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ORIGINAL ARTICLE

Damage control laparotomy and delayed pancreatoduodenectomy for complex combined pancreatoduodenal and venous injuries

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Abstract
Background This single-centre study evaluated the efficacy of damage control surgery and delayed pancreatoduodenectomy and reconstruction in patients who had combined severe pancreatic head and visceral venous injuries.
Methods Prospectively recorded data of patients who underwent an initial damage control laparotomy and a subsequent pancreatoduodenectomy for severe pancreatic injuries were evaluated to assess optimal operative sequencing.
Results During the 20-year study period, 312 patients were treated for pancreatic injuries of whom 14 underwent a pancreatoduodenectomy. Six (five men, one woman, median age 20, range 16–39 years) of the 14 patients were in extremis with exsanguinating venous bleeding and non-reconstructable AAST grade 5 pancreatoduodenal injuries and underwent a damage control laparotomy followed by delayed pancreatoduodenectomy and reconstruction when stable. During the initial DCS, the blood loss compared to the subsequent laparotomy and definitive procedure was 5456 ml, range 2318–7665 vs 1250 ml, range 850–3600 ml ($p < 0.01$). The mean total fluid administered in the operating room was 11,150 ml, range 8450–13,320 vs 6850 ml, range 3350–9020 ml ($p < 0.01$). The mean operating room time was 113 min, range 90–140 vs 335 min, range 260–395 min ($p < 0.01$). During the second laparotomy five patients had a pylorus-preserving pancreatoduodenectomy and one a standard Whipple resection. Four of the six patients survived. Two patients died in hospital, one of MOF and coagulopathy and the other of intra-abdominal sepsis and multi-organ failure. Median duration of intensive care was 6 days, (range 1–20 days) and median duration of hospital stay was 29 days, (range 1–94 days).
Conclusion Damage control laparotomy and delayed secondary pancreatoduodenectomy is a live-saving procedure in the small cohort of patients who have dire pancreatic and vascular injuries. When used appropriately, the staged resection and reconstruction allows survival in a previously unsalvageable group of patients who have severe physiological derangement.

Keywords Damage control laparotomy · Pancreatoduodenectomy · Trauma

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Introduction

Grade 5 injuries of the proximal pancreas with destruction of the pancreatic head are among the most devastating abdominal injuries trauma surgeons are likely to encounter [1, 2]. The complexity of these critical injuries is further compounded by the consequences of associated collateral vascular damage, especially when involving the vena cava and portal venous system [1, 2]. Survival is influenced by the severity of associated injuries, the magnitude and

duration of shock [3] and the speed and efficacy of surgical intervention [4, 5]. Mortality in severe pancreatic injuries may reach 46 % and is highest in those who are haemodynamically unstable [6]. Early mortality is due either to uncontrolled venous bleeding or major adjacent organ injuries [7, 8]. Late mortality is usually a consequence of infection or multiple organ failure [9–11].

In the small cohort of patients who have maximal injuries of the pancreatoduodenal complex and in whom there is no other rational surgical option for survival, a salvage pancreatoduodenectomy may be necessary [1, 12–14]. However, surgical intervention of such magnitude in those who are severely injured can only be contemplated in haemodynamically stable patients. The concept of damage control surgery (DCS) is now an essential element in the management of severely injured patients who are haemodynamically unstable and has dramatically improved outcome [15–18]. In the largest series to date of an emergency pancreatoduodenectomy in patients with complex non-reconstructable pancreatoduodenal injuries, we reported an overall survival in 84 % [1]. However, there is a lack of accurate and robust data assessing the role of DCS in patients who have combined severe pancreatic and vascular injuries. To date, there has been no detailed or comprehensive evaluation of the efficacy of an initial damage control laparotomy followed by a proximal pancreatic resection in this high-risk group of patients, nor has there been a critical analysis of the timing of the pancreatoduodenectomy. To address this deficiency, this single-centre study from one of the busiest high-volume trauma centres in the world evaluated patient outcome after initial DCS and subsequent pancreatoduodenectomy and reconstruction with particular appraisal of the advantages of delaying resection in unstable patients with associated major vascular injuries.

Patients and methods

The study design was a single-centre retrospective cohort analysis of prospective data on consecutive patients who underwent damage control surgery for trauma followed by a pancreatoduodenectomy between May 1, 1995 to April 30, 2014. The study used a registered departmental database which documents the details of all patients with pancreatic injuries treated at the Level 1 Trauma Centre and the Hepatopancreatobiliary and Surgical Gastroenterology units at Groote Schuur Hospital, Cape Town. Other aspects of pancreatic injury management using this database have been published previously [1, 9, 11]. Approval for this study was granted by the institutional review board at the University of Cape Town Health Sciences Faculty.

Data collection

Patient information in the registered departmental database entered prospectively on a standardised electronic Access data spreadsheet was analysed. During the 20-year study period, 312 patients were treated for pancreatic injuries, of whom 14 underwent a pancreatoduodenectomy for complex injuries involving the proximal pancreas and duodenum. Six of the 14 patients who had associated vascular injuries underwent an urgent laparotomy to control intra-abdominal bleeding. All six patients had initial DCS because of massive blood loss, hypothermia, acidosis and evidence of coagulopathy. These six patients later had a pancreatoduodenectomy when stable and constitute the study group. The remaining eight patients were haemodynamically stable and underwent a pancreatoduodenectomy and immediate reconstruction during the first laparotomy [1].

Data fields analysed comprised demographic information, mechanism of injury, time from injury to trauma centre admission, vital signs on admission including systolic blood pressure in mmHg, heart rate and details of the clinical examination including details of associated extra-abdominal injuries. The trauma scores recorded included revised trauma score (RTS), injury severity score (ISS) and APACHE II scores. Operative findings and associated intra-abdominal injuries, grade of the pancreatic injury, surgical procedure performed, duration of the operation, post-operative course including the presence and type of pancreas-related and other complications and mortality were recorded. The duration of both ICU and hospital stay was documented. Intra-operative crystalloid and colloid volumes were recorded and the number of packed red cells, fresh frozen plasma and platelet packs given were documented and the accuracy reconciled with blood bank records.

Operative management of pancreatic injury

Initial resuscitation was according to Advanced Trauma Life Support (ATLS) guidelines. All six patients underwent urgent surgery, because of evidence of major intra-abdominal bleeding. All were haemodynamically unstable with major abdominal vascular injuries and multiple visceral injuries which required a massive transfusion aggravated by severe metabolic acidosis, hypothermia and coagulopathy. During the index operation, a damage control procedure was performed before delayed definitive intervention.

Damage control laparotomy

Major intra-operative blood loss, acidosis and hypothermia necessitated the truncated procedure and a damage control

operation. In brief, the principles applied were an urgent laparotomy via a long midline incision and urgent control of intra-abdominal bleeding. The simplest means possible were used including supraceliac aortic cross-clamping, packing, suture or ligation, closure of visceral perforations by ligation, bowel stapling to prevent contamination of the peritoneal cavity and rapid volume replacement to correct acidosis, coagulopathy and hypothermia. The duodenum was rapidly kocherized using sharp and blunt finger dissection and rotated medially to expose the IVC, renal vessels and aorta. The Cattell–Braasch manoeuvre was used to expose the third part of the duodenum and the superior mesenteric vein and artery. Once haemostasis was complete, the abdomen was left open to avoid abdominal compartment syndrome, and temporary closure of the abdominal wound was achieved using a modified sandwich-vacuum pack technique [19].

After the damage control operation, patients were transferred to the intensive care unit on ventilator support for secondary resuscitation. Haemodynamic objectives were assessed by the patient's response to pulmonary artery wedge pressure levels. Once the predetermined end points of effective resuscitation were achieved with restoration of physiological haemostasis, the patient was returned to the operating room for definitive treatment including pancreatoduodenectomy and reconstruction.

Definitions

Acidosis was defined as a pH <7.3; hypothermia was defined as a temperature <35 °C; coagulopathy was defined as an INR >1.5. The Denver Multiple Organ Failure scoring system criteria were used to define organ dysfunction and multiple organ failure [20]. The International Study Group on Pancreatic Fistula (ISGPF) classification scheme determined fistula severity [21]. Post-operative complications were classified according to the Dindo–Clavien grading system [22].

Results

Six patients (five men, one woman, median age 20, range 16–39 years) with non-reconstructable AAST grade 5 pancreatoduodenal injuries underwent damage control surgery followed by ICU transfer and physiological stabilisation and subsequent pancreatoduodenectomy and reconstruction when stable (Table 1). Median delay from the time of injury to initial operation was 2 h, range 1–4 h. Mean RTS score was 6508 (range 6171–7108), mean ISS was 38 (range 25–75) and mean Apache II score was 12 (range 4–18). All six patients had associated abdominal injuries with a mean of 3.3 (range 3–6) organs involved. All had non-reconstructable injuries of the head of the pancreas involving the main pancreatic duct, intra-pancreatic distal common bile duct with devitalisation and destruction of the blood supply or combinations of both. In addition, all six patients had associated major visceral venous injuries with profuse retropancreatic bleeding due to portal vein, IVC and renal and lumbar vein injuries (Table 1).

Five patients had injuries to the IVC (Table 1). In three patients the IVC was partially lacerated and repaired with sutures. In one of these patients, lacerations in both the anterior and posterior caval walls were sutured. In two patients, extensive damage precluded repair and the IVC was ligated. In three of these five patients, a right renal vein laceration extended to the IVC and was repaired in addition to the IVC repair. Two of these patients required a right nephrectomy. In one patient, both renal veins were injured and ligated. Patient #5 had in addition problematic bleeding from retroperitoneal lumbar veins. Bleeding from the injured pancreas

Table 1 Clinical details of patients who underwent a pancreatoduodenectomy for trauma

Patient no.	Age (years)	Type of injury	Associated injuries	Vascular injuries	Type of resection	Post-operative complications (Clavien–Dindo grade)	Duration of hospital stay (days)	Follow-up
1	16 M	MVA	D,K,BD	IVC, right renal vein	PPPD	Pancreatic leak (2)	21	Alive, 52 months
2	39 M	GSW	D,L,BD	IVC	PPPD	Coagulopathy MOF (5)	2	Died, 2 days
3	36 M	MVA	D,L,BD	PV	Whipple	Wound sepsis (2)	15	Alive, 12 months
4	20 F	Stab	D,C,BD	IVC, right renal vein	PPPD	I/A sepsis, MOF, ARDS (5)	24	Died, 24 days
5	16 M	GSW	D,C,BD	IVC, lumbar veins	PPPD	Pneumonia, DIC, sepsis (4)	64	Alive, 14 months
6	20 M	GSW	D,S,K,BD	IVC, right and left renal veins	PPPD	Renal failure (3)	14	Alive, 2 months

MVA motor vehicle accident, *GSW* gunshot wound, *C* colon, *S* stomach, *D* duodenum, *K* kidney, *BD* bile duct, *IVC* inferior vena cava, *L* liver, *PV* portal vein, *PPPD* pylorus-preserving pancreatoduodenectomy, *MOF* multi-organ failure, *DIC* disseminated intravascular coagulopathy, *ARDS* adult respiratory distress syndrome

Table 2 Comparison of fluid and blood requirements during the initial DCS and the secondary delayed pancreatoduodenectomy

	Index DCL	Delayed resection
Duration of surgery	113 min (range 90–140 min)	335 min (range 260–395 min)
Estimated blood loss	5456 ml (range 2318–7665 ml)	1250 ml (850–3600 ml)
Mean total intra-operative fluid administered	11,150 ml (range 8450–13,320)	6850 ml (range 3350–9020)
Crystalloid	5000 ml (range 3000–8500)	3000 ml (range 2000–6000)
Blood units packed cells	10 units (range 6–16 units)	6 units (range 0–10 units)
Colloid	1500 ml (range 1000–2500)	1000 ml (range 500–1500)
Fresh frozen plasma	7 units (range 6–8 units)	3 units (range 2–8 units)
Platelets	4 packs (range 2–6)	1 (range 0–4)
Cryoprecipitate	2 (range 0–6)	1 (range 0–2)

was controlled. A portal vein laceration was suture repaired in patient #3. Collateral bowel damage was repaired by sutures or staples to avoid contamination. The bile duct was ligated and a tube cholecystostomy inserted to drain the bile externally. The operative site was widely drained with silastic PenSil drains. The duration of surgery and fluid requirements during the DCS are given in Table 2.

Median time in ICU for continued resuscitation and physiological stabilisation, before returning to the operation room, was 38 h (range 11–92 h). Five patients had a delayed pylorus-preserving pancreatoduodenectomy and one patient who had a pancreatoduodenal injury which involved the pylorus and precluded pylorus preservation underwent a standard Whipple resection. Four patients had a side-to-side hepaticojejunostomy with a stented anastomosis. In two, the bile duct measured 2 mm in diameter and in these two the gallbladder was preserved, the bile duct ligated below the cystic duct insertion and the biliary reconstruction completed using a cholecystojejunostomy. In four patients, the pancreatic stump was oedematous and the anastomosis was completed by draining the pancreatic remnant into the back wall of the stomach as a pancreaticogastrostomy. Two patients had a conventional end-to-side stented pancreaticojejunostomy. The duration of surgery and fluid requirements during the secondary pancreatoduodenectomy and reconstruction are given in Table 2.

Four of the six patients survived. Two patients died in hospital. Both had received massive blood transfusions for complex associated vascular injuries; the first patient received 18 units of packed cells and blood products including fresh frozen plasma, platelets and cryoprecipitate, but died of refractory coagulopathy and multi-organ failure after 48 h. The second patient died of drug-resistant infection after 24 days complicated by recurrent intra-abdominal sepsis, fungemia, multi-organ failure and ARDS despite percutaneous drainage and three laparotomies. The remaining four patients had complications which were managed non-operatively (Table 2). The median duration of intensive care was 6 days, (range 1–20 days) and the median hospital stay was 29 days, (range 3–94 days).

Discussion

The surgical management of severe grade 5 injuries of the pancreas and duodenum is complex and demanding, especially if all the elements comprising the pancreatic head are irreparably damaged [1, 2]. In the small cohort of patients with irretrievable pancreatic head injuries, the only rational surgical option for salvage is a pancreaticoduodenal resection and reconstruction [23]. However, the mortality of an emergency pancreatoduodenectomy in critically injured patients is disproportionately high and exceeds 30 % in collected series [23, 24]. The main factor responsible for this high mortality is the number and severity of the associated vascular injuries coupled with inappropriately prolonged surgery in haemodynamically unstable patients [1, 2].

We have previously reported that a primary pancreatoduodenectomy and reconstruction can be performed safely during the index laparotomy provided the patient is haemodynamically stable without continued blood loss after initial control [1]. Most experts agree that in a critically injured patient who has received a massive blood transfusion and is haemodynamically unstable, hypothermic, coagulopathic and acidotic, prolonged and complex surgery is ill-advised and unlikely to have a satisfactory outcome [3, 25]. Under these adverse conditions, it is crucial to apply damage control principles and stage the procedure by truncating the initial operation and returning later to complete the resection in a favourable environment and a stable patient [25, 26]. In this study, we have shown the usefulness of a staged procedure with initial damage control surgery followed by a delayed secondary pancreatoduodenectomy and reconstruction in critically injured patients with associated major vascular trauma. Despite being near to death on arrival, four of the six patients survived.

Table 3 Pancreatoduodenal resection strategies for complex pancreatic injuries

Category	Pancreatoduodenectomy and reconstruction strategy
A	No damage control laparotomy. Primary pancreatoduodenectomy and reconstruction during the index operation [1, 24]
B	Damage control operation. Primary pancreatoduodenectomy during the index operation. Delayed reconstruction [13, 27–29]
C	Damage control operation only. Staged delayed secondary pancreatoduodenectomy with reconstruction [1, 3]
D	Damage control operation only. Delayed pancreatoduodenal resection. Multistaged delayed reconstruction [30]

While there are several small published series [24, 25] confirming the worth of initial damage control surgery in complex pancreaticoduodenal injuries, there is no agreement on how to manage severe pancreatic injuries during the damage control phase. In particular, there are no published data detailing the benefits of instituting an initial damage control operation and delaying the pancreatoduodenectomy and reconstruction in terms of fluid management and blood requirements, nor are there accurate data on the timing of the relook and reconstruction after ICU resuscitation. Analysis of the existing published data shows that several strategies of dealing with the pancreatic injury during damage control laparotomy have been proposed and implemented (Table 3). All these methods involve an initial DCS to achieve control of bleeding and prevention of bowel contamination. The management of the pancreatic injury has differed substantially with either a primary resection and delayed reconstruction or a delayed secondary resection with reconstruction (Table 3). The first category involves the initial DCS and an immediate pancreatoduodenectomy with stapled closure of the pancreas, bowel and bile duct. Reconstruction is completed in a stable patient 36 h later. This technique was used by Eastlick and colleagues [27]. In their report the pancreas was not anastomosed during the reconstruction and the patient received permanent exocrine replacement. Koniaris [12] reported reconstruction 72 h later and Yong [28] reconstruction 96 h later. In a series from India, Gupta, Wig and Garg undertook reconstruction in four patients between 6 and 28 weeks after the initial pancreatoduodenectomy [29]. In a report by Mistry and Durham, DCS was performed with a secondary pancreatoduodenectomy 30 h later and the final reconstruction delayed until 10 weeks later. Pancreatic drainage was never re-established [30].

In the USC Medical Centre series reporting 18 patients who had a pancreatoduodenectomy for trauma, 5 (28 %) underwent initial damage control and staged reconstructive procedures [24]. However, no data or details are provided on the technique or timing of the reconstruction [24]. In a two-centre retrospective study from Philadelphia and Columbus, Ohio, on 42 patients who had sustained pancreatic injuries and had DCS, three patients underwent a pancreatoduodenectomy, one during the DCS with delayed reconstruction, and two had a delayed pancreatoduodenectomy and reconstruction [3] (Table 3). In a Seattle study, 12 patients had DCS as their initial operation and pancreatoduodenectomy performed in two stages in eight patients and in three stages in four patients. No information is provided regarding the timing of reconstruction [26].

The benefits of DCS in the literature are self-evident and substantial [31–33]. The objective is survival of the patient and the prevention and correction of those factors which threaten survival. It is prudent and safer to delay primary definitive care and use a staged approach, especially if the patient has significant physiological derangement [18]. A previous study from our trauma centre found that age, base excess, pH and core temperature were significant pre-operative predictors of death [16]. The study recommended that the specific trigger points at which DCS should be implemented were when pH falls below 7.20, the base excess exceeds −10.5 and the core temperature is less than 35 °C [16]. This is especially important when associated vascular repair has necessitated cross-clamping of major vessels with consequent reduced tissue perfusion.

The optimal timing of reoperation after initial DCS has not been standardised in previous publications and requires careful strategic consideration. Our policy has been that once the predetermined end points of effective resuscitation were achieved with restoration of physiological haemostasis including core temperature, normal coagulation and biochemistry, the patient was returned to the operating room for definitive treatment. Premature return to the operating room may result in increased rebleeding and the need for additional operations [34]. Patients who are returned to the operating room within 72 h have been shown to have improved morbidity and mortality, compared with patients who return later.

The effective treatment of complex pancreatic injuries associated with vascular damage continues to be a major challenge for surgeons dealing with abdominal trauma. The surgical decision to implement a damage control strategy is not regarded as a surgical retreat, but recognition that successful trauma surgery demands attention not only to the extent and magnitude of collective injuries sustained but also demands a careful assessment of the physiological status of the patient. It is important to identify the need for DCS at an early stage. Careful patient selection is crucial

for survival and prolonged surgical procedures consciously avoided. It is essential to appreciate that a damage control approach can be used in smaller hospitals where experience with complex pancreatic and vascular injuries may be limited or where the necessary resources are not available. After control of bleeding and contamination, the patient should be transferred to a major trauma centre where both trauma and HPB surgeons experienced in the management of proximal pancreatic resections and reconstruction are available.

Conflict of interest J E Krige, P H Navsaria and A J Nicol declare that they have no conflict of interest.

Compliance with ethical requirements This study was approved by the Human Research Ethics Committee at the University of Cape Town Health Sciences Faculty and conforms to the ethical standards in the 1964 Declaration of Helsinki.

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