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Covered stent treatment for arterial complications after pancreatic surgery: risk assessment for recurrence and peri-stent implantation management

Yingjie Chen[1] · Wei Huang[1] · Qin Liu[1] · Qingbing Wang[1] · Ziyin Wang[1] · Zhiyuan Wu[1] · Xiaoyi Ding[1] · Zhongmin Wang[1,2]

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Abstract

Objectives To explore the risk factors for recurrence of arterial complications after pancreatectomy during the period of covered stent implantation and to provide some opinions on peri-stent implantation management.

Methods Data on patients implanted with covered stents due to arterial complications after pancreatectomy between January 2017 and December 2021 were analyzed retrospectively. Technical success, clinical success, recurrence, and survival were evaluated to elucidate the practicability of covered stents. Wilson score, Random Forest, logistic regression, and Pearson's chi-square test with bootstrap aggregation were performed for determining the perioperative risk factors for recurrence.

Results Among all fifty-five patients, success stent implantation (technical success) was achieved 100%. Patients who were hemodynamically stabilized without further treatment for artery complications in situ (clinical success) accounted for 89.1%. Based on statistical analysis, pre-stent implantation pancreatic fistula was identified as a robust recurrence-related risk factor for preoperative assessment ($p = 0.02$, OR = 4.5, 95% CI [1.2, 16.9]; $p_{bootstrap} = 0.02$). Post-stent implantation pancreatic fistula ($p = 0.01$, OR 4.5, 95% CI [1.4, 14.6]; $p_{bootstrap} < 0.05$) and SMA branches or GDA stumps ($p = 0.02$, OR 3.4, 95% CI [1.1, 10.3]) were relevant to recurrence. The survival rate during hospitalization was 87.3%. All survivors were free from recurrence during the subsequent follow-up. Vasospasm and stent occlusion were observed as short-term and long-term complications, respectively.

Conclusion A covered stent implantation is a feasible and effective treatment option for post-pancreatectomy arterial complications. Rigorous management of pancreatic fistula, timely detection of problems, sensible strategies during stent implantation, and reasonable anticoagulation therapy are necessary for a better prognosis.

Key Points

- *A covered stent is feasible for various artery-related complications after pancreatectomy and has an ideal therapeutic effect.*
- *Pancreatic fistula during the perioperative period of the covered stent is an independent risk factor for recurrent arterial complications and SMA branches or GDA stumps are prone to be recurrent offending arteries.*
- *Rigorous management of pancreatic fistula, timely detection of problems, sensible strategies during stent implantation, and reasonable anticoagulation therapy are necessary for a better prognosis.*

Keywords Stents · Postoperative complications · Pancreatic fistula · Perioperative care

Yingjie Chen and Wei Huang contributed equally to this work and are joint first authors.

✉ Xiaoyi Ding
dxy10456@rjh.com.cn

✉ Zhongmin Wang
wzm11896@rjh.com.cn

[1] Department of Radiology, Ruijin Hospital, Shanghai Jiaotong University School of Medicine, 197 Ruijin Rd. (No.2), Shanghai 200025, People's Republic of China

[2] Department of Interventional Radiology, Luwan Branch of Ruijin Hospital, Shanghai Jiaotong University School of Medicine, 149 Chongqing Rd. (S), Shanghai 200020, People's Republic of China

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Abbreviations
ARAEs Artery-related adverse events

Introduction

The pancreas, endowed with a strategic position in the human body, abuts several major organs and abdominal vessels, which makes a series of pancreatic surgeries technically challenging. Although postoperative mortality (POM) in high-volume hospital systems has significantly decreased due to the centralization of high-risk surgery, the rate of postoperative complications is still relatively high (40–60%) compared with that of other abdominal operations, yet one-third of postoperative deaths are anticipated to be avoidable through rigorous management of perioperative complications [1–3].

Severe complications of pancreatectomy include biliary infection, abdominal infection, pancreatic fistula, and artery-related adverse events (ARAEs) that can occur spontaneously or be secondary to pancreatic fistula and infection [4–8]. Among them, due to the rapid progress of ARAEs, timely and effective treatment is required.

In recent years, endovascular procedures have been progressively regarded as the prime methods against ARAEs with the advantages of minimal invasion, outstanding clinical outcomes, and fewer complications [6, 9, 10]. Selective coil embolization can block the bleeding site or ruptured pseudoaneurysm quickly, especially for the tortuous arterial branches. However, the fact that vascular ligation during pancreatic surgery declines the blood supply of adjacent organs makes it necessary for interventional radiologists to retain the main artery and its important branches in the treatment of postpancreatectomy ARAEs. Stent graft implantation, broadly applied to intravascular interventional treatment, clinches the dilemma between sealing the target lesions and keeping the blood supply of downstream organs [11].

Several studies have shown that stent grafts are feasible for reversing ARAEs after pancreatectomy [8, 11–13]. However, most of them only focus on one kind of ARAEs and provide no comprehensive perspective of perioperative management. Therefore, the purpose of this study was to evaluate the clinical value of stent implantation in post-pancreatectomy ARAEs and explore the potential risk factors during the peri-stent period. We sought to present versatile and effective applications of stent grafts in ARAEs and provide experience in peri-stent implantation management.

Materials and methods

Patients

This retrospective study was approved by our institutional review board. All patients who underwent covered stent implantation as a therapeutic regimen for post-pancreatectomy ARAEs between January 2017 and December 2021 were included (n = 55). Other patients were excluded based on the criteria in Fig. 1a.

Procedure

The decision to perform stent implantation was made by pancreatic surgeons and interventional radiologists during consultations in the interventional department. The entire clinical course was shown in Fig. 1b. Informed patient consent was obtained from conscious patients or the immediate family of unconscious patients.

The patient was placed in a supine position, and the femoral artery (or the brachial artery) was punctured by the modified Seldinger method under local anesthesia. After the placement of a 5F vascular sheath (Terumo) through the access site, an angiographic catheter (aortography: pig catheter [Cordis]; selective angiography: RH catheter [Terumo] or C2 catheter [Cordis]; guidewire: 0.035 in. [Terumo]) was introduced for angiographic confirmation of arterial injury. The aortography and selective angiography in the celiac axis, superior mesenteric artery, and inferior mesenteric artery were carried out for patients with clinical bleeding manifestations. However, patients with ARAEs found in follow-up were supposed to undergo the selective angiography in offending artery directly and the selective angiographies in other arteries were finished after covered stent implantation to exclude other problems. The diameter (1–2 mm larger than that of the offending vessel) and length of the diseased artery were measured to determine the stent size after identifying the lesion site and checking the feasibility of stent implantation. If patients got arteriospasm caused by shock or redistribution of blood flow, the stent size was determined by the actual preoperative CT evaluation to avoid type I endoleak. The stent was intended to cover the proximal and distal 1 cm of the vascular rupture and maintain the patency of other arteries and their branches as much as possible. Then, a 7-10F sheath (Terumo) was employed in the ipsilateral artery to introduce a guiding catheter (Mach1, Boston). A 0.014 in. microguidewire (PT2, Boston) and a microcatheter (STC18, Boston Scientific) were adopted to assist operators in passing the distal end of the targeted artery. Next, a 0.018 in. guidewire (V-18, Boston) was exchanged and a GORE® VIABAHN® covered stent system (W. L. Gore & Associates) was introduced and released in the exact position, which completely and tightly covered the troublesome artery segment. The length of the covered stent was 25 mm or 50 mm with a diameter between 5 and 8 mm. After the stent placement was completed, the fine expansion and adhesion of the stent were verified by additional angiography (Fig. 2). If there was an extravascular branch adjacent to the diseased vessel, coil embolization was performed on this branch to avoid type II endoleak.

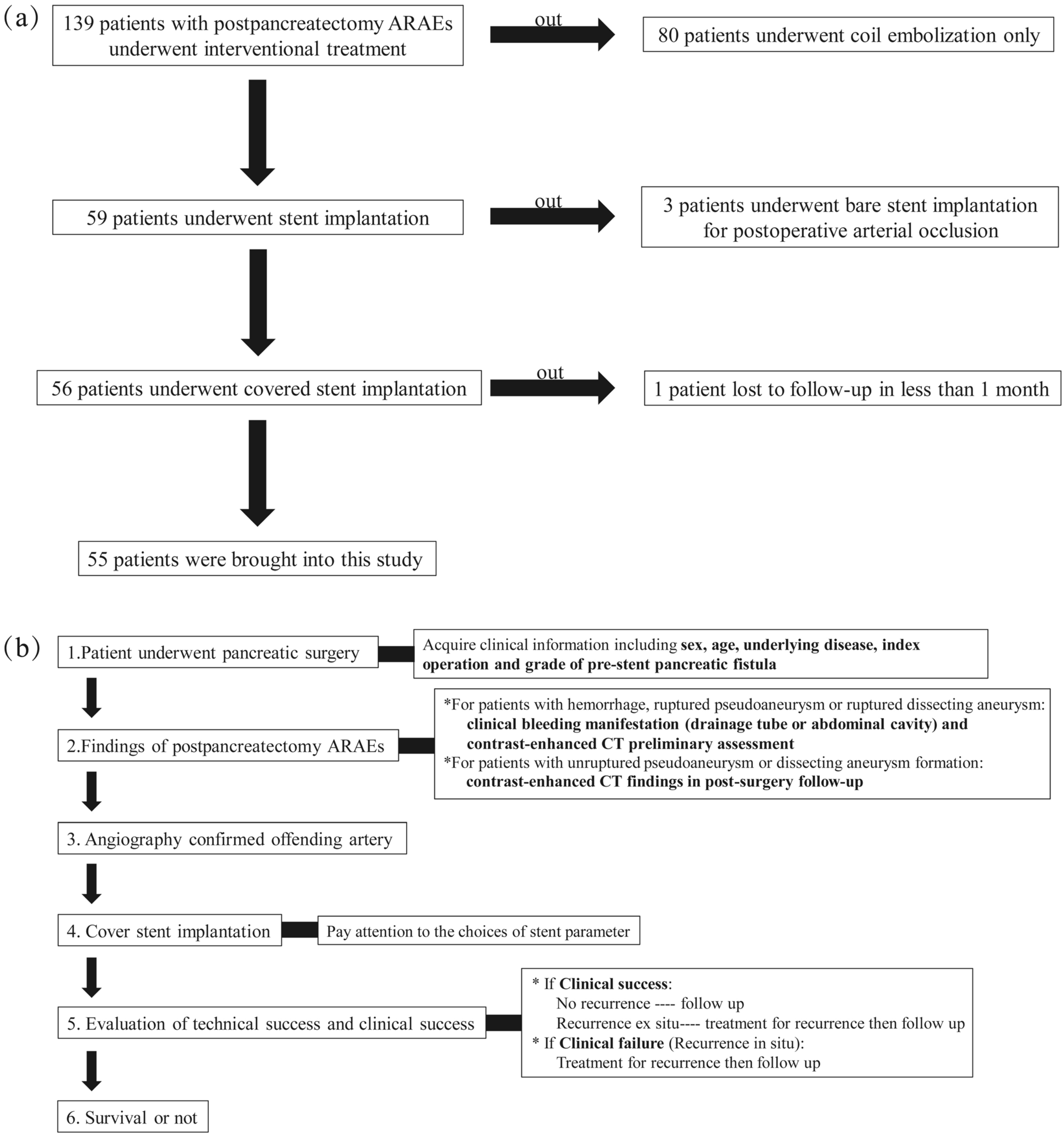

Fig. 1 The inclusion criteria (**a**) and clinical course (**b**) of the whole study

Follow-up

All patients were given active support care and symptomatic therapy. Routine analysis of blood, liver, and kidney functions and coagulation indexes were monitored constantly. Abdominal CTA was reviewed at 1 month and 3 months after stent placement to evaluate stent patency. Follow-up was conducted through the analysis of electronic medical records and outpatient records.

Definitions

ARAEs were classified by modifying the ISGPS's (International Study Group of Pancreatic Surgery) definition of post-pancreatectomy hemorrhage [14]. Technical success was defined as no angiographic signs of hemorrhage but the presence of significant patency of the diseased artery and its distal branches after stent placement. Clinical success was defined as hemodynamic stabilization without further treatment

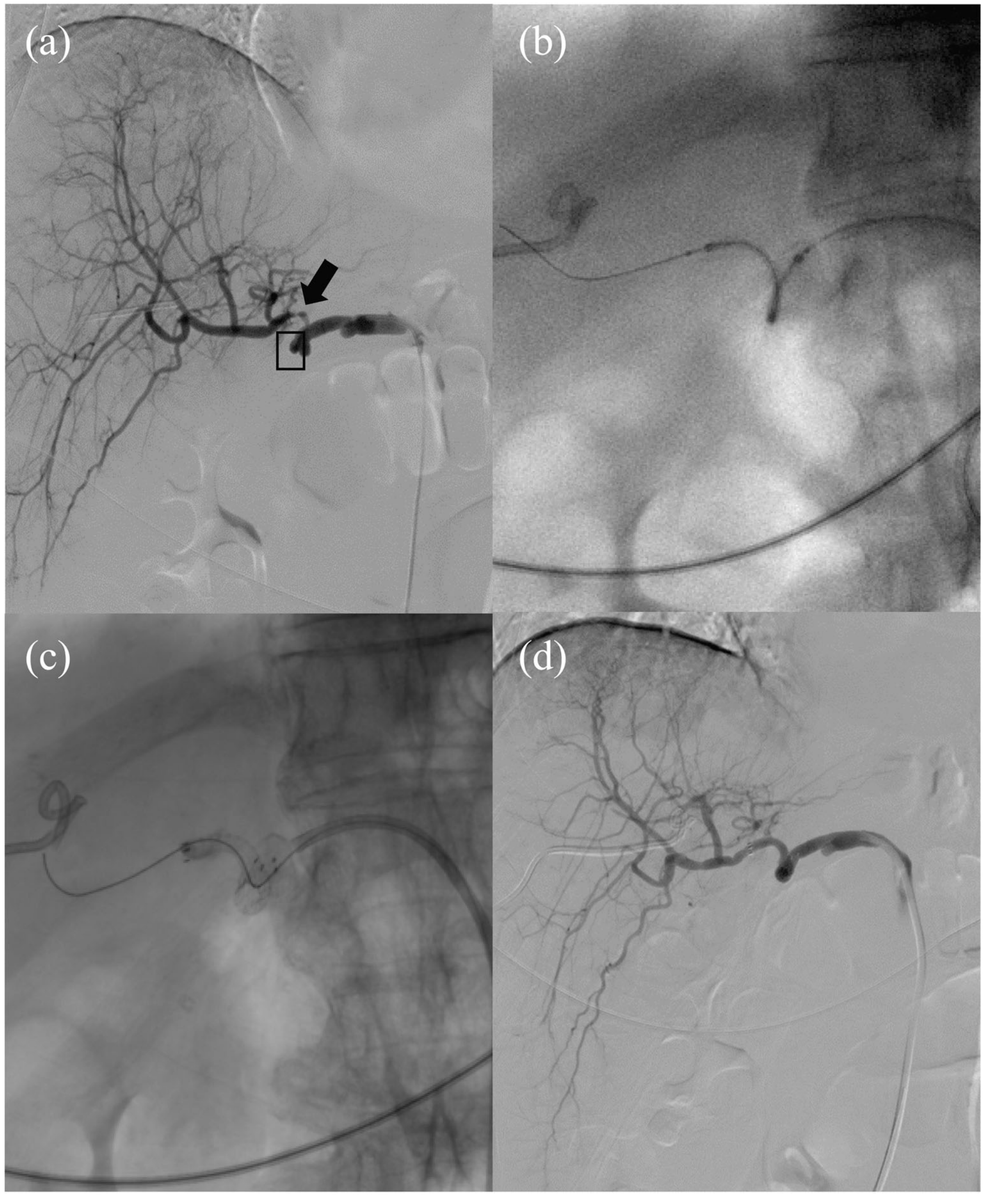

Fig. 2 A 63-year-old woman after pancreaticoduodenectomy experienced bleeding in the drainage tube (so-called sentinel bleeding). Angiography showed the rough wall of the common hepatic artery and a distal narrowing of the common hepatic artery (**a**, black arrow). A hepatic pseudoaneurysm was also confirmed (**a**, black rectangle). Although there was no sign of contrast agent extravasation, hemorrhage, or ruptured pseudoaneurysm still could not be excluded. Therefore, a covered stent (Viabahn®, 6 × 50 mm) was implanted, and further angiography showed a fine stent position, normal luminal diameter, and no sign of pseudoaneurysm (**b**–**d**). The clinical manifestation of bleeding disappeared after stent implantation

for ARAEs in situ after stent placement. Cases with recurrent ARAEs adjacent to the primary site were considered a clinical failure. Recurrent ARAEs was defined as recurrent arterial complications in primary or other arteries after stenting, which needed immediate re-intervention. The pancreatic fistula was classified according to the ISGPS's definition and divided into pre-stent or post-stent implantation pancreatic fistula for analyzing the risk factor in different end points [15]. The first end point was defined when the covered stent implantation was accomplished. The second end point was defined when recurrent ARAEs took place.

Statistical analysis

Categorical variables were presented as numbers followed by percentages. Continuous variables were presented as the mean ± standard deviation. Due to the small sample size, Wilson score, Random Forest (number of trees: 500, random seed: 12), and the binary logistic regression with bootstrap aggregation were used to explore potential pre-stent implantation risk factors associated with recurrent ARAEs. Both leave-one-out cross-validation (LOOCV) and ROC curve with AUC value, Brier score, and C index were performed for model evaluation. Pearson's chi-square test with or without bootstrap aggregation was used to compare the post-stent implantation clinical characteristics between the recurrence group and the no recurrence group in univariable analysis. $p < 0.05$ was defined as the level of statistical significance. The Wilson score was based on the lower limit of the Wilson score interval and applied for preliminary evaluation of the pre-stent risk factors ($\alpha = 0.05$, $Z \approx 2$). Random Forest model, LOOCV, and ROC curve with AUC value, Brier score, and C index were performed by using R (version 4.1.0) and R studio (version 1.1.463). The binary logistic regression and Pearson's chi-square test with or without bootstrap aggregation (N = 1000, random seed: 1234) were performed by using SPSS for windows (version 2.0, IBM). The importance ranking and stepwise analysis of Random Forest were drawn by using GraphPad Prism 8 (GraphPad Software).

Results

Patient characteristics (Table 1)

A total of fifty-five patients (mean age, 63 years ± 11 [standard deviation]) were included in this study (Supplementary Material). The most common underlying disease was pancreatic ductal adenocarcinoma (n = 38). Most of the patients were surgically treated by pancreaticoduodenectomy (n = 36) and distal pancreatectomy with or without splenectomy (n = 12). In this study, 49.1% (n = 27) of the patients had suffered from pancreatic fistula (Grade B or higher) before covered stent implantation and 40% (n = 22) of the patients got new pancreatic fistula (Grade B or higher) after covered stent implantation or refractory pre-stent pancreatic fistula.

In this study, grade B ARAEs took place in 20% (n = 11) of the patients while 80% (n = 44) of the patients suffering from grade C ARAEs. Hemorrhage including ruptured pseudoaneurysm or dissecting aneurysm took place in 83.6% (n = 46) of the patients as the most common postsurgical ARAE. The primary clinical manifestation of hemorrhage was bleeding in the drainage tube or abdominal cavity (n = 46). Other ARAEs (n = 9) were mostly confirmed by radiological examinations as being asymptomatic except for one case with abdominal pain. The superior mesenteric artery (SMA) including its branches (n = 18) and the stump of the gastroduodenal artery (GDA) (n = 17) were the most two confirmed diseased vessels.

Technical and clinical success (Table 1)

Fifty-five patients accepted fifty-seven covered stent treatments, two of whom required second stent implantation for their refractory ARAEs identified by angiography. As shown in Fig. 3, 0.018 in. compliant system made covered stent get more adaptation in the treatment of ARAEs. Femoral artery access was achieved in fifty-two patients, while three patients were punctured transbrachially for SMA-related ARAEs due to the failed stent implantation through femoral access (Fig. 4).

All cases were confirmed to show no contrast agent extravasation by angiography after fifty-seven stent implantations. The technical success rate of the endovascular stent treatment was 100%. However, immediate vasospasm of the proper hepatic artery at the far end of the stents was observed in two patients and was reversed successfully by trans-arterial injection of papaverine (3–6mg) or nitroglycerin (200–400μg). The clinical success rate of stent grafts applied to post-pancreatectomy ARAEs was 89.1% (n = 49). For six patients without clinical success, three patients confirmed recurrence in situ by angiography. One patient who underwent relaparotomy was found to have a new bleeding spot adjacent to the stump of the GDA. Two patients were unable to identify the exact bleeding spots. Although they were not confirmed recurrence in situ, these two cases were still considered a clinical failure from a conservative perspective (Table 2).

Recurrent ARAEs and potential risk factors

Recurrent ARAEs took place in 19 patients including 11 patients with identifiable re-hemorrhage, 6 patients with pseudoaneurysm formation, and 2 patients with unidentifiable re-hemorrhage (Table 3).

Based on results from the Wilson score at the first end point, grade of ARAEs (ΔS = 0.39), offending artery (ΔS = 0.26), pre-stent implantation pancreatic fistula (ΔS = 0.24), and age (ΔS = 0.23) were preliminarily identified as possible warning factors for recurrence (Table 4). To further explore the potential pre-stent risk factors, the Random Forest algorithm was adopted, and the importance ranking indicated that pre-stent pancreatic fistula, primary offending artery, and age were the most three important variables (Fig. 5a). The stepwise Random Forest was performed according to the result of importance ranking from high rank to low rank (Fig. 5b). The result showed that when the number of variables was 3, the out-of-bag error rate (OOB) was the lowest (OOB = 0.27). Therefore, the most three important variables in Random Forest were included in multivariable analysis, which showed that only pre-stent implantation grade B or higher pancreatic fistula (p = 0.02, OR = 4.5, 95% CI [1.2, 16.9]) was associated with recurrent ARAEs as a potential risk factor in pre-stent implantation assessment (Table 4). Due to the small sample size, bootstrap aggregation was performed during the logistic regression and the results indicated that both pre-stent grade B or higher pancreatic fistula (p = 0.02) and primary offending artery (p = 0.03) were significant. ROC curve was used to evaluate the model of logistic regression with bootstrap aggregation, which suggested an acceptable accuracy and efficiency (Fig. 5c). However, the kappa value of LOOCV was 0.36 and only 6 patients took place recurrence in situ. It reminded us that the primary offending artery in SMA or GDA had a warning effect but was not robust.

To evaluate the peri-stent implantation period comprehensively, a significant test with bootstrap aggregation was

Table 1 Characteristics of 55 patients with a covered stent for postpancreatectomy arterial complications

Characteristics	*n* = 55	%
Sex		
Man	37	67.3
Woman	18	32.7
Age (mean age ± standard deviation)	63 ± 11 years	
Underlying disease		
PDAC	38	69.1
IPMN with IGIN	8	14.6
Serous microcystadenoma	2	3.6
ANP	2	3.6
Invasion of CHOL	2	3.6
Others (DL-BCL [EBV+], SRCT, metastasis of SCLC)	3	5.5
Index operation		
PD	36	65.5
DP (with or without splenectomy)	12	21.7
TP	3	5.5
SR	3	5.5
TGD with SR	1	1.8
Pancreatic fistula (pre-stent implantation)*		
No	27	49.1
Grade B	23	41.8
Grade C	5	9.1
Pancreatic fistula (post-stent implantation)**		
No	33	60.0
Grade B	18	32.7
Grade C	4	7.3
Grade of ARAEs		
Grade B	11	20.0
Grade C	44	80.0
Complication type		
Hemorrhage (including ruptured pseudoaneurysm or ruptured dissecting aneurysm)	46	83.6
Pseudoaneurysm	8	14.6
Dissecting aneurysm	1	1.8
Clinical manifestation		
Bleeding (drainage tube)	38	69.1
Bleeding (abdominal cavity)	8	14.5
No (radiological follow-up)***	9	16.4
Offending artery		
SMA and branches	18	32.7
GDA stump	17	30.9
SA stump	6	10.9
CHA	5	9.1
CA	4	7.3
PHA	4	7.3
LGA	1	1.8
Operative approach		
Femoral artery	52	94.5
Branchial artery	3	5.5
Technical success		

Table 1 (continued)

Characteristics	$n = 55$	%
Yes	55	100
No	0	0
Clinical success		
Yes	49	89.1
No	6	10.9
Recurrence		
Yes (including 6 patients with recurrence in situ)	19	34.5
No	36	65.5
Survival****		
Yes	48	87.3
No	7	12.7

PDAC, pancreatic ductal adenocarcinoma; *IPMN with IGIN*, intraductal papillary mucinous neoplasm with low-grade intraepithelial neoplasia; *ANP*, acute necrotizing pancreatitis; *CHOL*, cholangiocellular carcinoma; *DL-BCL*, diffuse large B cell lymphoma; *EBV*, Epstein-Barr virus; *SRCT*, small round cell tumor; *SCLC*, small cell lung carcinoma; *PD*, pancreaticoduodenectomy; *DP*, distal pancreatectomy; *TP*, total pancreatectomy; *SR*, segmental resection; *TGD*, trans-gastric debridement; *CHA*, common hepatic artery; *PHA*, proper hepatic artery; *SMA*, superior mesenteric artery; *CA*, celiac axis; *SA*, spleen artery; *GDA*, gastroduodenal artery; *LGA*, left gastric artery

*Pre-stent implantation pancreatic fistula: pancreatic fistula had existed before covered stent implantation

**Post-stent implantation pancreatic fistula: pancreatic fistula took place after covered stent implantation or refractorily preoperative pancreatic fistula

***One Patient with dissecting aneurysm had abdominal pain

****During hospitalization

executed at the second end point. It should be mentioned that the sample size for analyzing the relationship between artery and recurrence is 91 because of a total sample of 110 arteries (Each patient has both two types of arteries, and those arteries are equally exposed in recurrence or not). The results reflected those patients with post-stent implantation grade B or higher pancreatic fistula were more liable to suffer from recurrent ARAEs ($p = 0.01$, OR 4.5, 95% CI [1.4, 14.6]; $p_{\mathrm{bootstrap}} < 0.05$). Compared with other arteries, SMA or gastroduodenal artery (GDA) had a higher rate of recurrent ARAEs ($p = 0.02$, OR 3.4, 95% CI [1.1, 10.3]) (Table 5). It may be related to the abundance of collateral vessels.

Survival

The survival rate during hospitalization was 87.3% ($n = 48$). Four patients underwent relaparotomy immediately after the rebleeding was confirmed. However, two of them passed away, expiring from infectious shock secondary to continuous rebleeding. One patient got continuous rebleeding even though another successfully covered stent in the common hepatic artery was implanted (Fig. 6). Five patients died due to cachexia and multiple organ failure. The patients surviving recurrent ARAEs underwent coil embolization or stent implantation and achieved both technical success and clinical success. There were no severe stent-related long-term

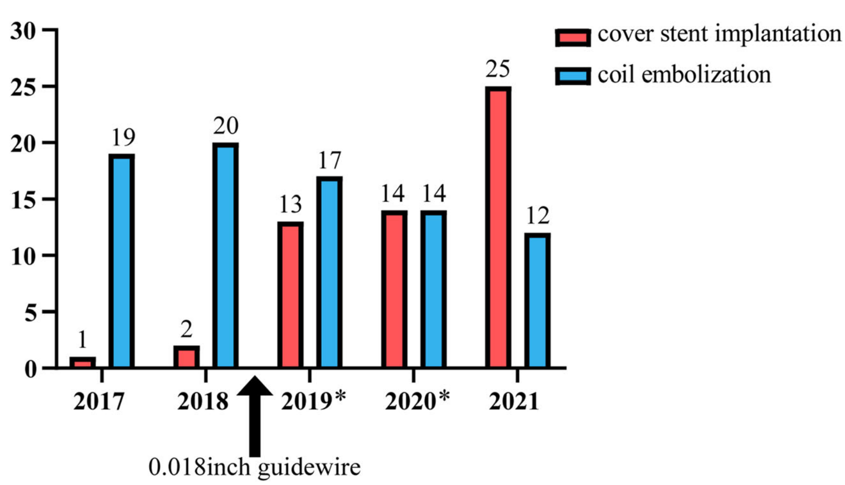

Fig. 3 Changes over time in covered stent implantation and coil embolization.*There are two patients in 2019 and 2020 who got both covered stent implantation and coil embolization treatment

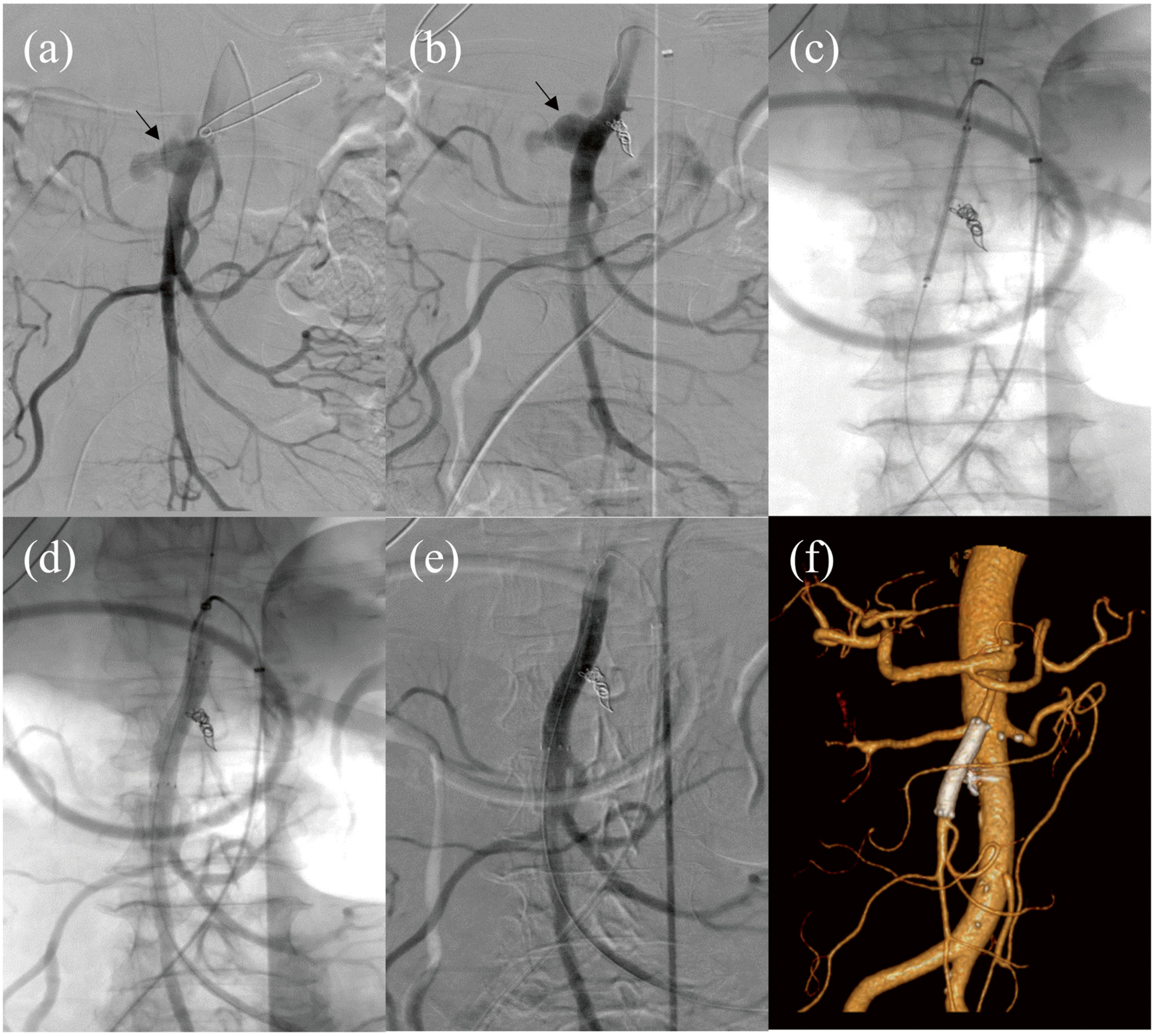

Fig. 4 A 71-year-old woman was confirmed bleeding in the junction of the main trunk of the superior mesenteric artery and branch of the jejunal artery (**a**). Coil embolization was used to block off the jejunal branch but another angiography showed contrast agent extravasation yet (**b**). This patient failed to receive a covered stent through femoral access. Therefore, the brachial artery was punctured and the stent (Viabahn®, 8 × 50 mm) was implanted successfully (**c**, location; **d**, release; **e**, angiography confirmed stent patency). Follow-up abdominal CTA reconstruction indicated an ideal treatment effect (**f**)

Table 2 Recurrent information of the six patients without clinical success

Patient	Recurrent site of ARAEs	Treatment for recurrence	Clinical outcome
1	Oozing of the blood in exploratory laparotomy	Relaparotomy	Failure
2	Oozing of the blood in exploratory laparotomy	Relaparotomy	Failure
3	Branch hemorrhage adjacent to the primary bleeding site	Coil embolization	Success
4	Branch hemorrhage adjacent to the primary bleeding site	Coil embolization	Success
5	Hemorrhage adjacent to the primary bleeding site	Relaparotomy	Success
6	Small pseudoaneurysm adjacent to the primary bleeding site	Coil embolization	Success

Table 3 Treatment and outcome of recurrent ARAEs

Variable	$n = 19$	%
Recurrent type		
Hemorrhage of the branch of the SMA	5	26.3
Hemorrhage of the stump of the GDA	3	15.8
Hemorrhage of the root of the SMA	2	10.5
Pseudoaneurysm in the branch of the SMA	2	10.5
Pseudoaneurysm in the stump of the GDA	2	10.5
Oozing of the blood in exploratory laparotomy	2	10.5
Hemorrhage of the stump of the SA	1	5.3
Pseudoaneurysm of the distal segment of the PHA	1	5.3
Pseudoaneurysm in the proximal segment of the CHA	1	5.3
Treatment		
Coil embolization	8	42.1
Stent implantation	6	31.6
Relaparotomy	4	21.1
Coil embolization + stent implantation	1	5.3
Outcome		
Success	16	84.2
Fail	3	15.8
Survival*		
Alive	15	78.9
Dead	4	21.1

CHA, common hepatic artery; *GDA*, gastroduodenal artery; *SMA*, superior mesenteric artery; *SA*, splenic artery; *PHA*, proper hepatic artery

*During hospitalization

complications, but stent thrombosis was found in one patient at 1-month follow-up, and in two patients at 3-month follow-up. All patients were free from recurrent ARAEs during the subsequent follow-up.

Discussion

Artery-related adverse events after pancreatectomy are mostly related to intraoperative injury of arteries, incomplete hemostasis of the surgical stump or anastomotic site, and vascular erosion caused by a pancreatic or biliary fistula and abdominal abscess [4, 16–18]. To date, there is still no clear consensus on the management of post-pancreatectomy ARAEs. Although it has been reported that coil embolization might incur postembolization syndrome, distal organ ischemia, infarction, or even necrosis, the risk is still relatively low in splenic, gastroduodenal, pancreatic, and mesenteric arteries due to collaterals formation [19–21]. This risk may increase in the proper hepatic artery, but it does not occur frequently after coil embolization. Stent implantation seems to be another satisfactory method against complex artery diseases with remarkable patency and has been applied in various vascular abnormalities [22, 23]. But it should be mentioned that covered stent implantation is still limited by the tortuosity of the visceral arteries in a minority of patients despite the adoption of the higher-compliant 0.018 in. guidewire and guide catheter has improved this problem to a certain extent. In this study, we collected cases of patients accepting covered stent implantation after pancreatectomy for various ARAEs. One hundred percent of the patients were treated with technical success, and 89.1% ($n = 49$) of the patients achieved complete control of the primary ARAEs, which demonstrated the broad applicability and excellent outcome of covered stents.

Pseudoaneurysm formation, chiefly resulting from pancreatic or biliary fistula and surgery-related abdominal infection, is a common complication after pancreatectomy, always with drainage bleeding as the primary symptom [14]. It was suggested that 34.5% ($n = 19$) of the patients in our research exhibited ruptured or unruptured pseudoaneurysms. All of them achieved technical success and 93.8% ($n = 15$) of the cases achieved clinical success after stent implantation. Intraoperative damage to the surrounding vessels or improper suturing of the stumps may result in the formation of dissecting aneurysms. These issues occurred in two patients in our study including a ruptured one. These kinds of “sentinel bleeding” often precede a potentially dangerous intra-abdominal hemorrhage in cases of ruptured (dissecting) pseudoaneurysm [24]. In consideration of the high risk of rupture, especially when complicated with pancreatic fistula, we recommend reasonable interventional treatment in patients with an aneurysm or dissecting aneurysm after pancreatectomy.

Pancreatic fistula after pancreatectomy should be treated immediately by drainage to avoid secondary infection and ARAEs in the operation area [4]. In this study, twenty-eight patients had suffered from grade B or higher pancreatic fistula when covered stents were planned to be placed and statistical analysis demonstrated that it was a potential risk factor for recurrent ARAEs in pre-stent implantation assessment. This study also indicated that post-stent grade B or higher pancreatic fistula was relevant to a high recurrent rate. Therefore, rapid control of pancreatic fistula is beneficial to the postoperative recovery of patients with ARAEs. Patients with grade B or higher pancreatic fistula should be closely monitored for hematologic indicators after stent implantation for a high risk of recurrent ARAEs.

Three patients with superior mesenteric ARAEs failed to implant stents from access to the femoral artery. Normally, the SMA forms an angle ranging from 38 to 65° when it comes off the aorta, which made it difficult for stents to be introduced into the lesion site transfemorally [25]. Therefore, obtuse angle access obtained from the brachial artery approach may be more suitable against SMA-related adverse events. However, transbrachial access requires a higher proficiency from interventional clinicians due to the risk of postoperative hematoma

Table 4 Wilson score and multivariable analysis for pre-stent implantation risk factors associated with recurrent ARAEs

Variable	No recurrence**	Recurrence***	Wilson score		Multivariable analysis	
			S	ΔS	*p*	OR****
Sex				0.06		
Man	24	13	0.22			
Woman	12	6	0.16			
Age				0.23	0.15	2.8 (0.7–11.7)
> = 63	18	15	0.30		0.14 (bootstrap)	
< 63	18	4	0.07			
Grade of ARAEs				0.39		
Grade C	26	18	0.41			
Grade B	10	1	0.02			
Underlying disease				0.16		
PDAC	23	15	0.25			
Non-PDAC	13	4	0.09			
Index operation				0.07		
PD	23	13	0.22			
Non-PD	13	6	0.15			
Pancreatic fistula*				0.24	0.02	4.5 (1.2–16.9)
Grade B or higher	14	14	0.32		0.02 (bootstrap)	
No	22	5	0.08			
Offending artery				0.26	0.08	3.8 (0.8–17.4)
SMA or GDA	19	16	0.30		0.03 (bootstrap)	
Other arteries	20	3	0.04			

OR, odds ratio; *PDAC*, pancreatic ductal adenocarcinoma; *PD,* pancreaticoduodenectomy, *SMA*, superior mesenteric artery.

*Pre-stent implantation pancreatic fistula: pancreatic fistula had existed before covered stents implantation

**The sample size of No recurrence group is 36

***The sample size of Recurrence group is 19

****Data in parentheses are 95% CIs

and nerve compression symptoms [26–28]. Operators should make quick and correct decision during the operation according to the actual situation. Further study is needed for a more optimized regimen to treat SMA complications.

In this study, low-molecular-weight heparin anticoagulant therapy (0.3 mL/3200IU S.C. Q12H) was generally started when the patient's blood pressure and hemoglobin level became stable after stent implantation, and long-term oral aspirin (100 mg P.O. Q.D.) and clopidogrel (75 mg P.O. Q.D.) antiplatelet therapy were implemented in all surviving patients. But stent occlusion was still observed in three patients in follow-up CTAs. However, several studies have reported

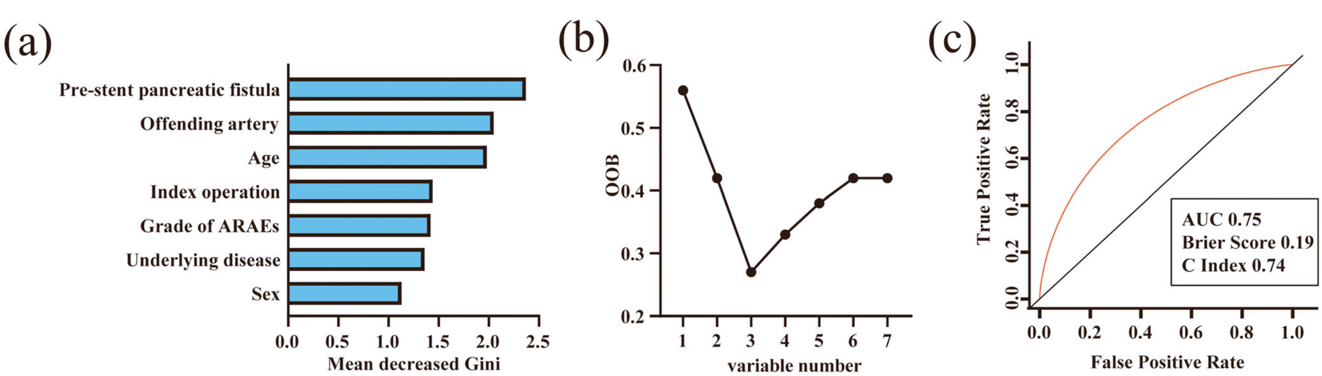

Fig. 5 Importance ranking (**a**) and stepwise analysis (**b**) of Random Forest and ROC curve (**c**) for logistic regression

Table 5 Significant test of the relationship between recurrence ARAEs and post-stent implantation pancreatic fistula or recurrent artery

Variable	No recurrence*	Recurrence**	χ^2	*p*	OR***
Pancreatic fistula****			6.5	.01	4.5 (1.4–14.6)
Grade B or higher	10	12		< .05 (bootstrap)	
No	26	7			
Recurrent artery			5.2	.02	3.4 (1.1–10.3)
SMA branches or GDA stump	41	14			
Other arteries	50	5			

SMA, superior mesenteric artery; *GDA*, gastroduodenal artery

*The sample size for analyzing the relationship between artery and recurrence is 91 because of a total sample of 110 arteries (each patient has both two types of arteries, and those arteries are equally exposed in recurrence or not)

**The sample size of Recurrence group is 19

***Data in parentheses are 95% CIs

****Post-stent implantation pancreatic fistula: pancreatic fistula took place after covered stent implantation or refractorily preoperative pancreatic fistula

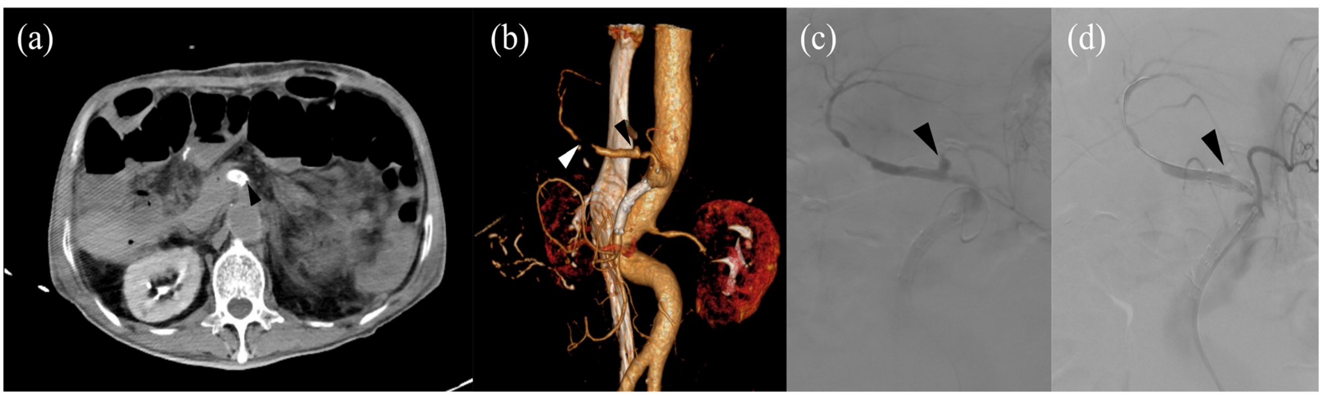

Fig. 6 A 69-year-old man after pancreaticoduodenectomy experienced bleeding of the superior mesenteric artery and a covered stent (Viabahn®, 8 × 50 mm) was implanted (**a**, black arrow). However, abdominal CTA reconstruction after 12 days showed a hepatic pseudoaneurysm (b, black arrow) and a distal narrowing of the common hepatic artery (**b**, white arrow). Angiography confirmed the hepatic pseudoaneurysm (**c**, black arrow). Therefore, a covered stent (Viabahn®, 7 × 25 mm) was implanted, and further angiography showed a fine stent position and no sign of contrast agent extravasation (**d**, black arrow). Although two covered stents got technical success, this patient eventually died of infection shock

anticoagulant-related bleeding in patients with stent implantation [29, 30]. Therefore, individualized regimens should be explored and tailored.

The limitations of our research can be summarized as follows. First, this is a single-center, retrospective study. Second, most patients in this study suffered from malignant tumor, which may have an influence on clinical outcomes. Finally, the lethality of post-pancreatectomy ARAEs makes it difficult to set up a traditional control group for comparing covered stents with other strategies. Therefore, there was only a comparison with the same method from an ethical perspective.

In conclusion, our results demonstrate that a covered stent is a safe and effective interventional technique for dealing with postpancreatectomy ARAEs while maintaining the patency of target vessels. As the basic clinical status of patients after pancreatic surgery is poor, seasoned interventional clinicians and multidisciplinary perioperative management are essential for patients to acquire long-term survival with high quality of life.

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Declarations

Guarantor The scientific guarantor of this publication is Zhongmin Wang.

Conflict of interest The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.

Statistics and biometry No complex statistical methods were necessary for this paper.

Informed consent Written informed consent was waived by the Institutional Review Board.

Ethical approval Institutional Review Board approval was obtained.

Methodology
• retrospective
• observational
• performed at one institution

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