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Surgical techniques for modular one-stage emergent pancreaticoduodenectomy for blunt abdominal trauma: experiences from three centres and a review of the literature

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Abstract

Background In this study, we report the use of a complex surgical intervention termed modular one-stage emergent pancreaticoduodenectomy (MOEPD) for the treatment of acute Grade IV or V pancreaticoduodenal injuries in haemodynamically stable patients. We summarize the experiences of surgeons performing MOEPD in 12 patients from 3 centres.

Methods From 2015 to 2021, the clinical data of patients with blunt abdominal trauma who underwent MOEPD were extracted from three Chinese centres. The patients' perioperative variables were assessed.

Results All twelve MOEPD cases were analysed. All patients had Grade IV or V pancreatoduodenal injuries and received intensive antishock treatment for haemodynamic stabilization. The mean age of the patients was approximately 45.2 years (22–74 years). Ten patients (83.3%) were male. In contrast to the ten patients who underwent pancreaticoduodenectomy (PD), two patients underwent laparoscopic pancreaticoduodenectomy (LPD). Two patients presented with a combination of severe abdominal injuries. None the patients died in the perioperative period. Five patients (41.7%) experienced postoperative complications. A postoperative pancreatic fistula (POPF) was detected in 16.7% of patients, both of whom recovered within 3–4 weeks with conservative drainage. All patients were released from the institutions after an average of 31.8 days (21–53 days). There was no statistically significant

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difference in the incidence of complications between the 20 reviewed studies and this group (60.7% vs. 41.7%, $P=0.33$), but the mortality rate was lower in this group (26.6% vs. 0%, $P=0.04$).

Conclusions The experiences at these 3 centres suggest that MOEPD may be a lifesaving procedure for haemodynamically stable patients with acute Grade IV or V pancreatoduodenal injuries, despite the small sample size of this study.

Clinical trial number Not applicable.

Keywords Modular one-stage emergent pancreaticoduodenectomy (MOEPD), Blunt abdominal trauma, Surgical techniques, Pancreaticojejunostomy

Introduction

Severe blunt abdominal trauma can result in pancreaticoduodenal injury, which is often severe and can be life-threatening. Grade I–III pancreaticoduodenal injuries were managed by conservative treatment with a smoother clinical course and good prognosis according to the previous studies. However, damage control surgery (DCS) including debridement and drainage may be performed for haemodynamically unstable patients with Grade IV or V pancreaticoduodenal injuries, and one-stage pancreaticoduodenectomy (PD) may be performed for haemodynamically stable patients.

Unlike elective PD, emergent pancreaticoduodenectomy (EPD) is performed to address severe injuries in the pancreas-periduodenal area. However, there have been no large-sample comprehensive studies, and the mortality rate remains approximately 30% [1]. This can be attributed to the specific nature of the trauma location. This type of trauma often results in damage to the pancreas and duodenum, along with damage to the surrounding colon, stomach, extrahepatic biliary system, mesenteric blood vessels, and other vital tissues. Furthermore, considering that patients are often in poor health, their haemodynamics are frequently severely impacted. Additionally, the soft texture of the pancreas and the relatively narrow main pancreatic duct increase the complexity of the surgery and the incidence of postoperative complications. The prognosis of these patients is determined by the proficiency and expertise of the surgeons. Owing to the infrequency of this procedure, few studies on EPD techniques exist. A standardized surgical approach for EPD is needed. This research introduces the idea of modular one-stage emergent pancreaticoduodenectomy (MOEPD) and provides a summary of the surgical outcomes of twelve patients across three institutions for peer review. A thorough literature review was subsequently performed.

Patients and approaches

We define MOEPD as the process that involves initially determining whether to perform a one or two-stage surgery based on the patients' haemodynamic status, followed by the selection of either LPD or PD, and then proceeding with standardized surgical procedures.

Basic patient information

We retrospectively queried the data at three centres in China, namely, the Affiliated Yixing Hospital of Jiangsu University (TAYHJU) in Jiangsu, Hunan Provincial People's Hospital (HPPH) in Hunan, and the Affiliated Hospital of North Sichuan Medical College in (TAHNSMC) Sichuan, for MOEPD procedures performed over the past six years (2015–2021). The inclusion criteria were as follows: (1) blunt abdominal trauma, (2) grade IV or V pancreaticoduodenal injuries, (3) stable preoperative haemodynamic status, (4) one-stage PD or laparoscopic pancreaticoduodenectomy (LPD), and (5) informed consent for surgery. All twelve patients who underwent MOEPD were included in this research. The following data were reviewed preoperatively: age, sex, mechanism of injury, comorbidities, history of trauma or surgery, and haemodynamic status. The surgical approach, duration of surgery and amount of blood loss were recorded intraoperatively. Length of stay and complications were evaluated postoperatively.

Operation approaches

The main surgical steps was similar at all three centres. The specific surgical aspects were as follows: (1) The length of the preserved gastroduodenal artery (GDA) stump was approximately 0.5 cm. The procedure involved two methods: ligation with 2–0 braided silk threads and clipping with hem-o-lok clips (Fig. 1A). (2) The uncinate process of the pancreas was then fully resected along the right wall of the superior mesenteric artery (SMA), and the inferior pancreaticoduodenal artery (IPDA) was appropriately managed (Fig. 1B). (3) Before the pancreas was cut, it was ligated with 0–0 braided silk threads at the proximal end. The pancreas was then "coldly incised" with scissors to locate the main pancreatic duct. A silicone stent tube suitable for the inner diameter of the main pancreatic duct was inserted into the main pancreatic duct and secured in situ using 4–0 Prolene sutures (Fig. 1C). (4) The bleeding part of the pancreas was cauterized using electrocoagulation. The stump of the

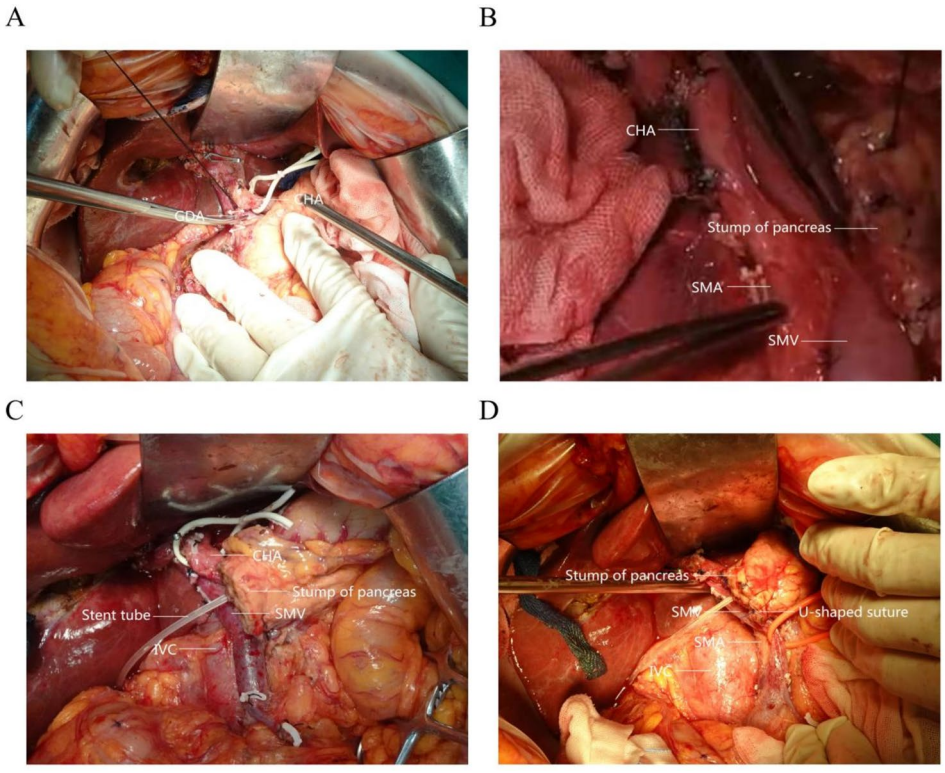


Fig. 1 Critical procedures for the extirpative part of MOEPD. (**A**) GDA was treated by double disposals. (**B**) The uncinate process of pancreas was completely resected. *There was an anatomical variation: CHA arose from SMA. (**C**) A sillicone stent tube was placed into the main pancreatic duct of stump of pancreas. (**D**) The stump of pancreas was U-shaped sutured with 3 – 0 prolene sutures. (CHA: common hepatic artery. IVC: inferior vena cava)

pancreas was dissected to a length of approximately 3 cm and sutured in a U shape using 3–0 Prolene sutures in preparation for anastomosis (Fig. 1D). (5) The tip of the electrocoagulation needle was used to pierce the opposite jejunal wall to the mesentery, and then the silicone stent tube was inserted into the opening (Fig. 2A). We conducted pancreaticojejunostomy using our modified method, known as "full-thickness U-suture combined with ductomucosal anastomosis" (Fig. 2B, C). ① When the diameter of the main pancreatic duct was less than 5 mm, interrupted, longitudinal and full-thickness "U-shaped" sutures were placed through the pancreas twice according to the width of the pancreas section, and the middle two sutures were placed as close as possible to the main pancreatic duct. ② When the diameter of the main pancreatic duct exceeded 5 mm, a ductomucosal anastomosis was created between the main pancreatic duct and jejunum after step ①. The pancreas is fragile and easily incised during surgery. Sutures should be tied carefully, with moderate power, to prevent damage. (6) At approximately 5 cm from the site of the pancreatic-intestinal anastomosis, the intestinal wall opposite the mesenterium of the jejunum was incised, with a diameter comparable to that of the bile duct opening. End-to-side hepaticojejunostomy was conducted using interrupted 4–0 polydioxanone sutures. A T-tube with an appropriate diameter was inserted into the proximal end of the common hepatic duct, positioned 1 cm from the anastomosis, with the long arm of the T-tube passing through the anastomosis. (7) Gastrojejunostomy was performed approximately 40 cm below the biliary-intestinal anastomosis using a tubular stapler (Fig. 2D, E). (8) A gastrojejunal decompression tube was inserted and passed through the gastrointestinal anastomosis and into the input loop. A jejunal feeding tube was inserted approximately 40 cm distal to the gastrointestinal anastomosis into the output loop. Both tubes were secured (Fig. 2F). (9) Two spiral negative pressure drainage tubes were placed above and below the three anastomotic stomas. (10) The omentum was used to wrap the pancreatic-intestinal anastomosis, and the falciform ligament was used to wrap the GDA stump.

Statistical analyses

Quantitative and qualitative variables are expressed as means and frequencies (%), respectively. Categorical variables were compared using Fisher's exact test or Yate's continuity correction chi-square test. A $P < 0.05$ indicated statistical significance. SPSS version® 27 (IBM, Armonk, NY, USA) was used for statistical analyses.

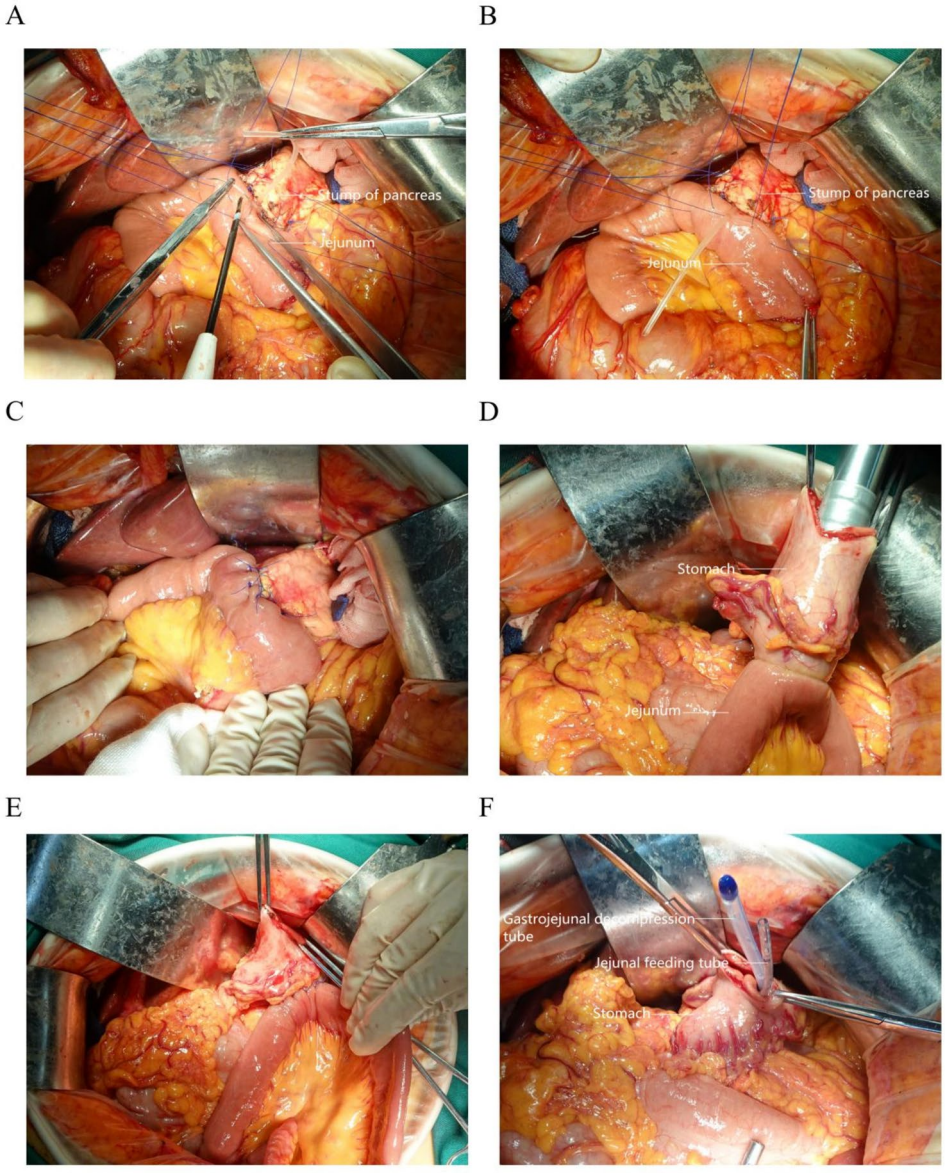


Fig. 2 Vital details of alimentary canal reconstruction. (**A**) A needle tip was used to pierce the opposite jejunal wall to the mesentery using electrocoagulation. (**B**) Pancreaticojejunostomy was performed followed the standard protocol called "full-thickness U-suture combined with ductomucosal anastomosis". (**C**) Pancreaticojejunostomy had been performed. (**D**) Gastrojejunostomy was created with a tubular stapler. (**E**) Gastrojejunostomy had been performed. (**F**) The gastrojejunal decompression tube and the jejunal feeding tube were placed

Results

From 2015 to 2021, we identified 12 patients from 3 centres (5 from TAYHJU, 5 from HPPH, and 2 from TAHNSMC) who had undergone MOEPD for trauma. The mean age of this cohort was approximately 45.2 years (22–74 years). Ten patients (83.3%) were male. Ten patients underwent PD, while the other two patients underwent laparoscopic pancreaticoduodenectomy (LPD). Two patients had a combination of severe abdominal injuries. One patient underwent right hemicolectomy for colonic and mesenteric injuries, while the other patient underwent repair of the SMA and ligation of the splenic vein (SV) for significant vascular injuries. Every patient remained haemodynamically stable during the perioperative period with antishock therapy, which included rapid rehydration and transfusion of red blood cells and fresh frozen plasma. The average intraoperative blood loss volume for all patients was 2190 ml. The surgeries were relatively complex, with an average operation time of 379 min (Table 1).

None of the patients died in the perioperative period. Postoperative complications occurred in 5 out of 12 patients (41.7%). The complications were graded according to the Clavien–Dindo classification and are presented

Table 1 Characteristics of patients undergoing MOEPD from 2015 to 2021 at the three institutions

No.	Age (y)	Gender	Comorbidities & history of trauma or surgery	Primary injury	Combined injuries	Preoperative hemodynamic status	Procedure	Blood loss (mL)	Operation time(min)	Complications & treatment	Length of stay
1	41	Male	None	1. Transection of the pancreatic head (IV)	None	Shock	PD	2000	375	Pleural effusion(Thoracocentesis and drainage)	26
2	43	Male	None	1. Disruption of D1 + D2 + D3 of the duodenum (V) 2. Massive disruption of the pancreatic head (V)	1. Rupture of the stomach 2. Compression fractures of the vertebral body (L1, L2)	Normal	PD	2000	355	Pleural effusion(Anti-infection management)	29
3	49	Male	None	1. Transection of the descending part of the duodenum (V) 2. Transection of the uncinate process of the pancreas (IV)	1. Extensive injury of mesocolon 2. Compression fractures of the vertebral body (L3)	Normal	PD	200	400	Abdominal effusion (Abdominal puncture and drainage)	24
4	48	Male	None	1. Disruption of the horizontal part of the duodenum (III) 2. Massive disruption of the pancreatic head (V)	None	Normal	LPD	NA	365	None	24
5	34	Male	None	1. Disruption of the descending part of the duodenum (V) 2. Contusion and laceration of the pancreatic head involving the ampulla (IV)	1. Contusion of the right kidney	Normal	LPD	NA	395	None	21
6	74	Female	Stage II essential hypertensive	1. Disruption of the descending part of the duodenum (V) 2. Massive disruption of the pancreatic head (V)	1. Injury of transverse mesocolon	Normal	PD	2200	380	None	53
7	55	Male	Stage II essential hypertensive	1. Massive disruption of the pancreatic head (V)	1. Liver rupture	Shock	PD	3000	405	None	42
8	46	Male	None	1. Disruption of the horizontal part of the duodenum and devascularization of duodenum (V) 2. Massive disruption of the pancreatic head (V)	1. Injuries to the right colon and mesentery	Shock	PD + Right hemicolectomy	3500	435	None	26
9	22	Male	None	1. Transection of the descending part of the duodenum (V) 2. Massive disruption of the pancreatic head (V)	1. Fracture of the sternum 2. Compression fractures of the vertebral body (T12-L1)	Normal	PD	500	315	None	23

Table 1 (continued)

No.	Age (y)	Gender	Comorbidities & history of trauma or surgery	Primary injury	Combined injuries	Preoperative hemodynamic status	Procedure	Blood loss (mL)	Operation time(min)	Complications & treatment	Length of stay
10	58	Male	Stage I essential hypertensive	1. Disruption of the horizontal part of the duodenum and devascularization of duodenum (V) 2. Transection of the uncinate process of the pancreas (IV)	1. Injury to the superior mesenteric artery 2. Rupture of the splenic vein 3. Laceration of the greater omentum 4. contusion of bilateral kidney	Normal	PD + Repair of the superior mesenteric artery + Ligation of the splenic vein + Repair of the greater omentum	4000	385	Pancreatic fistula(Continuous drainage)	41
11	42	Male	None	1. Disruption of the descending part of the duodenum (V) 2. Transection of the pancreatic head (IV)	None	Normal	PD	2000	355	Pancreatic fistula(Continuous drainage)	45
12	30	Female	None	1. Massive disruption of the pancreatic head (V)	1. Extensive mesenteric injury	Normal	PD	2500	385	None	28

in Table 2. The incidence of postoperative pancreatic fistula (POPF) was 16.7%. Both patients were classified as having Grade B POPFs according to the International Study Group on Pancreatic Fistula and recovered after 3–4 weeks with conservative drainage. In addition, two patients in this cohort had postoperative pleural effusion. One patient was treated with thoracentesis and drainage, while the other received only anti-infection therapy. One patient developed abdominal effusion and was cured with abdominal puncture and drainage. All patients ultimately recovered and were discharged, with a mean length of hospital stay of 31.8 days (21–53 days). Table 3 presents a list of published literature on EPD [1–20]. There was no statistically significant difference in the incidence of complications between the 20 reviewed studies (Table 3) and this group (60.7% vs. 41.7%, $P=0.33$) (Fig. 3A), but the mortality rate was lower in this group (26.6% vs. 0%, $P=0.04$) (Fig. 3B).

Discussion

In patients with abdominal trauma, pancreatoduodenal injuries occur at a relatively low rate (4%), but the consequences are far more severe than those of other abdominal injuries. Retrospective studies indicate that approximately 30% of individuals with pancreatoduodenal injuries who undergo EPD have postoperative complications. Postoperative complications may include POPF, bile leakage, traumatic pancreatitis, abdominal infection, postoperative haemorrhage, and pancreatic pseudocysts. The incidence of POPF is the highest, at approximately 10-18%, with a total postoperative mortality of approximately 28.2% [21, 22]. Owing to advancements in surgical techniques and surgeons becoming experts in pancreatic surgery, EPD has become safer, resulting in fewer postoperative complications and a considerable decrease in mortality. Pancreatic surgeons have become increasingly proficient in performing EPD in emergencies.

Most pancreaticoduodenal injuries are mild and can be managed without surgery. Noninvasive therapy is safe for individuals with Grade I or II pancreatoduodenal injuries. However, Grade IV and V damage to the pancreas and duodenum along with severe damage to surrounding tissues and blood vessels are indications for surgical EPD (Table 4) [23, 24]. However, one-stage or two-stage EPD remains the subject of controversy. M.E.A.J. de Carvalho et al. [21] reviewed 22 articles and concluded that the haemodynamic status of trauma patients affected the surgical method and strategy selected. Among the patients with Grade IV or V pancreatoduodenal injuries, those who were haemodynamically stable had higher survival rates when they received one-stage EPD; however, for haemodynamically unstable individuals with such injuries, the survival rates did not differ between one- and two-stage EPD. Moreover, most studies have suggested

Table 2 Clavien-Dindo classification of surgical complications

The Claviene-Dindo classification of surgical complications	Number of patients with complications (%)	Complications incidence
Grade I	0(0)	None
Grade II	3(25.0%)	Pleural effusion (1), Pancreatic fistula(2) (ISGPF Grade B)
Grade III	2(16.7%)	Pleural effusion (1), Abdominal effusion (1)
Grade IV	0(0)	None
Grade V	0(0)	None

ISGPF: International Study Group on Pancreatic Fistula

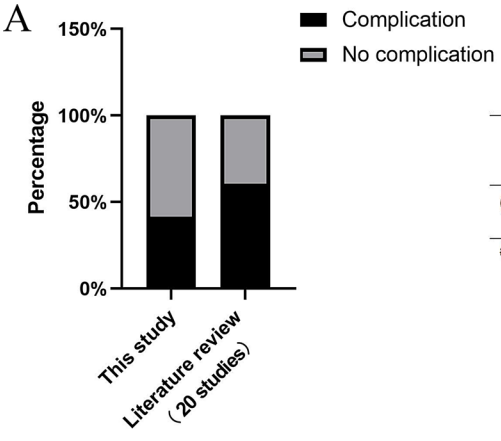
that two-stage EPD is more suitable for haemodynamically unstable patients [20, 24]. It is important to note that severe trauma patients often experience a disruption of homeostasis, particularly those with unstable haemodynamic status. If such patients are further subjected to the stress of a prolonged and complex surgery, such as one-stage EPD, their physiological imbalance may enter a vicious cycle, thereby complicating recovery. Therefore, for haemodynamically unstable patients, DSC is simple and rapid. This approach provides the opportunity for subsequent treatments such as two-stage EPD once the patients' overall condition have improved. DCS, centred on debridement and drainage, is a quick and straightforward procedure that reduces the risk of secondary trauma and facilitates faster recovery [25]. Notably, on the basis of our clinical experience and relevant literature, patients who are considered haemodynamic stable typically receive fewer than 6 units of packed red blood cells within 6 h after injury and have a stable systolic blood pressure above 90 mmHg, a heart rate less than 120 beats per minute, and a base excess (BE) > -6 mmol/L.

In this study, we report the surgical experience of twelve patients who underwent EPD in three institutions and did not die. All patients suffered from Grade IV or V pancreatoduodenal injuries (Fig. 4A-D), and two patients had severe abdominal collateral injuries. In this cohort, three patients presented with shock upon admission and received intensive antishock treatment for haemodynamic stabilization before surgery. The other nine patients remained stable during the perioperative period. Thus, all twelve patients met the criteria for one-stage EPD.

Over the years, our three medical centres have established close connections. Surgeons from these centres frequently share their clinical experiences and participate in surgical training both online and offline. We share surgical videos and clinical data for research purposes. We have reached a consensus on the key aspects of EPD surgery, adopting a fundamentally consistent surgical approach, allowing us to conduct this multicentre retrospective study together. Furthermore, all three medical institutions are top-grade comprehensive hospitals,

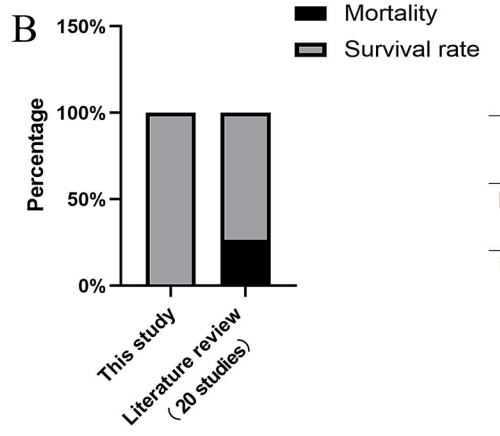
Table 3 Results of this study and review of case series reported in the literature on EPD

Author	Year	Number	Mechanism (*N*)			Mortality (*N*/%)	Complication (*N*/%)	Preoperative haemodynamics (*N*)		stage	
			Penetrating	Blunt	Operative			Shock	Normal	1st	2st
Xing Wang et al.	2024	12	0	12	0	0(0)	5(41.7)	3	9	12	0
Menahem et al.	2016	1	1	0	0	0(0)	1(100.0)	1	0	1	0
Schroeppel et al.	2016	3	3	0	0	2(66.7)	2(66.7)	0	3	3	0
Bao et al.	2015	8	0	8	0	1(12.5)	6(75.0)	1	7	8	0
Krige et al.	2014	19	13	6	0	3(15.8)	16(84.2)	5	14	14	5
Van der Wilden et al.	2014	39	30	9	0	13(33.3)	6(15.4)	23	16	39	0
Aiste Gulla et al.	2013	10	3	4	3	0(0)	8(80)	6	4	10	0
Thompson et al.	2013	15	10	5	0	2(13.3)	13(86.7)	15	0	3	12
Chinnery et al.	2011	13	13	0	0	3(23.1)	Unknown	Unknown	Unknown	9	4
Tan et al.	2009	3	0	3	0	2(66.7)	1(33.3)	2	1	1	2
Seamon et al.	2009	3	3	0	0	0(0)	Unknown	2	1	1	2
Gupta et al.	2008	5	2	3	0	1(25)	Unknown	5	0	2	3
Lin et al.	2004	2	0	2	0	1(25)	Unknown	2	0	2	0
Asensio et al.	2003	18	17	1	0	5(27.8)	18(100)	Unknown	Unknown	18	0
Oláh et al.	2002	2	0	2	0	0(0)	Unknown	1	1	2	0
Boghdadly et al.	2000	2	0	2	0	2(100)	Unknown	1	1	1	1
Oreskovich et al.	1984	10	7	3	0	0(0)	1(10)	9	1	10	0
Jones et al.	1978	7	5	2	0	3(42.9)	4(57.1)	5	2	7	0
Yellin et al.	1975	10	8	2	0	6(60)	10(100)	4	6	10	0
Anderson et al.	1973	2	2	0	0	1(50)	1(50)	1	1	2	0
Smith et al.	1971	5	4	3	0	2(40)	4(80)	2	3	5	0



	This study (N/%)	Literature review of 14 studies (N/%)	*P*#
Complication	5 (41.7)	91 (60.7)	0.33

Yates' continuity correction chi-square test



	This study (N/%)	Literature review of 20 studies (N/%)	*P**
Mortality	0 (0)	47 (26.6)	0.04

* Fisher's exact test

Fig. 3 The comparison of complication rate and mortality between the 20 reviewed studies and this group. (**A**) There was no statistically significant difference in the incidence of complications (60.7% vs. 41.7%, *P* = 0.33). (**B**) The mortality was lower in this group (26.6% vs. 0%, *P* = 0.04)

Table 4 Pancreaticoduodenal injury scale by the American Association for the Surgery of Trauma (AAST)

Grade	Organ	Injury description	Number(%)
I (Hematoma /Laceration)	Pancreas	a. Minor contusion without ductal injury	0
		b. Superficial laceration without ductal injury	
	Duodenum	a. Hematoma: involving a single portion of duodenum	0
		b. Laceration: partial thickness, no perforation	
II (Hematoma /Laceration)	Pancreas	a. Major contusion without ductal injury or tissue loss	0
		b. Major laceration without ductal injury or tissue loss	
	Duodenum	a. Hematoma: involving more than one portion	0
		b. Laceration: with disruption of less than 50% of circumference	
III (Laceration)	Pancreas	Distal transection or parenchymal injury with ductal injury	0
	Duodenum	a. Disruption 50–75% of circumference of D2	1 (8.3%)
		b. Disruption 50–100% of circumference of D1, D3, and D4	
IV (Laceration)	Pancreas	Proximal transection or parenchymal injury involving the ampulla	5 (41.7%)
	Duodenum	Disruption > 75% of circumference of D2 involving ampulla or distal common bile duct	0
V (Laceration)	Pancreas	Massive disruption of the pancreatic head	7 (58.3%)
	Duodenum	a. Laceration: massive disruption of duodeno-pancreatic complex	8 (66.7%)
		b. Vascular: devascularization of duodenum	

with appropriate hardware and experienced physicians. Additionally, as medical institutions in China, we primarily treat patients with blunt trauma, with similar mechanisms of injury. All these conditions ensure the homogeneity of our research subjects and the uniformity of the surgical methods.

Compared to patients undergoing elective PD, those undergoing EPD are in a state of trauma and the most

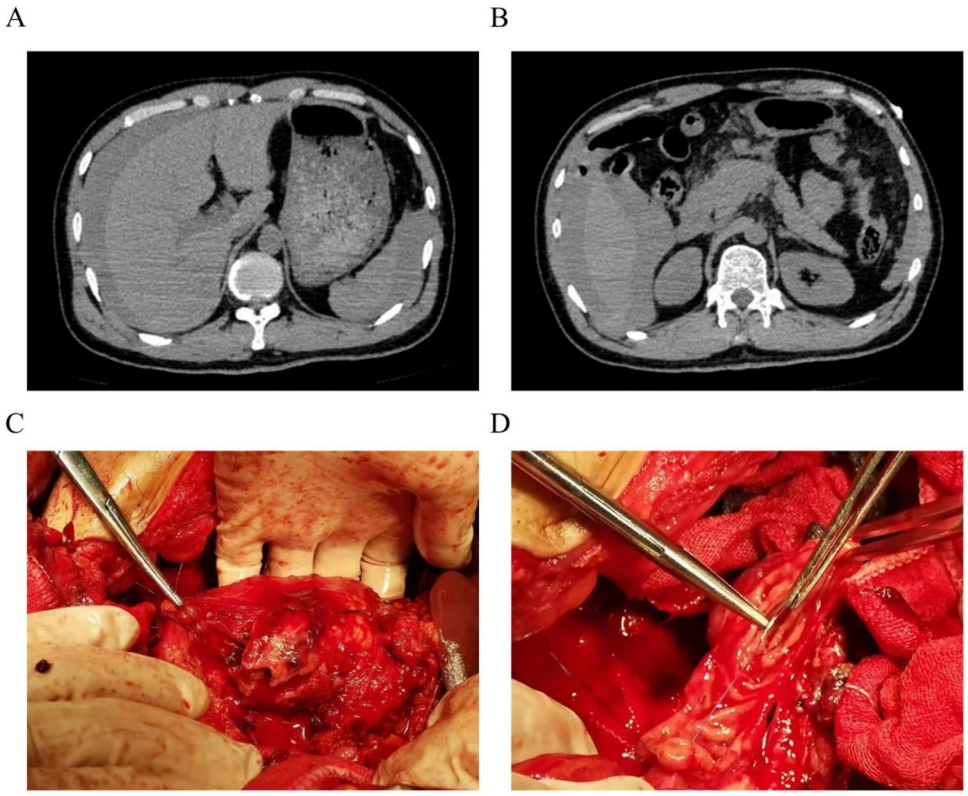


Fig. 4 Preoperative CT images and intraoperative exploration of one patient. (**A**) CT image: abdominal fluid. (**B**) CT image: swollen pancreatic head. (**C**) Massive disruption of the pancreatic head. (**D**) Disruption of the horizontal part of the duodenum

critical preoperative assessment is the patients' haemodynamic status. Furthermore, several factors contribute to a poor prognosis and increased surgical difficulties of trauma patients: the pancreas exhibits a soft consistency, the main pancreatic duct is generally narrow (<5 mm), intraoperative blood loss is substantial (>400 ml), the pancreas is of a high-risk pathological type (other diseases besides pancreatic cancer or chronic pancreatitis), and the common bile duct is not dilated. These factors necessitate special modifications in surgical techniques to address the challenges. We have summarized and simplified the operational procedure of MOEPD (Fig. 5). Unlike traditional surgery, the special surgical techniques in MOEPD are summarized below: (1) Management of main pancreatic duct: Different from the pancreas with tumors, the emergent traumatic pancreas often lacks fundamental lesions like chronic pancreatitis and is identified by its comparatively soft texture and absence of a dilated pancreatic duct. Therefore, we separated the pancreas using a "cold incision" technique, without energy equipment, to make it easier to locate the main pancreatic duct. In addition, the precise placement of the pancreatic duct stent tube during surgery was crucial due to the unique texture of the pancreas and the narrow diameter of the main pancreatic duct. We highlight the use of 4 – 0 prolene sutures to anchor the stent tube in the main pancreatic duct. (2) Management of the pancreatic cross-section: We used 3–0 Prolene sutures to suture the pancreatic cross-section in a "U-shaped" pattern. This process has three benefits. First, it may efficiently stop bleeding and prevent postoperative haemorrhage of the pancreatic stump induced by different factors. Second, it may increase the tension of delicate pancreatic tissue, making it more favourable for pancreaticojejunostomy. It may also close the orifices of the accessory pancreatic ducts to minimize the risk of POPF development. (3) Pancreaticojejunostomy: Various types of pancreaticojejunostomies exist worldwide; however, most experts agree that every suture should pass through the entire thickness of the pancreas at least once. We used a modified pancreaticojejunostomy technique named "full-thickness U-suture combined with ductomucosal anastomosis". We used the U-suture technique to ensure that each suture passed through the whole thickness of the pancreas twice, which was more effective for preventing the development of early POPF and fistula of the posterior wall (Fig. 6A). We did not directly incise the intestinal wall with an electrotome but rather with the needle tip. The aim of using the tip of the electrocoagulation needle to penetrate the intestinal canal is to create the smallest possible incision in the intestinal wall and reduce the space between the intestinal wall and

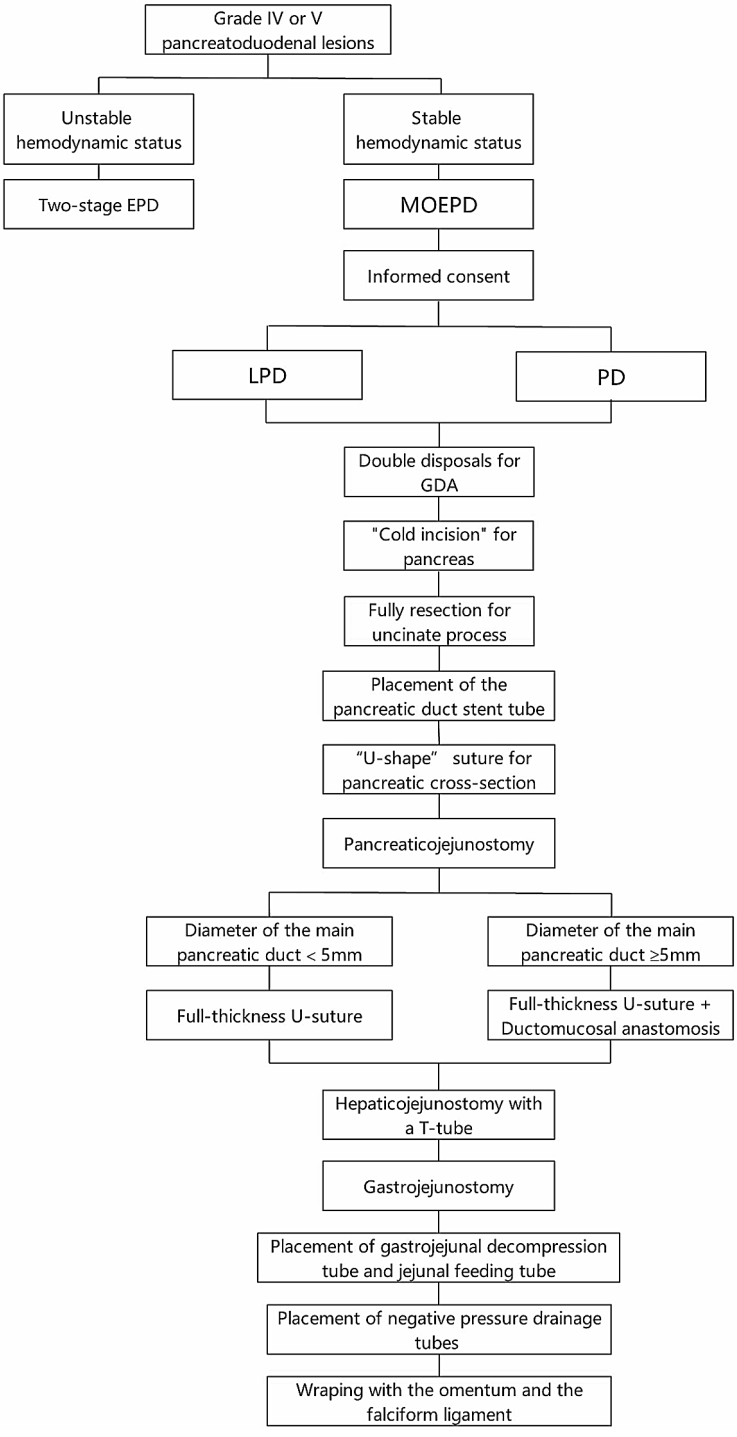


Fig. 5 Surgical procedure flowchart for patients with Grade IV or V pancreatoduodenal lesions

the pancreatic stent tube. This approach can achieve the same result and is quicker than using purse string sutures to secure the pancreatic stent tube in the intestinal wall, as recommended by other scholars. It is recommended that the two sutures near the main pancreatic duct be placed as close as possible to the pancreatic stent duct to minimize the "micro dead space" between the pancreatic cross-section and the intestinal wall. This may promote healing of the pancreaticojejunal anastomosis. In most cases of trauma, the main pancreatic duct has a diameter of 5 mm or less. Nevertheless, the diameter exceeds 5 mm in certain instances. We created a "ductomucosal anastomosis" between the main pancreatic duct and the jejunum in these patients to prevent leakage of pancreatic

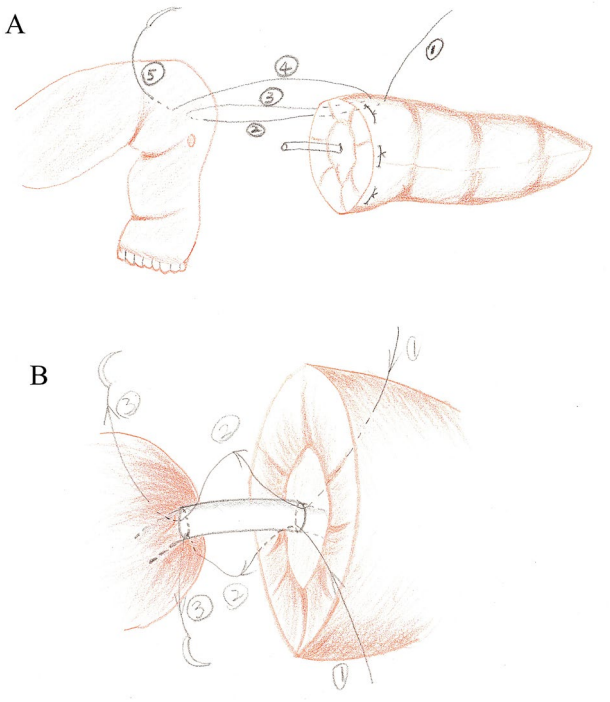


Fig. 6 The modified pancreaticojejunostomy called "full-thickness U-suture combined with ductomucosal anastomosis". (**A**) A kind of interrupted, longitudinal and full-thickness " U-shaped " suturing through the pancreas twice. (**B**) "Ductomucosal anastomosis" of the main pancreatic duct and the jejunum

juice around the stent tube (Fig. 6B). This modified pancreaticojejunostomy technique may be adaptable to the various sizes of the main pancreatic duct. This technique combines the benefits of many traditional pancreaticojejunostomy methods, such as Blumgrt anastomosis [26] and Chen's anastomosis [27], while also addressing the limitations of any isolated anastomosis. It aims to minimize the risk of leakage of pancreatic juice and the activation of pancreatic enzymes while maintaining patency and preventing strictures in the pancreatico-intestinal anastomosis. Overall, this type of pancreaticojejunostomy is straightforward and easily adaptable. It is also appropriate for pancreases with diverse textures and diameters of the main pancreatic duct. (4) Hepaticojejunostomy: Both intermittent and continuous sutures with absorbable materials can be feasible. We often inserted a T-tube in high-risk patients with common bile ducts not dilated to provide a smooth pathway for bile decompression, aiming to decrease pancreatin activation. This kind of anastomosis promotes the successful healing of the biliary-intestinal anastomosis and helps prevent the potential activation of secondary pancreatin.

LPD is still rarely performed in patients with trauma. All the surgeons at our three medical centres are proficient in elective LPD. The key techniques and principles of PD and LPD, such as the three anastomoses, are essentially consistent, ensuring the homogeneity of the study. For patients with acute injuries, the indications for PD or LPD are essentially the same: haemodynamically stable patients with Grade IV and V pancreatoduodenal lesions. For all haemodynamically stable patients with abdominal trauma, either open or laparoscopic surgery can be chosen, unaffected by the severity of the injury or the surgeon's preference, as long as the family provides informed consent. If severe contamination and structural disorder in the abdominal cavity leading to unclear visualization are encountered during LPD, or if there is an emergency with uncontrollable bleeding, conversion to open surgery may be necessary. In this study, only two patients' families agreed to undergo LPD, and neither required conversion to open surgery. They both had favourable postoperative results without any severe complications. Preliminary evidence has shown that LPD is effective and safe in treating abdominal injuries, but more extensive trials are needed to confirm its benefits (Fig. 7).

POPF and related complications are the leading causes of death after PD and EPD. A recent study revealed that postoperative acute pancreatitis (AP) is a frequent complication in the early stages following PD and is an independent risk factor for the development of POPF [28]. POPF formation is linked to the delicate texture of the acutely damaged pancreas and the narrow main pancreatic duct [29, 30]. Several variables, including the removal of numerous organs, extensive surgical injuries, prolonged operative times, excessive handling of the remaining pancreatic tissues, and insufficient blood flow or congestion in the remaining pancreatic tissues, might increase the risk of postoperative AP [31]. Furthermore, perioperative hypoxia, hypotension and medication usage may cause or worsen AP [32]. In this study, we used several approaches to decrease the occurrence of AP and POPF. First, reliable pancreaticojejunostomy and the surgical techniques related to pancreaticojejunostomy mentioned previously are central to our approach in reducing the risk of fatal postoperative complications. Additionally, during the procedure, the left branch of the pancreatic dorsal artery was preserved, and mild dissection of the pancreatic stump was performed to ensure proper pancreatic blood flow and avoid residual pancreatic ischaemia. When dissecting the portal vein (PV), SMV and SV, it is important to handle these vessels with care and avoid blocking them for a prolonged period. The diameter of the pancreatic stent tube should match the diameter of the main pancreatic duct. The pancreatic stent tube should be trimmed using scissors to create lateral holes and inserted into the pancreatic stump not too tightly to avoid occluding the main pancreatic duct. We made every effort to minimize the gap between the main pancreatic duct and jejunum during

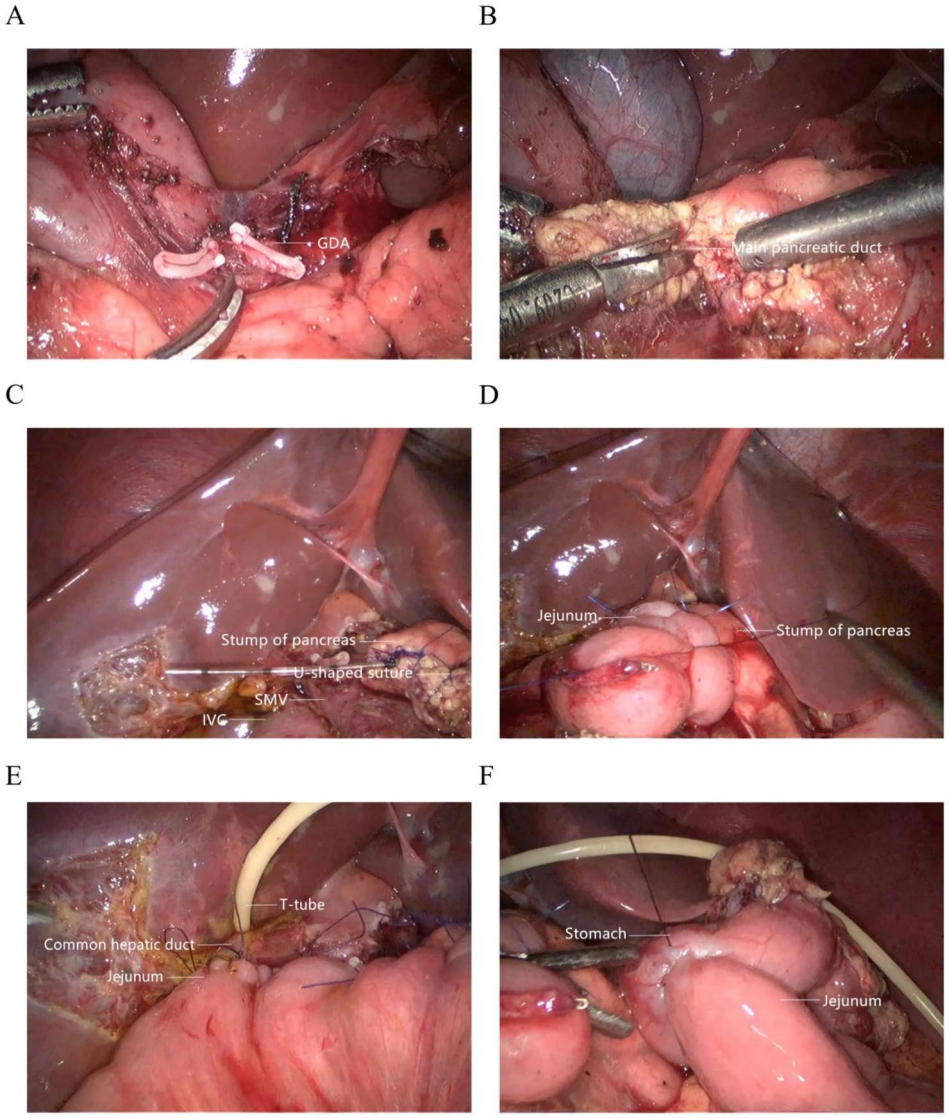


Fig. 7 The key steps of LPD. (**A**) GDA was treated by double disposals. (**B**) The pancreas was "coldly incised" with a scissor to locate the main pancreatic duct. (**C**) The stump of pancreas was U-shaped sutured with 3 – 0 prolene sutures. (**D**) Pancreaticojejunostomy had been performed. (**E**) An end-to-side hepaticojejunostomy was conducted and a T-tube was inserted into the common hepatic duct. (**F**) Gastrojejunostomy had been performed

pancreaticojejunostomy to reduce the risk of leakage of activated pancreatic juice into the peritoneal cavity. Managing fluid volume during surgery and providing additional collagen supplements enhanced tissue blood flow and prevented pancreatic swelling. Placing a drainage tube under the pancreatic-intestinal anastomosis may successfully avoid the buildup of fluid around the pancreas. Insufficient drainage may lead to fluid buildup in the subdiaphragmatic space, the persplenical space and the paracolonic sulcus. Early peritoneal puncture drainage is essential for relieving localized abdominal effusion. Administering heparin for anticoagulation shortly after surgery and correctly using somatostatin and its equivalents may improve the microcirculation of the residual pancreas and other related organs. Postoperative serum amylase and lipase levels were evaluated, and abdominal CT scans were conducted if needed to promptly identify AP and POPF formation. No patients in this group developed AP; however, two individuals had POPFs and recovered with continuous drainage. Compared with other abdominal surgeries, PD is associated with a higher incidence of postoperative complications and mortality. EPD is performed under poorer conditions, resulting in even greater risks. In this study, our multifaceted perioperative management effectively reduced the incidences of postoperative complications and mortality associated with EPD. However, the sample size of our study is too small, necessitating further research with larger cohorts to validate our conclusions.

Blunt trauma to the abdomen may result in pancreaticoduodenal damage, which is associated with high mortality and complication rates. Although the sample size of this study was small, the findings were encouraging. There was no statistically significant difference in complication rates between the 20 reviewed studies (Table 3) and this group (60.7% vs. 41.7%, $P = 0.33$) (Fig. 3A). However, the mortality rate was lower in this group (26.6% vs. 0%, $P = 0.04$) (Fig. 3B). Notably, when the mortality rates were compared between the two groups, the P value of the chi-square test was near the significance threshold α (0.05), indicating that Fisher's exact test was more suitable than Yate's continuity correction chi-square test. Additionally, the relevant literature is limited, and some data are missing, making it difficult to compare haemodynamic-related variables. On the basis of the available data, the proportion of patients with preoperative haemodynamic stability in this study significantly differed from that in the literature review (75.0% vs. 41.8%, $P = 0.03$). This variable may be associated with the prognosis of patients. In the future, we will further expand the sample size and continue to collect data from the relevant literature for detailed comparison and analysis to improve the reliability of the statistical results.

A small number of cases were included in this study, and the lack of a large-sample control study affects the credibility of the research results. We plan to extend the research time, include more medical institutions in the study, expand the sample size, and strive for more satisfactory results.

Conclusion

First, MOEPD is indicated for haemodynamically stable patients with Grade IV or V pancreaticoduodenal injuries resulting from blunt abdominal trauma. MOEPD greatly decreases the risks of perioperative mortality and postoperative complications. In conclusion, in our experience, MOEPD can be lifesaving if injuries are accurately and quickly diagnosed and preoperative therapy is provided. The effectiveness of the procedure relies on the surgical teams' surgical proficiency and clinical expertise. High-quality postoperative support and rehabilitation are essential for patient recovery.

Author contributions

X. Wang, Z.T. Zhang and Z.W. Shen (first author) contributed to conceptualization, methodology, investigation, formal analysis, writing - original draft. T. Jin and X.D. Wang contributed to statistics. L. Ren contributed to investigation. F. Zhan contributed to preparing figures. W. Zheng contributed to validation. K. Li contributed to writing - review & editing. K. Zhang，J.D. Li and W. Cheng (corresponding author) contributed to conceptualization, funding acquisition, resources, supervision, writing - review & editing. All authors read and approved the final manuscript.

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Data availability

Data and materials are provided within the manuscript or supplementary information files.

Declarations

Human ethics and consent to participate

The experimental protocol was established, according to the ethical guidelines of the Helsinki Declaration and was approved by the Human Ethics Committee of The Affiliated Yixing Hospital of Jiangsu University(Yixing People's Hospital). The ethical approval number was IRB-2024-RESEARCH-070-01. This was a retrospective study, so informed consent was not required. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication

Consent for publication was obtained from each patient.

Competing interests

The authors declare no competing interests.

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