) and reinforced with staples or suture, to promote hemostasis in the setting of varices as well as adherence between the stomach and walled-off pancreatic necrosis.
- Delaying transgastric debridement by approximately 4 weeks from onset of necrotizing pancreatitis will allow for development of a mature wall around the necrosum. This also promotes adherence of the necrosum to the posterior wall of the stomach and ease in creation of cystgastrostomy.
- Surgical transgastric debridement allows for single stage necrosectomy with ongoing internal drainage of remaining necrosum through wide surgical cystgastrostomy.

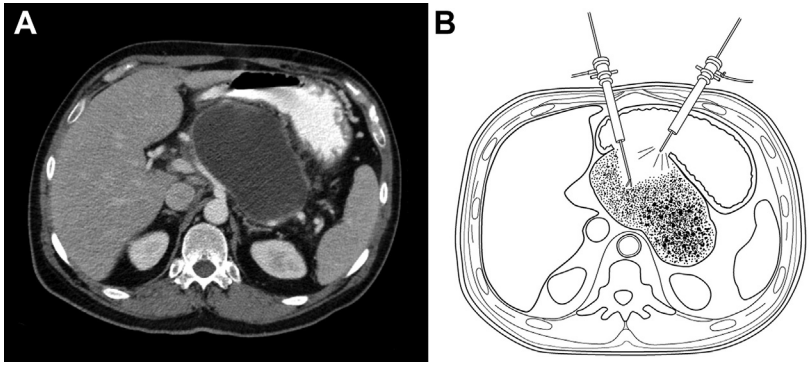

Fig. 7. Surgical transgastric necrosectomy. (*A*) Computed tomography axial imaging of a large retrogastric walled-off pancreatic collection with a large area of contact with the posterior gastric wall. (*B*) During laparoscopic transgastric necrosectomy, after obtaining pneumoperitoneum, the stomach is insufflated to achieve contact between the anterior stomach and abdominal wall so that radially dilating trocars can be placed directly into the stomach. A laparoscope and other instruments are used to proceed with debridement.

The "MIS" correlate, *laparoscopic transgastric necrosectomy*, is performed by the following steps [68,69] (Fig. 7, Video 1):

1. Endoscopic gastroscopy is performed first, then the abdomen is accessed laparoscopically through the umbilicus, and potential sites for transgastric trocars are identified.
2. The stomach is maximally insufflated with the endoscope, and intraabdominal insufflation is lowered to allow contact between the abdominal wall and anterior gastric wall.
3. Under direct laparoscopic and endoscopic vision, 2 to 3 Versastep (Medtronic) trocars are placed through the anterior abdominal wall and anterior gastric wall to access the gastric lumen.
4. The insufflation is transferred from the intraperitoneal trocar to an intragastric trocar. The peritoneal insufflation is released so that the stomach can be insufflated.
5. The laparoscopic ultrasound probe is used to locate the collection of pancreatic necrosis, then confirmed with laparoscopic needle aspiration.
6. A posterior gastrotomy is created with electrocautery and extended with LigaSure (Covidien) and/or laparoscopic vascular stapler. A wide gastrotomy will help facilitate adequate intraoperative debridement as well as ongoing postoperative internal auto-debridement.
7. Debridement of necrosis is performed with laparoscopic graspers (with hand-over-hand technique, for solid debris) and suction (for liquid necrosis). Necrosis can be pulled into the stomach and/or pushed into the duodenum.
8. After completing debridement, the intragastric trocar sites are closed individually.

We published our initial series of laparoscopic TGN in 2014, reporting 21 patients [69]. Most patients recovered without complications (43%) or minor

complications (29%), with major complications in 6 patients (29%). No additional drainage/debridement were needed, and no patients developed fistula. Our ongoing experience since those initial publications has continued to demonstrated that laparoscopic TGN provides effective debridement in a single operation with low rate of complications overall (with no fistulas) [68].

A larger multicenter retrospective study of 178 patients evaluated surgical transgastric management (combined open and laparoscopic series) of pancreatic necrosis across three institutions (including 43 patients from our institution) recently reported morbidity of 38% and mortality of 2%. The rate of pancreatic fistula was only 4%, and only three patients required additional necrosectomy (1.7%) [70]. The postoperative median length of hospital stay was a mere 8 days (as compared to prolonged hospitalizations of 50+ days for endoscopic and surgical step-up patients in the Dutch trials [54,55,70]). It is worth noting that 39% of patients from this multicenter cohort were confirmed to have infected necrosis [70], while the Dutch trials' rigorous guidelines selected for patients with confirmed or suspected infected pancreatitis necrosis [54,55]. Nonetheless, this publication confirmed that surgical TGN, whether open or laparoscopic, is an excellent and durable single-stage surgical option for patients with retrogastric walled-off necrosis.

The MISER trial was a single-center randomized controlled trial that compared minimally invasive surgery (n = 23 laparoscopic cystgastrostomy, 9 VARD) to endoscopic step-up approach (transluminal drainage with or without necrosectomy, n = 34) [71]. The authors did not find a difference in mortality between cohorts (8.8% in endoscopic cohort, 6.3% in surgical group), but there was a higher number of complications in the surgical group, particularly fistulas in the surgery arm (28% vs 0% in endoscopic). However, there was no significant difference in reinterventions performed for lack of clinical improvement (38% vs 44%), the number of interventions performed per patient (median 1 intervention [IQR 1–2] in both arms), or postprocedural hospital length of stay (18.5 vs 14 d) [71]. This is the only randomized trial examining surgery against endoscopic step-up approach, but the inclusion of VARD into the surgical arm begs the question of whether these patients are anatomically equivalent to those who underwent endoscopic treatment. The authors noted that of the 8 patients with postoperative pancreatic fistula, four patients underwent VARD, and an additional four "who underwent percutaneous catheter placement at laparoscopic debridement" (This is difficult to understand and not typical of the surgical transgastric strategy.). This may have led to an elevated incidence of this complication in the MISER trial, and indeed, when pancreatic fistula is excluded, the trial composite endpoint was similar for both treatment arms [72]. Finally, it is notable that the same center was conducting an overlapping randomized trial of endoscopic pigtails against LAMS [73], suggesting that there may have been some selection bias in accrual to competing trials. Thus, the MISER trial has not yet clarified the relative role of the surgical and endoscopic approaches.

In contrast, in our own single-center retrospective study, Dua and colleagues reviewed 74 patients who underwent transgastric intervention for necrotizing

pancreatitis, of which 40 underwent laparoscopic TGN and 34 endoscopic cystgastrostomy [74]. In this study, there were no postprocedural pancreatic fistulas, despite 29% of patients found to have disconnected duct syndrome (13 in laparoscopic cohort, 9 endoscopic). Of these patients, only two (both from the endoscopic cohort) required future resection in the form of distal pancreatectomy [74], whereas resection has traditionally been performed for up to 45% of patients with unstable anatomy [16]. There were no differences in other morbidity. The endoscopic cohort required an average of 2.5 debridements. Although this study is limited by its sample size and patient selection, these findings suggest that creation of an internal fistula via cystgastrostomy through laparoscopic or endoscopic means can adequately drain an isolated tail remnant, without requiring resection of healthy pancreatic tissue [74]. Surgical cystgastrostomy, in particular, is an effective transgastric strategy that leads to resolution with the index procedure.

Taken together, the data described previously demonstrate that the transgastric approach, whether endoscopic or surgical, is a very effective strategy overall, avoiding in particular the need for prolonged drains. We have found that the surgical approach provides an effective debridement with a single operation and expedites patients' return to prepancreatitis health without the need for repeat debridement and drains [68]. The endoscopic approach is improving with larger LAMS and better instrumentation, so there is clearly a wide overlap in the application of these techniques. The decision regarding which to perform (surgical or endoscopic) must be individualized to patient and should be made based on local expertise, the nature of the WOPN (relative quantity of solid vs liquid necrosis), and the clinical status of the patient.

Percutaneous drainage

Percutaneous drainage acts as a bridge to definitive debridement in septic patients. However, in a subset of patients, percutaneous drainage alone may adequately treat WOPN. As noted previously in the Dutch trials, 35% of step-up patients in the PANTER trial and 51% in the TENSION trial did not require surgical debridement after primary percutaneous drainage [54,55]. While systematic reviews have reported successful primary percutaneous drainage in approximately 55% of patients in the pooled data [75,76], individual studies' success rates range widely from 10% to 90% [2,75–79]. This wide variation may be due to the heterogeneity in disease severity as well as patient selection study to study. It is also possible that the quality of pancreatic necrosis may be a determinant factor in the success of drainage alone, especially with largely liquid collections.

Nonetheless, even though percutaneous drainage alone may be effective in select patients, catheter drainage is not benign, and there are shortcomings in this treatment strategy. The major morbidity associated with percutaneous drainage are pancreatic fistulas, which have been reported in up to 50% of patients [75,76]. In addition, patients experience pain and discomfort from the drainage catheter. Often, patients are committed to prolonged duration with a drain and may require

several additional drain exchanges. These drawbacks should be weighed against operative morbidity in management of necrotizing pancreatitis.

SUMMARY

The approach to management of walled-off pancreatic necrosis has evolved considerably over the past three decades, transforming the landscape of surgery from open debridement to laparoscopic options to development of step-up approaches that combine percutaneous/endoscopic drainage and minimally invasive debridement. However, there is no one ideal approach for all patients, as patients vary widely in clinical status, contents of the pancreatic collection (liquid vs solid), and anatomic location. Owing to heterogeneity of the disease process, the timing and specific treatment strategies are tailored toward each individual patient, focusing on minimizing morbidity and mortality. Our current approach is percutaneous drainage followed by minimally invasive retroperitoneal debridement with a two-trocar technique for collections located in the paracolic gutters. We advocate for laparoscopic transgastric necrosectomy for retrogastric collections with a significant solid component, particularly for patients with disconnected duct and isolated tail remnant, as this results in an effective debridement in one operation and frees patients from the morbidity associated with a percutaneous drain. Given the improvements in mortality with better data and understanding in the management of necrotizing pancreatitis, therapeutic focus should be trained on returning the patient to prepancreatitis wellness.

CLINICS CARE POINTS

- Asymptomatic walled-off pancreatic necrosis does not warrant intervention, and these patients can be safely monitored.
- Percutaneous or endoscopic drainage can be performed to bridge critically ill patients to definitive debridement (surgical and endoscopic step-up approaches).
- Anatomic location of walled-off pancreatic necrosis can dictate treatment: Retrogastric collections are amenable to transgastric interventions (endoscopic or surgical drainage/debridement); collection locations in the paracolic gutter are appropriate for retroperitoneal percutaneous drainage and/or debridement.
- Surgical transgastric necrosectomy is an effective single-stage debridement procedure, with the creation of a large cystgastrostomy that allows ongoing internal auto-debridement.
- A patient with isolated tail remnants is best managed by surgical as opposed to endoscopic methods, as a surgical cystgastrostomy is durable and allows for ongoing internal drainage without requiring additional interventions.

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SUPPLEMENTARY DATA

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