Surgical Strategies for the Management of Necrotizing Pancreatitis

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ABSTRACT

The surgical management of necrotizing pancreatitis continues to evolve and now includes multiple alternatives to traditional open debridement – minimally invasive strategies have been developed with the intent to decrease the physiologic stress associated with this procedure. Proponents of each procedure report their technical success and the "safety and feasibility" of their favored strategy. However, extension into routine clinical practice is limited by considerable variation in technique and lack of widespread expertise. No single approach is optimal for all patients. The strategy for drainage/debridement among the breadth of techniques now available must be individualized according to patient presentation and anatomy. The purpose of this review is to present the current state of interventions for necrotizing pancreatitis and provide a practical guide to understanding the indications and application of these procedures.

INTRODUCTION

Necrotizing pancreatitis remains a devastating disease, associated with significant morbidity and mortality [1-3]. Improved management of the early systemic complications (as a result of better intensive care and nutritional management) has led to reduced mortality during the systemic inflammatory response syndrome (SIRS) phase of severe acute pancreatitis; however, up to 70% of patients with necrotizing disease develop infected pancreatic necrosis later in the course of their disease [4]. Infection of the necrosis is thus the predominant risk factor for multi-organ dysfunction and death in the second phase of this disease. Failure to achieve source control in patients with clearly infected necrosis (whether by debridement or wide drainage) has been associated with nearly 100% mortality. Accepted indications for surgical intervention include proven infected necrosis, clinical deterioration, or persistent symptoms due to complications of pancreatic infection. There is the general consensus to delay intervention to at least 3-4 weeks after onset of disease and preferably as late as is feasible [4, 5]. Over the last decade, a variety of minimally invasive interventions for the treatment of acute necrotizing

Received May 20th, 2015 Accepted July 20th, 2015 Key words Pancreatitis, Acute Necrotizing Correspondence Monica M Dua Stanford University School of Medicine 300 Pasteur Drive H3691 Stanford, California 94305 Phone +650-736-1355 Fax +650-724-9806 E-mail mdua@stanford.edu pancreatitis have been introduced as alternatives to the traditional open necrosectomy [6]. Once the decision to intervene has been made, the clinician is faced with the decision of which approach (surgical, endoscopic, or percutaneous) to use.

Conventional open surgical debridement has long been considered the gold standard for the treatment of infected pancreatic and peripancreatic necrosis. This invasive approach in a critically ill patient is associated with high rates of complications and significant mortality. Advances in diagnostic imaging, laparoscopic technology, interventional and endoscopic access have spawned a number of less invasive approaches to necrosectomy. These include retroperitoneal pancreatic necrosectomy (referred to as MIRP or VARD) [7, 8], laparoscopic or laparoscopicassisted necrosectomy [9], endoscopic necrosectomy [10, 11], and various percutaneous approaches, used alone or in combination with other techniques [12, 13]. The published reports are generally single institution series, and there is considerable heterogeneity of technique even within each modality (e.g., "How- I-do-it" technical reports). In addition, these techniques may be combined in a step-up fashion (where percutaneous or endoscopic procedures are initially used for temporary source control followed by laparoscopic or video-assisted pancreatic debridement). Each series compares their new technique against open necrosectomy, and there is little data comparing the newer approaches to each other. Some authors include avoidance of operative intervention as a desirable clinical endpoint, despite the need for repeated endoscopic or percutaneous procedures over weeks or months. However, the goal of intervention must be the most rapid return to prepancreatitis health, by whatever means safely achieves that endpoint.

No single approach will be optimal for all patients and therefore, the choice of procedure must be tailored to the individual patient with respect to timing, degree, and anatomic location of the necrosis. The purpose of this review is to describe the current state of procedures for pancreatic necrosectomy and specifically provide a practical discussion of the indications and treatment strategy behind each approach through case examples.

Open Necrosectomy

The traditional treatment of necrotizing pancreatitis with secondary infection has been open laparotomy with manual debridement of all necrotic tissue. Necrosectomy is primarily done by blunt dissection; formal resections are generally avoided to minimize incidence of bleeding, fistulae and injury to surrounding organs. Depending on the series and severity of illness, open necrosectomy is associated with mortality between 11-39%, morbidity of 36-95% and risk of long-term pancreatic insufficiency up to 25% [2, 13, 14]. It has been suggested that the increased rates of endocrine and exocrine pancreatic insufficiency seen after open necrosectomy is related to the unintentional debridement of viable pancreatic tissue [13].

Depending on the timing and completeness of necrosectomy, "adjuncts" to the open necrosectomy may be required to manage necrosum that was left behind or ongoing necrosis. These strategies include serial debridements [15], open packing with planned re-laparotomy [16], "closed packing" [17], and closedsuction drainage for postoperative lavage [18]. There is overwhelming evidence supporting delaying necrosectomy for 4 or more weeks after initial presentation to avoid surgery during the acute insult of the SIRS phase and to allow maturation and demarcation of the necrosis [4]. "Late" necrosectomy also reduces the need for multiple operations, which is itself associated with a multitude of negative consequences [19]. For this reason, more recent reports of open necrosectomy have advocated for closure with postoperative continuous irrigation through the use of multiple catheters left in the lesser sac or retroperitoneum [19]. Rodriguez et al. retrospectively reviewed 167 patients with necrotizing pancreatitis treated with single stage debridement by blunt necrosectomy via a transmesocolic approach [17]. This large, modern series is representative of the "best" results that are likely to be achieved via "traditional" open necrosectomy. The authors used a closed packing technique of gauzed filled Penrose and closed suction drains. The authors report a 15% reoperation rate, 30% postoperative percutaneous Interventional Radiology (IR) drainage requirement, and overall operative mortality of 11% [17]. The low mortality demonstrated was attributed, in part, to the routine use of preoperative percutaneous drainage to delay intervention (>28 days). Although this group achieved favorable outcomes with open necrosectomy, the continued

emergence of alternative less invasive techniques has suggested a more judicious use of this type of debridement.

Nonetheless, open debridement continues to be the preferred (or even required) approach in a variety of situations. These situations include significant necrosis extending into or behind the root of the mesentery (where the central location and proximity to mesenteric vessels may preclude safe percutaneous or transluminal access) and cases during which other concurrent operations are required (e.g., colectomy due to transverse colon ischemia, hemorrhage failing endovascular embolization). Furthermore, patients with head dominant necrosis or otherwise "unstable anatomy" (e.g., significant necrosis in the neck with a viable body and tail) often are best managed via an open approach. While partly related to the inability of other techniques to safely access and debride the head of the pancreas, more importantly necrosis in the head or neck are often associated with pancreatic duct disruption. Ongoing pancreatic leak from unstable ductal anatomy into the necrotic cavity severely limits chances for spontaneous recovery. Nealson *et al.* demonstrated in their review of ductal changes in association with severe or necrotizing pancreatitis that in those cases with duct obstruction or a disconnected duct, initial treatment with percutaneous catheter drainage or endoscopic management was uniformly unsuccessful [20]. In these situations, an open approach allows for simultaneous debridement of pancreatic necrosis as well as distal or total pancreatectomy to minimize the sequelae of continuous pancreatic drainage; there is direct access to all types of collections with very little technical limitation. Long-term morbidity from an open approach can include chronic pancreaticocutaneous and enterocutaneous fistula, diabetes, exocrine insufficiency, and abdominal wall hernias. The following cases illustrate these scenarios where open necrosectomy was required.

Case #1

A fifty-eight-year-old male developed extensive necrosis of the pancreas from gallstones. The necrosis was noted to extend to the root of the mesentery and into the retroperitoneum along the psoas muscles bilaterally. Although the body and tail of the pancreas were replaced by necrosis, there was no overt evidence of infection and he was initially managed with enteral feeds and supportive care in the acute phase. He did have a small nonocclusive thrombus in the portal vein and was started on a heparin drip to prevent propagation. About one month after transfer, he began to spike fevers and developed a leukocytosis. Simultaneously, he had a precipitous drop in his hematocrit. A CT angiogram showed bleeding into the necrosis (Figure 1a), though there was no clear pseudoaneurysm or active bleeding. An open necrosectomy was chosen because of both the extensive infected necrosis behind the root of the mesentery and the acute hemorrhage (Figure 1b), fearing that debridement would release the tamponadeeffect and that bleeding might be difficult to control with minimally invasive techniques. The gastrocolic omentum



Figure 1. (a.). CT angiogram showed high density material (white arrow) consistent with bleeding into the necrosis. (b.). Extensive infected necrosis behind the root of the mesentery and acute hemorrhage of patient in Case 1. (C.). Resolution of the necrosis is seen on a follow-up CT scan 6 months later.

was opened with careful exploration to access the lesser sac. This revealed pancreatic necrosis and pancreatic fluid – the entire pancreas was necrosed and required a total pancreatectomy performed with blunt debridement. The retroperitoneum just below the transverse mesocolon was also bluntly dissected to remove another area of fat necrosis and old clot. A cholecystectomy and feeding jejunostomy were also performed as part of the procedure. He required one drain by interventional radiology on postoperative day (POD) 19 for fever and a residual fluid collection noted on CT scan but otherwise recovered well and discharged soon after.

Case #2

A fifty-nine-year-old male developed necrotizing pancreatitis as a result of gallstone disease. Over the course of the next several weeks, he suffered a profound ileus with massive dilation of his transverse colon up to 17cm as a result of the pancreatitis and was maintained on TPN for nutritional support as he was not able to tolerate tube feeds. Several attempts to decompress the colon with colonoscopy were unsuccessful yet showed the mucosa of the colon to be healthy. He clinically deteriorated and developed a gram negative bacteremia and the clinical suspicion was that this was related to infection of the pancreatic necrosis (Figure 2). He was taken to the operating room as an open approach for a combined colon and pancreas resection. He first underwent an extended right hemicolectomy with end ileostomy for the dilated and edematous right and transverse colon. With the colon removed, the exposure to the pancreas improved and it was clear that the pancreas was foul-smelling and infected and completely involved. In addition to the pancreatectomy done principally with blunt dissection, a splenectomy was performed given the patient had splenic vein thrombosis. The patient spent one month recovering in the ICU due to postoperative respiratory failure and another month on the floor prior to discharge to a rehab facility tolerating a diet and supplementing with tube feeds. He required outpatient management of his drains and ultimately underwent ileostomy reversal and a ventral hernia repair with bioprosthetic mesh and component separation closure 10 months later.

Percutaneous Therapy

Percutaneous catheter drainage (PCD) of pancreatic and peripancreatic necrosis is an effective treatment option at various stages of necrotizing pancreatitis. In selected cases PCD can be used as primary therapy, but more frequently, its role serves as a temporizing measure prior to other forms of necrosectomy or as an adjunct for residual fluid collections after surgery. Most often, PCD targets walled-off, infected fluid collections with single catheters. Isolated centers report a more aggressive strategy which amounts to an IR necrosectomy: multiple large bore (12-30F) catheters for irrigation, sometimes in combination with snares and baskets for additional debridement [21]. Repeated catheter exchanges are required for multiloculated, viscous necrotic collections. Most fluid collections are located in the lesser sac, the anterior pararenal space or other parts of the retroperitoneum making a retroperitoneal approach through the lateral flank a preferred access route for PCD to minimize risks of enteric leaks, bacterial contamination and hemorrhage [22]. Of note, the percutaneous retroperitoneal drain tract may also be used as guidance for future retroperitoneal debridement (MIRP or VARD).

A recent systemic review of PCD as primary treatment for necrotizing pancreatitis reported on 11 studies, mostly retrospective case studies published between 1998 and 2010 involving a total of 384 patients [23]. Of the 384 patients, 271 (70.6%) had infected peripancreatic necrosis (gas on CT or as a positive culture from fineneedle aspiration). The percentage of patients surviving without additional surgical necrosectomy was 55.7% (214 patients), additional necrosectomy was required in 34.6% (133 patients), and the remaining 9.6% (37 patients) died before further intervention could be performed. The majority of complications described were fistulas (51.5% of 103 complications reported). The difficulty in assessing this data lies in the fact that the authors don't state how many patients at these institutions underwent other



Figure 2. Patient in Case #2 with massive dilation of the transverse colon and central pancreatic necrosis.

forms of necrosectomy first (rather than PCD as primary treatment). This is retrospective data, thus the criteria by which PCD was chosen as primary treatment remains uncertain. Nonetheless, it does demonstrate that PCD may be suitable as primary therapy for selected patients.

Two recent prospective multicenter trials incorporate a combined approach, utilizing PCD as the initial primary treatment for infected pancreatic necrosis. In the PANTER trial, 88 patients were randomized to either open necrosectomy (45 patients) or a "step-up" approach of PCD followed by VARD if no clinical improvement was seen after maximal drain optimization. Of those assigned to the step-up approach, 35% of patients were treated with PCD only [13]. In the other single-arm study, similarly looking at PCD as initial treatment followed by VARD, 40 patients were prospectively enrolled and treated with PCD; drains were upsized every 3 to 4 days until a 20F catheter size was reached. Patients with more than 75% reduction in collection size on repeat scan at 10 days post PCD were treated with continued drainage, making up 23% of this cohort treated with drainage alone [8].

Taking the data as a whole, the percutaneous approach to infected pancreatic necrosis is most useful as an intermediate method to control sepsis and postpone surgery in the setting of early necrotic collections. For this reason, PCD has become popularized as a prelude to definitive necrosectomy in the "step-up" fashion. However, PCD requires frequent CT imaging and subsequent exchange, upsizing, or manipulation of catheters and suffers from a very limited ability to deal with non-liquid necrotic material. These drains typically must remain in place for extended periods of time, which itself can delay return to full health. Despite these limitations, selected subsets of patients with largely liquid or low volume infected necrosis are appropriately treated with PCD alone as in Case #3.

Case #3

A seventy-three-year-old female was transferred from an outside facility 3 weeks after acute onset of severe acute pancreatitis. She developed persistent fever and her CT scan demonstrated the area of infected pancreatic necrosis to be small and localized to the distal pancreas. Her presentation was still in the early phase of necrotizing pancreatitis and there was a retroperitoneal route of access to the collection (**Figure 3**) and therefore, percutaneous catheter drainage was used in this scenario. The catheter was exchanged and upsized one time after initial placement for optimal drainage. Given the overall low volume of infected necrosis present, she recovered well and did not require any further debridement.

Endoscopic Necrosectomy

Endoscopic transmural drainage of pancreatic pseudocysts is a well-established modality, largely successful because pseudocysts are devoid of any solid debris. With improvements in endoscopic techniques and instrumentation, this strategy has now increasingly been applied to drain peripancreatic fluid collections with adjunctive direct endoscopic "necrosectomy" for debridement of walled-off pancreatic necrosis [24]. The breadth of endoscopic approaches is highlighted in a retrospective study by Seewald et al. in which they describe their endoscopic treatment algorithm for the management of pancreatic fluid collections or necrosis [25]. In 13 patients that were considered too ill for immediate surgical necrosectomy (due to comorbid conditions or early time course of disease), EUS-guided transmural drainage was performed through the gastric or duodenal wall, followed by daily endoscopic necrosectomy and Water-Jet lavage. Double-pigtail stents and nasocystic catheters were adjunctive tools used to maintain access for subsequent continuous irrigation. All patients received pancreatic sphincterotomy; two patients had additional



Figure 3. Small area of infected pancreatic necrosis in patient of case #3 (medial to the spleen) and with adequate retroperitoneal access for percutaneous drainage.

transpapillary drainage (nasopancreatic catheters into the necrotic cavity) when duct disruption or duct stenosis was present on endoscopic retrograde pancretogram. Over a median follow-up of 9.5 months, all except one patient had complete resolution of necrosis by endoscopic therapy alone. In this last patient, surgery was required due to extensive necrosis extending down the paracolic gutter. Two other patients required surgery for recurrent pseudocysts; one as a result of pancreatic duct-disruption at the head of the pancreas and the other for pancreatic cancer (diagnosed by brush cytology of a stenotic pancreatic duct after endoscopic drainage). Although this algorithm of aggressive endoscopic therapy offers new therapeutic dimensions for the treatment of pancreatic abscesses and necrosis, the initial goal was to bring these 13 patients to a more stable condition by endoscopic drainage and avoid the complications of emergent surgery. Indications for surgery in this cohort were for ineffective removal of necrotic debris due to poor endoscopic access and for continued disconnected duct syndrome.

In cases of central walled-off necrosis that abuts the stomach or duodenum, direct necrosectomy is performed by passage of a flexible endoscope transorally followed by transgastric or transduodenal access into the necrosum. Endoscopic necrosectomy has been demonstrated to be safe and effective in a selected population with acute necrotizing pancreatitis [26]. The first randomized control trial comparing clinical outcomes of endoscopic transgastric necrosectomy compared to surgical necrosectomy (VARD or open necrosectomy if VARD not possible) was recently published by the Dutch Pancreatitis Study [11]. In this multi-center trial, outcomes from the endoscopic group showed a decreased proinflamatory profile and a reduction in composite clinical end points of death and major complications (20% vs 80%, p=.03). New onset multi-organ failure did not occur after endoscopic transgastric necrosectomy (0% vs 50%, p=.03) and fewer patients developed pancreatic fistulas (10% vs 70%, p=.02).

Direct endoscopic necrosectomy is performed by passage of a flexible endoscope transorally followed by transgastric or transduodenal access into the necrotic cavity. Linear array endoscopic ultrasound is used to assess extent of necrosis and localize nearby vasculature as well as determine optimal trajectory for the puncture site [27]. After initial transmural entry into the cavity, balloon dilation of the tract allows for direct entry of the gastroscope into the necrotic cavity. Necrotic debridement and irrigation is accomplished under direct endoscopic vision using a variety of instruments and techniques. The addition of transmural stents for continued lavage or transpapillary stents in patients with pancreatic duct disconnection have been reported [25, 28, 29]; however reliability of these adjunctive endoscopic procedures is unknown and not widely accepted. Covered metal stents with a diameter of 10 mm or more are increasingly used to enhance drainage, maintain cystgastrostomy tracks and facilitate repeat endoscopic necrosectomy procedures, although there is limited comparative data. A systemic review of endoscopic necrosectomy for pancreatic necrosis described the outcomes of 10 studies, incorporating 260 patients and more than 1100 procedures. Of the total number of patients, 60% were proven to have culturepositive infected necrosis and 76% of patients achieved definitive resolution with endoscopic techniques alone. Overall mortality was 5%; complications were reported in 30% of patients with post-procedural bleeding being the most common problem [26].

Selection of the type of necrosis that can be endoscopically managed is important to its technical success. Central WON that involves the lesser sac and abuts the lumen of the stomach or duodenum are almost always accessible but may take several weeks to become organized. The ability to perform endoscopic necrosectomy under conscious sedation over general anesthesia increases its therapeutic potential in treating critically ill patients who are poor operative candidates. In addition, use of natural orifice transluminal endoscopic surgery provides an alternative access route for necrosectomy avoiding the morbidity of open surgery and potential external fistula formation. The primary technical limitation of this approach is that the instruments used for debridement are limited in size by the endoscope and therefore, multiple interventions are often required to attain adequate cavity debridement. Typically 3 to 6 endoscopic sessions are necessary [19, 26], highlighting the need for serial imaging and a dedicated team with endoscopic expertise to avoid local risks of bleeding and perforation with each subsequent debridement.

Case #4

A sixty-seven-year-old male was referred to the gastroenterologist at 7 weeks from initial presentation of necrotizing pancreatitis for persistent unwellness,



Figure 4. Endoscopic images of the debridement of the necrotic cavity in Case 4. **(a.).** The EUS puncture with a 19 gauge needle into the necrotic cavity is shown in, **(b.).** followed by another image of the large necrotic cavity. **(c.).** Endoscopic necrosectomy is shown in after much debridement through the scope and **(d.).** demonstrates dilation of the cystgastrostomy track.

abdominal pain, poor oral tolerance and weight loss. He had a single peripancreatic area of necrosis at the tail of the pancreas. On endoscopic ultrasound, the necrotic cavity was seen in the expected location of the pancreas. The collection was punctured with a 19 gauge needle and an Olympus 0.035wire was passed to dilate the track with a 15mm balloon. The necrotic cavity was debrided (**Figure 4**) and a covered metal viabil stent was deployed through the cystgastrostomy at the end of the procedure for further drainage and future access (**Figure 5**). The patient underwent a total of three endoscopic sessions and debridement over the couse of a 2 week period.

Laparoscopic and Laparoscopic Transgastric Necrosectomy

Laparoscopic necrosectomy offers access to multiple compartments of the abdomen. Along the spectrum of minimally invasive necrosectomy, although more invasive than transoral procedures, a transperitoneal approach combined with patient rotation and positioning allows access to fluid collections that are not amenable by an endoscopic approach, including the right and left paracolic gutters, the perinephric and retroduodenal space, as well as the root of the mesentery [6, 9]. Several retrospective case series have reported on the successful use of laparoscopic necrosectomy [30] laparoscopic handassisted debridement [9] and single-port laparoscopy [31]. From these studies, several approaches to debride necrosis located in the anterior aspect of the pancreas have been proposed; Zhu et al. used four standard ports to go through the gastrocolic ligament and placed a fan retractor to elevate the stomach for exposure. The procedure described by Parekh primarily used a hand access GelPort device with three other ports to accomplish an infracolic approach to the lesser sac through the transverse meocolon. In the latter part of their experience, a direct approach to the lesser sac through the gastrocolic ligament between the stomach and colon was used. Only one out of



Figure 5. CT image post-placement of the covered metal wall stent through the cystgastrostomy in patient of Case 4.

19 patients required conversion to open procedure [9]. Summarizing four of the most recent studies, the clinical success of necrosectomy was between 70-92%, need for reoperation 0-11%, morbidity around 20% and mortality 10-18% [9, 19, 32, 33].

The ability to attain complete removal of the necrotic sequestrum has been advocated as a primary benefit of the laparoscopic approach over other minimally invasive procedures; in addition, other potential advantages over open necrosectomy include decreased wound and pulmonary complications as well as reduced systemic response [9, 34]. However, the reluctance to use this approach in critically ill patients with infected necrosis stems from the concern of disseminating infection throughout the peritoneal cavity and possible bowel injury when using a mesocolic approach.

Another laparoscopic approach is the laparoscopic transgastric necosectomy (LTN): transperitoneal entry followed by direct trocar placement (using radially dilating trocars) into the gastric lumen under endoscopic guidance to facilitate transgastric necrosectomy [35, 36]. Once the trocars are in position, the laparoscope is moved to within the gastric lumen. One technical challenge in this procedure is to maintain a good seal of the trocars as they pass through the gastric wall; this is critical to maintain the laparoscopic CO2 insufflation within the stomach and have good visualization during the procedure. Two 5mm and one 10mm ports are typically used - if there is any leakage of CO2 insufflation around one of the 5mm ports, this can be upsized to a 10mm to create an adequate seal. The debridement is performed by opening the posterior gastric wall under direct vision of the laparoscope to enter into the cavity and bluntly remove the necrotic material into the stomach. Although LTN is limited to retrogastric well-demarcated WON, the intended fistula created between the necrotic collection and stomach allows for continued internal drainage, thereby decreasing the need for multiple interventions. In our own series, of 21 patients that underwent laparoscopic transgastric necrosectomy, 19 achieved sufficient debridement in a single procedure; two patients required post-operative percutaneous drainage. With a median follow-up of 11 (7-22) months, no patients required additional operative debridement, developed pancreatic/enteric fistulae, or suffered wound complications [36]. In those patients that are hemodynamically stable and the etiology of the pancreatitis is due to gallstones, simultaneous cholecystectomy can be performed after closure of the gastrostomy sites. A notable risk of LTN is post-operative pseudoaneurysm; bleeding into the cavity presents as gastrointestinal bleeding and should prompt an immediate CT angiogram and embolization if contrast extravasation is present. Where the anatomic location of the necrosis permits, LTN is now our preferred approach. The surgical posterior gastrotomy allows much of the necrosis to be debrided at the time of surgery, but moreover permits rapid resolution of necrosis that is left behind (in comparison to the time required after endoscopic techniques). Furthermore, there is no need

for long-term drains, which add greatly to the morbidity experienced by these patients. In our early experience, it allows the fastest return to pre-pancreatitis health among the techniques described.

Case #5

A seventy-three-year-old man presented to our hospital 2 months after initial episode of idiopathic pancreatitis. He was transferred to our facility for acute respiratory distress syndrome and management of two separate areas of infected pancreatic necrosis – one near the pancreatic head and one at the pancreatic tail (**Figure 6**). Because of these two distinct



Figure 6. (a.). Axial and **(b.).** Coronal CT of patient in Case 5 demonstrating two distinct central areas of pancreatic necrosis at the root of the mesentery. **(c.).** Interval CT scan one week later demonstrating near resolution of the pancreatic necrosis after laparoscopic debridement and drain placement.

locations, this case was performed laparoscopically so that each individual area of peripancreatic necrosis could be debrided. The colon was retracted cephalad and the necrosis at the pancreatic head was accessed through the bare area of the transverse mesocolon; the similar procedure was done for the pancreatic tail. The necrotic cavities were examined with the laparoscope, the necrosum was placed into an endocatch bag and the sites irrigated. A drain was placed in both necrotic cavities and a feeding tube was placed for nutritional supplementation. Postoperatively, the patient was extubated on POD 3. An interval CT scan was performed at one week postoperative with both left and right-sided surgical drains in good position and near resolution of the pancreatic collections. There was interval development of two new anterior abdominal fluid collections (both under 6cm) and the patient underwent ultrasound guided aspiration of these collections at the bedside given their superficial position. Both had the appearance of simple fluid and were gram stain negative. The patient recovered well and was discharged home 2 weeks later.

Case #6

This eighty-three-year-old female with a BMI of 38 was transferred to our institution just under 4 weeks from initial presentation of pancreatitis. Upon transfer, she had acute renal insufficiency (ARI), atrial fibrillation, and a leukocytosis >30×10³ µL. Her non-contrast enhanced CT scan demonstrated a single collection of peripancreatic necrosis which was infected (Figure 7a). Given this retrogastric position of the necrosis, LTN was performed where three ports were placed through the anterior abdominal wall and into the anterior wall of the stomach under endoscopic guidance. A cystgastrostomy was created between the necrotic cavity and the posterior stomach to allow for debridement and continuous drainage into the stomach of the pancreatic necrosis. The patient was discharged to home within one week and her scan at 6 weeks postoperatively (Figure 7b) demonstrated good resolution of her necrosis after this procedure.

Case #7

A forty-five-year-old man initially had a 9 day hospital admission for idopathic acute pancreatitis. His CT scan on admission was without any pancreatic fluid collections or necrosis. He improved and was discharged home. About one month later, he presented with poor oral intake at home, abdominal pain, and a 30 lb weight loss over the last month. He was admitted for pain control and nutritional support via a feeding tube. Repeat imaging demonstrated a retrogastric walled-off area of pancreatic necrosis. The gastroenterology service had been consulted and considered endoscopic drainage but due to the amount of solid necrosis present in the late phase, it was determined that drainage alone would not be effective treatment. One week after admission, he had worsening abdominal pain, tachycardia, and poor oxygenation. A CT scan now showed the complex area of necrosis anterior to the pancreas to

consist of a large amount of air indicating superinfection. He was taken to the operating room for LTN and recovered post-operatively in the ICU, extubated on POD 1. He developed delayed gastric emptying (DGE) requiring NG decompression for 5 days and supplemental post-pyloric tube feeds for nutritional support. By POD 19, the patient had recovered well and was discharged home tolerating a regular diet. His CT scan prior to discharge demonstrated good resolution of the area of necrosis (**Figure 8**).

Retroperitoneal Debridement

Many variants of minimally invasive retroperitoneal pancreatic necrosectomy (MIRP) have evolved for pancreatic necrosis accessible via a retroperitoneal access route. In one form of sinus tract endoscopy, initial retroperitoneal percutaneous access into the necrotic collection is established followed by subsequent dilation of the tract for passage of a flexible or rigid endoscope [37, 38]. A wide variety of endoscopic instruments can be passed through the endoscope to facilitate irrigation and lavage of necrotic slough; however, only small fragments of necrotic tissue can be removed with each pass of the endoscope. Other methods include serial dilation of the percutaneous drainage tract under fluoroscopic guidance for rigid nephroscopy debridement. Initial copious irrigation is used to create a cavity in which long biopsy forceps are then used to remove the necrotic debris. At the end of the procedure, various irrigation and drainage systems are created using nasogastric or chest tubes for continuous postoperative irrigation and for re-introduction in the case of repeat procedures [39].

Horvath et al. described VARD technique, which involves a small subcostal incision to access the retroperitoneum from a left flank, mid-axillary approach [40, 41]. Using a previously placed percutaneous drain as a guide into the pancreatic collection, the cavity is bluntly cleared of purulent material and loose necrotic material with long grasping forceps. When no further debridement under direct vision is possible, a laparoscopic port is placed into the incision for completion of debridement under videoscopic assistance with CO2 insufflation through the percutaneous catheter [40]. Large bore single lumen drains are positioned in the cavity for continuous postoperative lavage until evidence of clear effluent. With this technique, the safety and efficacy of VARD for infected pancreatic WON was demonstrated in a prospective multicenter single arm study [8]. Out of 40 patients with infected pancreatic necrosis, 31 patients required surgery and 25 patients (60%) underwent VARD. There was no 30-day mortality in the surgical group. Ten patients crossed over to require open necrosectomy after VARD, primarily patients with persistent centromedial collections extending into the mesenteric root which were not accessible from the flank.

Although this highlights the anatomical considerations that need to be incorporated into selecting a particular



Figure 7. Pre-operative (performed without contrast because of ARI) (a.). and post-operative (b.). images of the patient in Case #6 with retrogastric and walled off infected pancreatic necrosis. This was debrided via LTN.



Figure 8. Pre-operative (a.). and post-operative (b.). CT images of the patient in Case #7. Another example of retrogastric and walled-off infected pancreatic necrosis treated with LTN.

procedure for necrosectomy, the PANTER trial reported only 3 out of 26 patients planned for VARD in which open necrosectomy was required for anatomical limitations to the retroperitoneal access route [13]. In the 43 patients randomized to the step-up approach in the PANTER study, 93% underwent a first step of percutaneous drainage through the left retroperitoneum, thereby facilitating minimally invasive retroperitoneal necrosectomy at a later stage. These techniques are suitable for collections extending deep into the left side of the retroperitoneum that are partly liquefied. In some circumstances, patients with a right-sided retroperitoneal collection can also be accessed via VARD although this approach is less common. The Liverpool pancreas group reported their retrospective review of 137 patients who underwent a minimally invasive retroperitoneal approach. Overall, although the patients in the minimally invasive group required more procedures and therefore longer length of hospital stay, they reported fewer complications (55% vs 81%, p=.001) and deaths (19% vs 38%, p=.009) compared to a cohort of 52 patients requiring open necrosectomy [7]. Collectively, several other studies have demonstrated clinical success with retroperitoneoscopy of 60-84% and mortality of 0-40% [19].

Significant advantages of MIRP exist, namely the ability to reach areas not accessible by endoscopy and the potential to debride a greater amount of necrotic sequestrum. Compared to direct laparoscopy, the theoretical advantage exists of decreasing intraperitoneal spread of infection; however, patient selection is the dominant factor for improved outcomes. For MIRP to be successful, the extent of necrosis needs to be in continuity so that complete debridement can be achieved. Walled off necrosis of the head and uncinate process or isolated areas of necrosis in the paracolic gutters are not readily amenable for retroperitoneal percutaneous drainage, thereby limiting MIRP in these settings [39, 42]. Technical feasibility of the MIRP requires fluoroscopic expertise to perform catheter and wire exchanges in upsizing the track for further debridement. Initial debridement with the nephroscope can be challenging as the working space starts out small and the visualization is limited; the debridement must proceed cautiously as the area of retroperitoneal necrosis can be close to the splenic vessels. More favorable anatomical locations as we demonstrate in the following case would include posterior pancreatic collections around the distal aspect of the pancreas.

Case #8

A twenty-one-year-old man developed idiopathic severe acute pancreatitis. He was managed medically and was discharged to home after 10 days. At 3 weeks after initial episode of pancreatitis, he was readmitted for fevers and tachycardia. Although the area of pancreatic necrosis was similar to the previous case (along the tail and left paracolic gutter), he was also diagnosed with a massive PE and suffered cardiogenic shock requiring extracorporeal membrane oxygenation which required a long inpatient stay of one month. His pancreatic necrosis was not infected on serial scans and therefore no surgical intervention was proposed given his other medical issues. At 8 weeks after initial presentation, he came to clinic with fevers and tachycardia and was noted to have infected necrosis (Figure 10a). A minimally invasive route was chosen given his recent recovery and also due to the retroperitoneal area of necrosis tracking along the left gutter. At the time of MIRP, the percutaneous catheters were upsized to sheaths (under fluoroscopic wire guidance, Figure 9a) to be able to proceed with initial nephroscopic debridement (Figure 9b). Once adequate working space in the retroperitoneum was created, the sheaths were exchanged for radially dilating 12 mm laparoscopic ports for completion of the necrosectomy via laparoscopy. Two chest tubes are left in place at the completion of the procedure for continued drainage (Figure 10b). By POD 7, we had IR downsize the chest tubes to two percutaneous drains in the upper collections for easier home management and place an additional drain in a residual lower collection seen on CT. No further operative procedures were required and the patient was discharged two days later on POD 9. The drains were removed on an outpatient basis over the following month after complete resolution of the collections (Figure 10c).

CONCLUSION

The rapid proliferation of interventions for necrotizing pancreatitis has greatly expanded our treatment options



Figure 9. (a.). Fluoroscopic image of the exchange of a percutaneous drain for a 30F sheath using a nephrostomy dilator set over wire access. **(b.).** Outside view of one remaining percutaneous drain and the parallel sheath now in place for insertion of the nephroscope through the sheath for debridement.



Figure 10. Serial coronal images of the patient in Case 8 who underwent a MIRP for pancreatic debridement for infected pancreatic necrosis. **(a.).** The pre-operative images of the column of retroperitoneal area of necrosis. **(b.).** The completion of the MIRP procedure with percutaneous drains placed by IR exchanged intra-operatively for chest tubes placed for continued drainage. The chest tubes were downsized by IR to percutaneous drains and an additional lower drain was placed in a residual inferior collection prior to discharge home. **(c.).** A repeat CT scan at 3 weeks shows complete resolution of all remaining collections.

Table 1	. Treatment	strategies for	necrotizing pancreatitis.
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Necrosectomy Technique	Anatomical Location	Advantages	Limitations
Open Debridement	Pancreatic head	Direct access all collections	Higher morbidity
	Disrupted pancreatic duct	Complete debridement	Endocrine/exocrine insufficiency
	Root of mesentery	Cholecystectomy if indicated	Higher rate of fistulas
	Centromedial collections	Concurrent procedures possible (e.g., colectomy)	
Percutaneous Drainage (PCD)	Anterior pararenal space	Less invasive	Limited utility in (semi-) solid necrosis
	Retroperitoneum	Sepsis control	Introduce contamination /infection if not already present
		Postoperative drainage	
			 Long duration of drainage and slow recovery if only technique used
Endoscopic Drainage/	Central walled off necrosis	Less invasive	Limited instrumentation for
Debridement	abutting stomach (occasionally	Decreased fistula formationSome debridement possible	debridement
	uuouenunij		Multiple EGDs typically required
			 Small "cystgastrostomy" so slow auto- debridement
Laparoscopic Drainage/	Anterior collections	Abdominal exploration	 Lap instrumentation may limit debridement of extensive necrosis Difficult to control bleeding compared to open surgery
Debridement	Paracolic gutters	Multiple areas accessible	
	Lesser sac	Some debridement possible	
		Cholecystectomy if indicated	
Laparoscopic Transgastric	Retrogastric walled off necrosis	No fistula formation	Limited to retrogastric collections
Debridement		 Primarily single procedure without any external drains required 	
		 Debridement does not need to be complete (wide cystgastrostomy permits auto- debridement) 	-
		Cholecystectomy if indicated	
Minimally Invasive Retroperitoneal Debridement	 Posteriolateral collections, including gutters and those 	Allows continued lavage and drainage	 Tedious and may require repeated procedures
(MIRP)	extending to pelvis	Direct debridement	Limited ability to control bleeding

in the current management of this disease. A summary of the advantages and disadvantages of the various treatment strategies discussed is included in **Table 1**. Appropriate timing and use of these new techniques can potentially lower morbidity and mortality associated with complications of infected necrosis; however, the conceptual and technical applicability of these novel approaches is still left to wide variation. Differences in institutional preferences, availability of expertise, diagnostic modalities and equipment, as well as severity of disease and comorbid conditions all contribute to variability in efficacy of a particular approach.

The first consensus guidelines on interventions for necrotizing pancreatitis were recently published after an international multidisciplinary conference from multiple specialties. The objectives were to incorporate the recent developments in minimally invasive techniques for necrosectomy [19]. Percutaneous catheter drainage, endoscopic, laparoscopic and videoscopic assisted retroperitoneal methods are all feasible approaches for treatment of pancreatic necrosis. They concluded that current evidence favors PCD or endoscopic necrosectomy followed by minimally invasive necrosectomy as the preferred routes for intervention for infected necrosis. However, these conclusions should be considered as very preliminary given the limited data available and the fact that expertise in many of these techniques remains limited to a handful of centers internationally. It is perhaps too soon to generalize their conclusions to widespread practice. It is well accepted that interventions within the first few weeks are generally associated with worse outcomes and should be reserved for infected necrosis with severe clinical deterioration. Poorly organized necrosis is more difficult to manage by any of the above methods than liquefied collections and WON. In adhering to these common principles, the combination of techniques as a step-up procedure has become increasingly popular whereby temporizing methods are used to control infection and allow demarcation of necrosis followed by minimally invasive or open necrosectomy as indicated. Future comparison studies will certainly further our capabilities of minimally invasive approaches to necrosectomy. Challenges moving forward will include learning curves associated with refinements in technology and new product lines in the endoscopic and laparoscopic fronts. Knowledge of the techniques available provides multiple options for treatment; however, many cases may be amenable to several approaches or perhaps a combined approach will be superior to a single intervention. In addition to demonstrating safety and feasibility of these techniques, these studies should also serve to guide our understanding of the different treatment strategies in managing pancreatic necrosis. As demonstrated in this review, incorporation of the timing of disease process, anatomical constraints and individual clinical scenario is paramount to selection of the optimal intervention and technical success.

Conflicting Interest

There is no conflict of interest to report on the part of any author.

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