



# Predictors of technical success of percutaneous transhepatic common bile duct stone removal: is it only a matter of stone size?

Hsun-Chieh Chiu<sup>1,2</sup> · Chien-An Liu<sup>1,2,3</sup> · Hsiuo-Shan Tseng<sup>2,4</sup> · Kan Ling<sup>1,2</sup> · Yin-Chen Tsai<sup>1,2</sup> · Hsuen-En Huang<sup>1,2</sup> · Pei-Shan Wu<sup>2,5,6</sup> · Rheun-Chuan Lee<sup>1,2</sup>

Received: 28 August 2022 / Revised: 2 February 2023 / Accepted: 22 February 2023 / Published online: 21 April 2023  
© The Author(s), under exclusive licence to European Society of Radiology 2023

## Abstract

**Objectives** The common practice is to remove symptomatic common bile duct (CBD) stones in patients. This study aimed to investigate the factors affecting the percutaneous transhepatic removal of CBD stones.

**Methods** We retrospectively analyzed the data of 100 patients (66 men and 34 women; age: 25–105 years, mean 79.1 years) with symptomatic CBD stones who underwent percutaneous transhepatic stone removal (PTSR) from January 2010 through October 2019. After balloon dilation of the ampulla of Vater or bilioenteric anastomosis, the stones were pushed out of the CBD into the small bowel with a balloon catheter. If failed, basket lithotripsy was performed. Technical success was defined as complete clearance of the bile ducts on a cholangiogram.

**Results** The technical success rate was 83%, and achieved 90.2% in patients with altered gastroduodenal/pancreatobiliary anatomy. Multivariable analysis revealed that CBD diameter (odds ratio [OR]: 506.460,  $p=0.015$ ), failed ERCP (OR: 16.509,  $p=0.004$ ), Tokyo guidelines TG18/TG13 severity (grade III; OR: 60.467,  $p=0.006$ ), and left-sided transhepatic approach (OR: 21.621,  $p=0.012$ ) were risk factors for technical failure. The appropriate cutoff CBD size was 15.5 mm (area under the curve: 0.91). CBD stone size, radiopacity of stones, and CBD angle between retroduodenal and pancreatic portion did not influence technical success.

**Conclusions** PTSR is effective for CBD stone removal in older adults and individuals with altered gastrointestinal tract anatomy. The aforementioned risk factors for technical failure should be considered in preoperative evaluation before PTSR to improve the success rate.

## Key Points

- PTSR is effective in symptomatic CBD stone management among older adults and individuals with altered anatomy. Investigating clinical/anatomic factors can guide radiologists toward a more comprehensive preoperative evaluation to maximize the success rate.
- Our data indicate that dilated CBD (diameter  $\geq 15.5$  mm) and left-sided PTBDs reduce the technical success rate by 506-fold and 22-fold, respectively.
- Clinical factors such as previous failed ERCP for stone removal and higher severity of acute cholangitis lessen the technical success rate.

**Keywords** Common bile duct (CBD) · Endoscopic retrograde cholangiopancreatography (ERCP) · Percutaneous transhepatic biliary drainage (PTBD) · Percutaneous transhepatic biliary stone removal (PTSR)

✉ Chien-An Liu  
caliu@vghtpe.gov.tw

<sup>1</sup> Department of Radiology, Taipei Veterans General Hospital, Taipei, Taiwan, Republic of China

<sup>2</sup> School of Medicine, National Yang Ming Chiao Tung University, Taipei, Taiwan, Republic of China

<sup>3</sup> Institute of Clinical Medicine, National Yang Ming Chiao Tung University, Taipei, Taiwan, Republic of China

<sup>4</sup> Department of Medical Imaging, Cheng Hsin General Hospital, Taipei, 201, Section 2, Shi-Pai Road, Taipei 112, Taiwan, Republic of China

<sup>5</sup> Division of Gastroenterology and Hepatology, Department of Medicine, Taipei Veterans General Hospital, Taipei, Taiwan, Republic of China

<sup>6</sup> Endoscopy Center for Diagnosis and Treatment, Taipei Veterans General Hospital, Taipei, Taiwan, Republic of China

## Abbreviations

aCBD	CBD angulation between retroduodenal and pancreatic portion
ALKP	Alkaline phosphatase
AUC	Area under the curve
CBD	Common bile duct
CI	Confidence interval
CRP	C-reactive protein
CT	Computed tomography
ERCP	Endoscopic retrograde cholangiopancreatography
ESCP	Endosonography-guided cholangiopancreatography
ESWL	Extracorporeal shock-wave lithotripsy
fERCP	Previous ERCP failure for stone removal
HU	Hounsfield unit
IHD	Intrahepatic bile duct
MRCP	Magnetic resonance cholangiopancreatography
OR	Odds ratio
PAD	Periampullary diverticulum
PTBD	Percutaneous transhepatic biliary drainage
PTSR	Percutaneous transhepatic biliary stone removal
T.bil	Total bilirubin
TG18/TG 13	Tokyo guideline 2018/2013 for acute cholangitis severity

## Introduction

Cholelithiasis or gallstones is a common disease affecting up to 20% of the population [1]. Among them, 15% have stones in the common bile duct (CBD) or choledocholithiasis. Approximately 50% of patients with CBD stones remain asymptomatic; however, 2% of patients with CBD stones exhibit elevated liver function tests, cholangitis, dilated CBD, jaundice, pancreatitis, or even death. The management of CBD stone extraction is crucial for symptom relief and infection control.

Endoscopic retrograde cholangiopancreatography (ERCP) with limited sphincterotomy and balloon and/or basket catheters is the mainstay for CBD stone extraction nowadays [2]. Additional techniques including endoscopic papillary large-balloon dilation, mechanical lithotripsy, cholangioscopy-assisted electrohydraulic/laser lithotripsy (Spyglass), or extracorporeal shock-wave lithotripsy (ESWL) may be required when dealing with difficult biliary stones [2–4]. The recent introduction of deep enteroscopy-assisted ERCP [5–7], endosonography-guided cholangiopancreatography (ESCP) [8, 9], and laparoscopy-assisted ERCP [10–12] are aimed to improve the success in patients with surgically altered gastroduodenal or pancreatobiliary

anatomy. Laparoscopic bile duct exploration (transcystic or transcholedochal) [13–16] or laparotomy with CBD exploration [14] are considered when less invasive techniques fail or are unavailable.

Percutaneous transhepatic biliary stone removal (PTSR) could be an effective alternate for CBD stone extraction. Perez et al. [17] and Clouse [18, 19] first reported PTSR with a Dormia basket. In 1981, Centola et al. introduced balloon dilatation of the sphincter of Oddi to allow biliary stone passage [20]. In a retrospective Turkish study involving 261 patients, percutaneous transhepatic papillary balloon dilation (PTPBD) demonstrated a success rate of 97.5% (242 of 248) [21]. A 2021 multicenter prospective cohort study from China compared PTPBD with ERCP for CBD stone removal and reported similar success rates (99% vs. 98%) but lower complication rate for PTPBD (4% vs. 8%) [22]. Other techniques for PTSR management include percutaneous transhepatic cholangioscopic lithotripsy [23–26], percutaneous transcholecystic removal of CBD stones [27], or percutaneous transhepatic cholangioscope combined with intracorporeal electrohydraulic lithotripsy, laser lithotripsy, ESWL, and electromagnetic lithotripsy for fragmentation of the large stones [23–25, 28–32].

The success rate of endoscopic CBD stone extraction decreases with an increase in stone size [33] and remains challenging in patients with surgically altered anatomy; however, to date, no study has explored the factors affecting technical success in PTSR. Therefore, we conducted a retrospective study to evaluate the contributing factors in a successful percutaneous transhepatic CBD stone removal.

## Materials and methods

### Patients

In our institute, patients with symptomatic CBD stones are initially referred to gastroenterologists for ERCP. If the patients have altered gastroduodenal or pancreatobiliary anatomy, PTSR, deep-enteroscopy-assisted ERCP, or ESCP were provided as alternative treatment, and only patients who received PTSR were enrolled. Suppose the patients are not suitable for ERCP because of uncooperativeness, multiple comorbidities, advanced age, low cardiopulmonary reserve (as indicated by endotracheal intubation or tracheostomy), or who experienced ERCP failure (fERCP). In that case, PTSR is in preference over laparoscopic CBD exploration. Symptomatic CBD stones were diagnosed based on clinical evidence and imaging studies, including abdominal ultrasound (US), computed tomography (CT), or magnetic resonance cholangiopancreatography (MRCP).

The data of all patients with symptomatic CBD stones who underwent PTSR between January 1, 2010, and October

31, 2019, were retrospectively collected from our electronic medical records and reviewed. The inclusion criteria included patients with symptomatic CBD stones who had PTSR regardless of native or altered gastroduodenal/pancreatobiliary anatomy. Suspected but CT-nondetectable stones were defined as follows: recent abdominal pain and leukocytosis or abnormal blood biochemistry findings, including total bilirubin (T.bil), alkaline phosphatase (ALKP), and C-reactive protein (CRP) levels, and were confirmed by US or MRCP. Patients with uncorrectable coagulopathy (INR > 1.5 and platelet < 80 × 10<sup>9</sup>/L), unsafe access, lack of evidence for CBD stones, malignant pancreatic biliary or ampullary disorders, primary sclerosing cholangitis, or choledochal cysts or those with incomplete medical and imaging records were excluded from the study.

Written informed consent was obtained from all patients before the procedure. This study was approved by the Institutional Review Board.

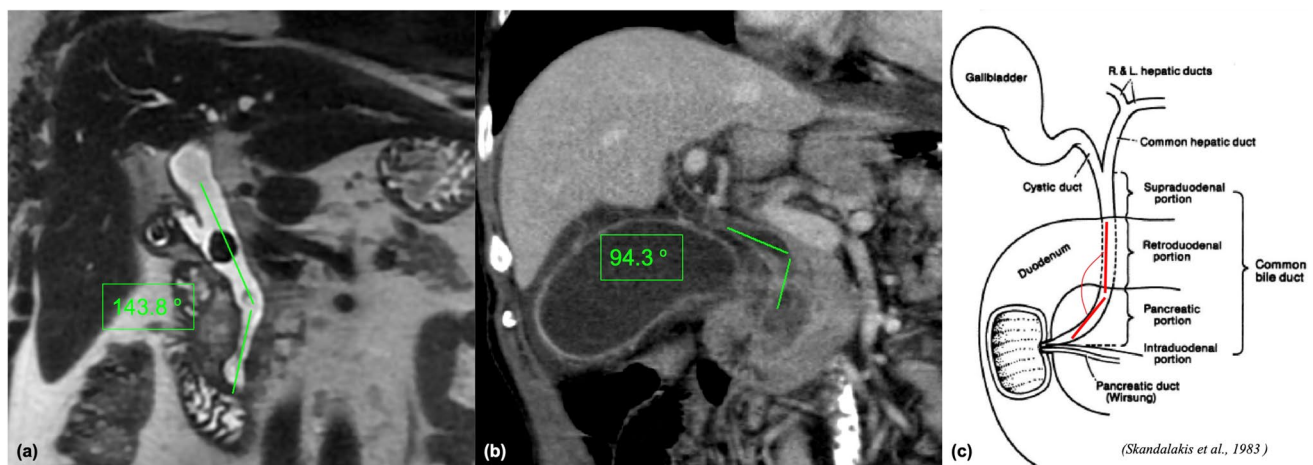
### Data collection

Before the procedure, all patients' medical data (including age, sex, past gastroduodenal or pancreatobiliary operative history, reasons for failed endoscopic stone extraction, complete blood count, and biochemical data); indications for percutaneous transhepatic biliary drainage (PTBD); acute cholangitis severity according to the Tokyo guidelines 2018/2013 (TG18/TG13) [34]; radiological findings including the size, numbers, and radiopacity of the stones; CBD diameter of the largest portion (CBD size); and angle between retroduodenal portion and pancreatic portion CBD (aCBD) were recorded (Fig. 1) [35]. aCBD was measured

using coronal images of CT or MRCP. Peri-procedural data included the side of the transhepatic approach of PTBD (right-sided or left-sided), the device of the procedure (balloon or basket), and total sessions of stone removal. Post-procedural hospitalization time, complications, mortality, and conversion treatment were also obtained.

### Technique

All patients received a prophylactic broad-spectrum antibiotic immediately before the procedure and continued as long as the external catheter was in place. Two experienced interventional radiologists (H.-S.T, and C.-A.L.) performed PTSR by balloon sphincteroplasty flushing technique or basket grasp. The anatomy of the intrahepatic bile duct (IHD) was evaluated to select the best duct for catheterization. All patients were monitored continuously during the procedure. PTBD was established with a 22-gauge Chiba needle, a Neff mini-access set (Cook Medical), a 9-Fr dilator, and a 8.3-French polyethylene ring-type catheter (Cook Medical) for catheterization. Most patients ( $n = 82$ ) had external drainage first for 2–3 days to decompress the biliary tree, and the remaining 18 patients underwent PTBD and PTSR in the same session. PTSR was performed under intravenous sedation. Narcotic analgesics were administered intravenously. When the ring catheter was removed, an 8–9-French-long (25 cm) vascular introducer sheath (Radifocus, Terumo Medical) was advanced into the common hepatic duct. Through the vascular sheath, the guidewire was passed through the ampulla of Vater or bilioenteric anastomosis into the duodenum or jejunum. The ampulla of Vater was dilated with a Gruentzig-type balloon catheter (diameter: 8–12 mm; length: 20–40 mm; Wanda or



**Fig. 1** Measurement of CBD angulation (aCBD) **a** This was a 48-year-old man who experienced failed ERCP due to stone impaction. Pre-operative MR with single-shot fast spin echo sequence showed the aCBD was 143.8 degrees. **b** This 85-year-old man had a history of gastric cancer post radical total gastrec-

tomy and radial total gastrectomy. His aCBD was 94.3 degrees measured on contrast-enhanced CT scan. **c** aCBD was defined as the angle between retroduodenal portion and pancreatic portion CBD, based on the coronal image (Credits: Skandalakis et al., 1983 [35])

Mustang or XXL, Boston Scientific; Advance, Cook Medical) for approximately 60–90 s until the waist disappeared; this was repeated twice. After sphincter or anastomosis dilatation, the stones were pushed out into the duodenum with a Gruentzig-type balloon catheter or an embolectomy balloon catheter (Fogarty Thru-lumen, Edwards Lifesciences; Python, Applied Medical) (Fig. 2a–d). This procedure was repeated until complete clearance was visualized on a cholangiogram. In case of CBD stone impaction, the stones were grasped and crushed with a basket and lithotripsy instrument (Olympus stone extraction basket, 4-wire) (Fig. 2e–f). After the end of the procedure, the introducer sheath was removed and bleeding was checked. A 6–8-French Pigtail drainage catheter was positioned in the CBD for 2–5 days. The residual stone may be obscured by blood clots or air bubbles on cholangiogram right after the stone removal so another cholangiogram was obtained through the external biliary drainage catheter 2 days after the procedure to verify the absence of residual stones. If there was free flow of contrast material into the duodenum and no evidence of biliary stones, the drainage catheter was withdrawn. If residual stones were present, PTSR was repeated.

### Definition of outcome

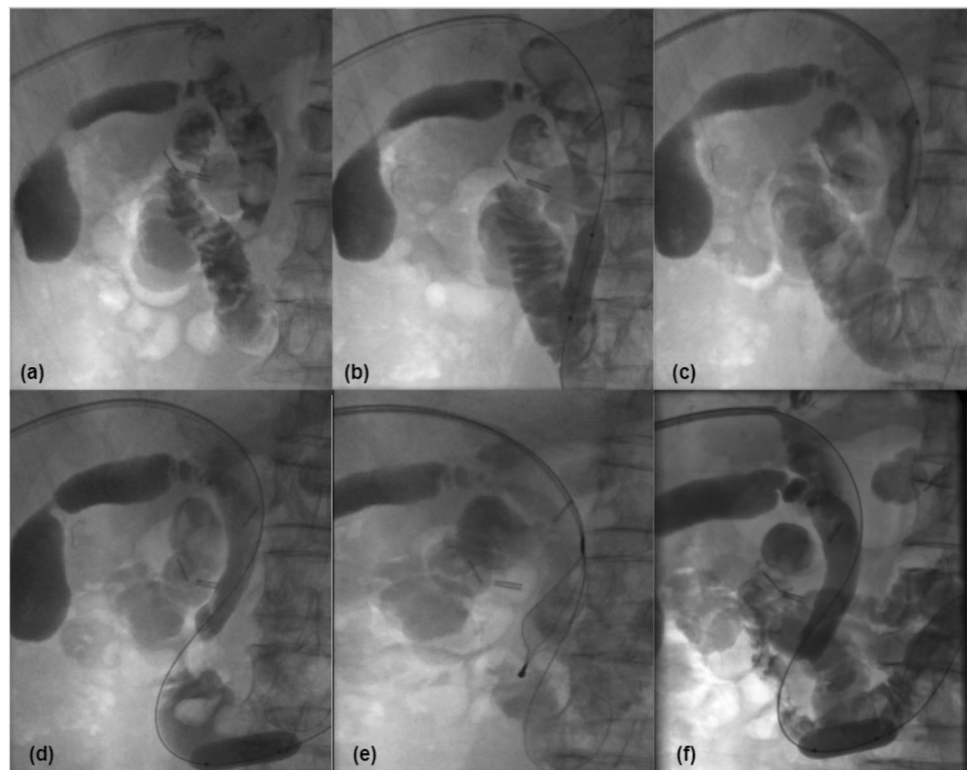
Technical success was defined as no filling defect in the CBD on cholangiography. Clinical success was defined as improvement in sepsis (e.g., fever, chills, and leukocytosis) or a decrease in the serum bilirubin level of more than 20% from

the baseline after 5–7 days of PTSR. Postprocedural complications were categorized according to the Society of Interventional Radiology classification system [36]. Minor complications were defined as transient cholangitis, pancreatitis, fever, chilliness, or percutaneous hematoma at the puncture site. Postprocedural bleeding was defined as hematemesis, melena, pulsatile fresh blood out of the incision site when changing the PTBD catheter, or a  $> 2$ -g/dL decrease in hemoglobin level after the procedure. Cholangitis was defined as new-onset fever ( $38\text{ }^{\circ}\text{C}$ ) for more than 24 h or cholestasis [19, 37]. Pancreatitis was defined by the 2012 revised Atlanta classification as abdominal pain consistent with acute pancreatitis and serum amylase/lipase greater than 3 times of normal limit [38]. Mortality was regarded as any event 30 days after the procedure.

### Statistics

All statistical analyses were conducted using IBM SPSS 25.0 for iOS. Quantitative data are reported as mean  $\pm$  standard deviation or median and range. Qualitative data are reported as proportions and percentages. Categorical variables were analyzed using the chi-square test or Fisher's exact test. Univariate and multivariable analyses for risk factors for technical failure were included in a multiple logistic regression model, the results of which were presented as odds ratio (OR) and 95% confidence interval (CI). All the tests were two-sided, and  $p < 0.05$  was considered statistically significant.

**Fig. 2** Percutaneous transhepatic biliary stone removal (PTSR): balloon sphincteroplasty flushing technique or basket grasp and crush for CBD stone removal. This was an 85-year-old man with multiple CBD stones who has had radical subtotal gastrectomy and Roux-en-Y gastric bypass for gastric cancer. **a** After contrast injection via a 9-Fr sheath, multiple filling defects were identified in the CBD, compatible with CBD stones. **b** The Ampulla of Vater was dilated with a Gruentzig-type balloon catheter. **c–d** The stones were pushed into the duodenum with a Gruentzig-type balloon catheter. **e** Since incomplete clearance of the cholangiogram, a retraction basket was introduced to grasp and crush stones. **f** After basket lithotripsy, flushing technique was repeated. Finally, no filling defect was noted in the cholangiography



## Results

Table 1 summarizes the patients' baseline clinicodemographic characteristics. One hundred patients (66 men and 34 women; age range, 25–105 years; mean age, 79.1 years) were recruited. Fifty-one patients (51%) had a history of altered gastroduodenal or pancreatobiliary anatomy,

including Billroth II or Roux-en-Y gastric bypass ( $n=49$ ), Whipple's procedure ( $n=1$ ), and esophagectomy and gastric tube reconstruction ( $n=1$ ). Forty-eight out of 51 patients with surgically altered anatomy received PTSR as initial treatment for stone removal. Twenty-seven patients (27%) had ERCP failure and were referred for PTSR. The main recorded reasons for fERCP included large periampullary

**Table 1** Baseline clinicodemographic characteristics of the 100 patients

Patient characteristics	<i>N</i>	%
Number of patients	100	
Age—mean $\pm$ SD (range) in years	79.07 $\pm$ 12.76 (25–105)	
Gender, M:F—number (%)	66:34	66:34
Altered gastroduodenal or pancreatobiliary anatomy	51	51
Whipple operation	1	1
Billroth-II gastrectomy or Roux-en-Y	49	49
Esophagectomy and gastric tube reconstruction	1	1
Failed ERCP [reported reasons]	27	
periampullary diverticulum: 8 (29.6%),		
	distal CBD narrowing or stricture: 6 (22.2%) duodenal bulb deformity: 3 (11.1%); others are listed in Figure S1.]	
	<i>Mean <math>\pm</math> SD (range)</i>	<i>Reference value</i>
Severity of acute cholangitis (TG18/TG13* grade I:II:III) ( <i>n</i> , %)	49:41:10 (49%:41%:10%)	
Pre-procedural serum T.bil level (mg/dL)	4.16 $\pm$ 3.73 (0.16–16.27)	$\leq 0.3$
Pre-procedural serum ALKP (U/L)	278.6 $\pm$ 262.4 (49–2026)	40–129
Pre-procedural blood WBC (/ul)	11,353 $\pm$ 6102 (2370–32,800)	4500–11,000
Pre-procedural blood platelet count ( $\times 10^3/\mu\text{L}$ )	198.9 $\pm$ 75.75 (7.5–398)	150–350
Pre-procedural INR	1.11 $\pm$ 0.21 (0.86–2.78)	0.85–1.15
Pre-procedural CRP (mg/dL)	6.61 $\pm$ 6.08 (0.05–30.0)	< 0.5
Pre-procedural shock status (Y:N) ( <i>n</i> , %)	85:15 (85%:15%)	
Largest impacted CBD stone size (mm)	12.8 $\pm$ 5.42 (3–32)	
Largest CBD diameter (mm)	15.2 $\pm$ 4.93 (5–33)	
Numbers of stones—piece(s), pc(s)	1 pc ( $n=36$ ), 2–5 pcs ( $n=51$ ), > 6 pcs ( $n=13$ )	
Radiopacity of CBD stones (HU) (exclusion of patients without CT image)	88.69 $\pm$ 69.16 (34–532) > 150 HU: $n=6$	150 $\geq$ HU > 80: $n=34$ HU $\leq$ 80: $n=43$ non-radiopaque: $n=12$
Angle between retroduodenal and pancreatic portion CBD (aCBD)	121.8° $\pm$ 19.2° (90.6°–180.0°)	
Transhepatic approach of PTBD	Right-sided: $n=82$	
Left-sided: $n=18$		
Total session(s) of stone removal	1 time ( $n=84$ ),	
2 times ( $n=15$ ),		
3 times ( $n=1$ )		
First PTBD to discharge (days)	20.7 $\pm$ 13.1 (3–73)	
PTSR to discharge (days)	14.3 $\pm$ 11.2 (1–54)	
Interval between first PTBD and PTSR (days)	6.4 $\pm$ 10.1 (0–69)	

\*TG18/TG13: 2018/2013 revised Tokyo guideline for acute cholangitis; *T.bil* total bilirubin, *ALKP* alkaline phosphatase, *WBC* white blood count, *CRP* C-reactive protein, *CBD* common bile duct, *PTBD* percutaneous transhepatic biliary drainage, *PTSR* percutaneous transhepatic biliary stone removal, *SD* standard deviation, *HU* Housefield unit

diverticulum (PAD) ( $n=8$ ), distal CBD narrowing or stricture ( $n=6$ ), duodenal bulb deformity ( $n=3$ ), and others are listed in the Supplementary Figure S1. Twenty-five patients (25%) initially underwent PTSR rather than ERCP because of patient uncooperativeness, multiple comorbidities, advanced age, low cardiopulmonary reserve (as indicated by endotracheal intubation or tracheostomy), or critical medical conditions such as septic shock. The majority was concluded into mild (grade I, 49%) and moderate (grade II, 41%) severity in TG18/TG13; while ten patients (10%) into grade III with severe grading.

The mean size of the largest impacted stone was  $12.8 \pm 5.42$  mm, and the mean CBD size was  $15.2 \pm 4.93$  mm. Most patients had approximately 2–5 pieces of stones, which were detected on CT scan. The attenuation patterns of CBD stones on CT were classified as follows: heavily calcified (mean Hounsfield unit  $> 150$ ), radiopaque (mean Hounsfield unit: 81–150), less radiopaque (mean Hounsfield unit  $\leq 80$ ), and undetectable (gas in or around the stones) [39]. In all, 77% of the cases exhibited radiopaque to less radiopaque stones. A mean aCBD was  $121.8^\circ \pm 19.2^\circ$ . Most patients (82%) underwent right-sided biliary drainage. Furthermore, 84% of patients required only one session of PTSR for complete stone clearance, whereas 15% and 1% of patients required two and three sessions, respectively.

The technical and clinical results of the procedure are summarized in Table 2. The overall technical success rate was 83%; the clinical success rate was higher at 93%, suggesting symptomatic relief after PTBD/PTSR even with small retained stones or sludge in the CBD. In the subgroup analysis, the fERCP group had a significantly lower technical success rate in PTSR than patients who received PTSR as the first-line treatment (66.7% vs. 89.0%,  $p=0.008$ ). Patients with altered gastrointestinal tract anatomy had significantly higher clinical success rate than those with normal gastrointestinal tract anatomy (98% vs. 87.8%,  $p=0.044$ ), and the technical success rate was almost significantly higher in altered anatomy group ( $p=0.051$ ).

Table 3 lists the procedure-associated complications. Eight patients (10%) had minor complications. To note that two patients enduring mild elevated serum amylase/lipase after PTSR were not met the criteria of Atlanta classification for acute pancreatitis. Six (6%) had major complications

involving subcapsular biloma requiring drainage ( $n=1$ ), hemorrhage requiring embolization ( $n=4$ ), and cholethorax ( $n=1$ ). The reasons for embolization included active bleeding from the PTBD tract ( $n=2$ ), pseudoaneurysm formation at the right hepatic artery ( $n=1$ ), and duodenal bleeding from a branch of the gastroduodenal artery ( $n=1$ ). No procedure-related mortality was noted. However, four patients had persistent septic shock and intractable cholestasis even after PTSR. Technical failure occurred in 17 (17%) patients due to stone impaction ( $n=7$ ) or incomplete clearance ( $n=10$ ). Of them, 13 (13%) underwent conversion treatment: 7 underwent choledochoscope through the PTBD tract, but 3 of 7 eventually found no residual stones in choledochoscope; 2 underwent choledochoscope for IHD stones; 3 underwent ERCP for stone impaction; only one patient underwent choledocholithotomy and open cholecystectomy surgery.

Blood biochemistry panels were evaluated before PTBD or PTSR (Table 1) and followed up  $6.2 \pm 4.5$  days (range: 1–24) after PTSR. Compared with before, PTBD/PTSR, T.bil, ALKP, and CRP levels significantly decreased after PTBD/PTSR (all  $p < 0.05$ ; Fig. 3).

Table 4 displays the univariate and multivariable analyses conducted to identify the predictors of technical failure. The appropriate cutoff for CBD size was 15.5 mm (AUC: 0.91) and that for CBD stone size was 13.5 mm (AUC: 0.73). Because of small AUCs, the cutoff value of CBD stone attenuation was defined according to the literature [39]; the mean of aCBD and of the interval between PTBD and PTSR were determined as a cutoff point. The significant risk factors for technical failure in univariate analysis were male sex ( $p=0.022$ ), TG18/TG13 grade III ( $p=0.008$ ), fERCP ( $p=0.011$ ), CBD stone size  $> 13.5$  mm ( $p=0.006$ ), CBD size  $> 15.5$  mm ( $p=0.002$ ), and left-sided PTBD ( $p=0.002$ ). No significant difference was noted in technical success due to altered gastroduodenal or pancreatobiliary anatomy, stone attenuation, or aCBD. Multivariable analysis revealed that the fERCP group ( $p=0.004$ , OR: 16.509, 95% CI: 2.471–110.288), CBD size  $> 15.5$  mm ( $p=0.015$ , OR: 506.460, 95% CI: 3.369–76,140.166), left-sided PTBD ( $p=0.012$ , OR: 21.621, 95% CI: 1.962–238.226), and TG18/TG13 grade III ( $p=0.006$ , OR: 60.467, 95% CI: 3.339–1095.164) were independent risk factors for technical

**Table 2** Successful rate of PTSR to achieve complete stone clearance in different patient groups

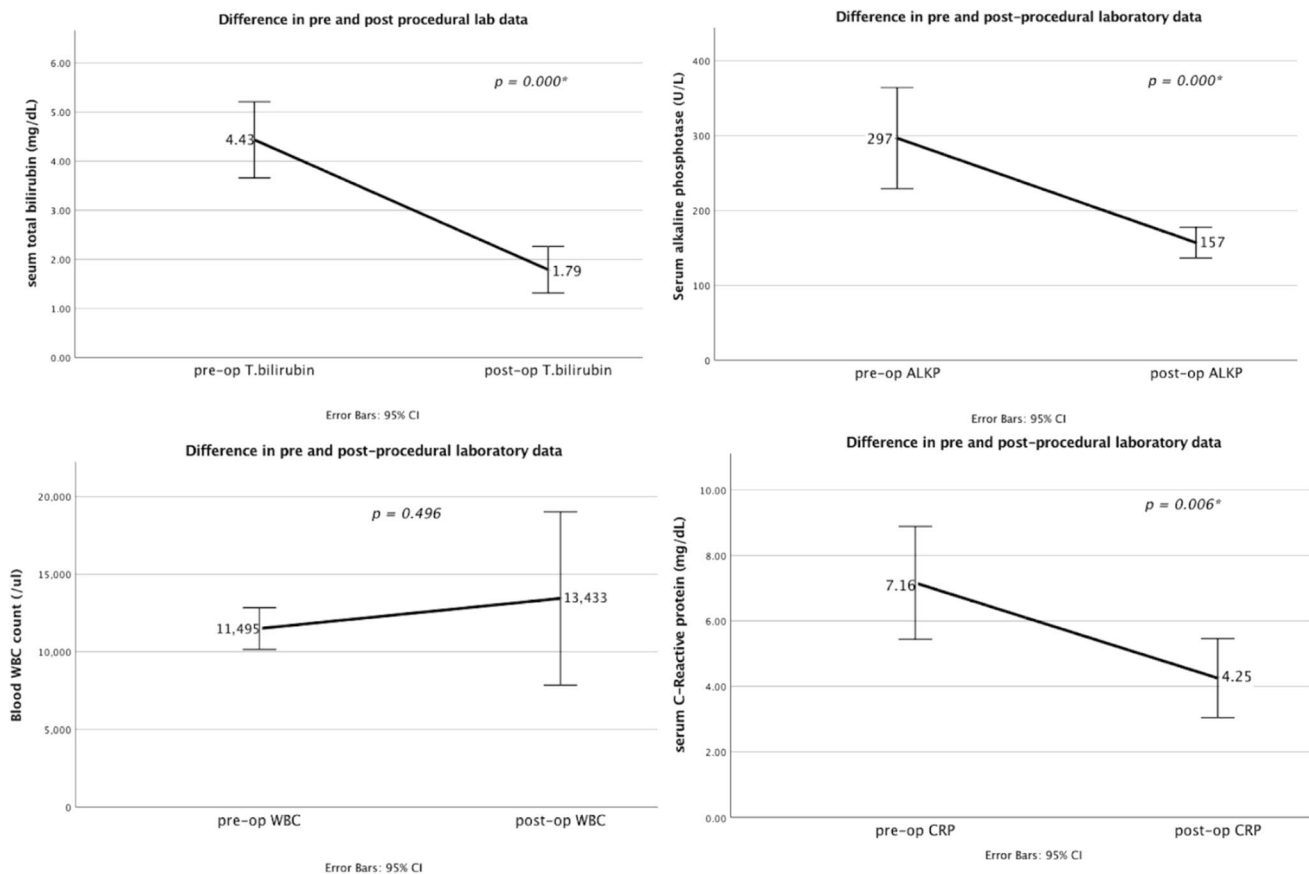
	Technical success	$p$ -value <sup>1</sup>	Clinical success	$p$ -value <sup>1</sup>
Overall (numbers of patients)	83.0% (83/100)		93.0% (93/100)	
With ERCP failure (27)	66.7% (18/27)	*0.008	92.6% (25/27)	0.924
W/o ERCP failure (73)	89.0% (65/73)		93.2% (68/73)	
With altered anatomy (51)	90.2% (46/51)	0.051	98.0% (50/51)	*0.044
W/o altered anatomy (49)	75.5% (37/49)		87.8% (43/49)	

<sup>1</sup>Chi-square test for difference between the two groups.  $p < 0.05$  was considered statistically significant (\*)

**Table 3** Outcome of PTSR and conversion treatment

	Parameters	Numbers of patients
I	Minor complications	<i>n</i> = 10 (10%)
	1. Cholangitis	<i>n</i> = 6
	2. Percutaneous hematoma at puncture site	<i>n</i> = 2
	3. Elevated amylase/lipase (< 3 times of UNL)	<i>n</i> = 2
	Major complications	<i>n</i> = 6 (6%)
	1. Subcapsular biloma requiring drainage	<i>n</i> = 1
II	2. Hemorrhage requiring embolization	<i>n</i> = 4
	3. Cholethorax after removal of PTBD	<i>n</i> = 1
	Procedural related mortality	<i>n</i> = 0 (0%)
III	Non-procedural related mortality	<i>n</i> = 4 (4%)
	1. Persistent septic shock and intractable cholestasis	<i>n</i> = 4
	Conversion treatment	<i>n</i> = 13 (13%)
	1. PTCS for CBD stones	<i>n</i> = 7 *(3 PTCS found no residual stones)
	2. PTCS for IHD stones	<i>n</i> = 2
	3. Surgery (open cholecystectomy, choledocholithotomy)	<i>n</i> = 1
	4. ERCP	<i>n</i> = 3

PTCS percutaneous transhepatic cholangioscopy, ERCP endoscopic retrograde cholangiopancreatography, PTBD percutaneous transhepatic biliary drainage, CBD common bile duct, IHD intrahepatic bile duct, UNL upper normal limit



**Fig. 3** Comparison of mean T.bilirubin, ALKP, WBC, and CRP before, and at an average of 6 days after PTSR. *p* values of chi-square test are presented in the plot

**Table 4** Univariate and multivariable analyses for risk factors to technical failure of transhepatic removal of CBD stones

		Univariate			Multivariable		
		OR	95% CI	<i>p</i> -value	OR	95% CI	<i>p</i> -value
Age (years)		0.987	0.951–1.025	0.490			
Gender	Male vs. female	0.285	0.097–0.835	0.022*	0.313	0.056–1.758	0.187
TG18/TG13 grade	III vs. I, II	6.500	1.634–25.851	0.008*	60.467	3.339–1095.164	0.006*
Pre-op T.bilirubin (mg/dL)		1.021	0.890–1.171	0.767			
CBD stone size (mm)	> 13.5 vs. ≤ 13.5	4.978	1.592–15.562	0.006*	1.662	0.318–8.697	0.547
CBD size (mm)	> 15.5 vs. ≤ 15.5	26.839	3.391–212.407	0.002*	506.460	3.369–76,140.166	0.015*
Stone attenuation (HU)	> 80 vs. ≤ 80	0.859	0.270–2.726	0.796			
aCBD (degrees)	< 122 vs. ≥ 122	0.507	0.172–1.500	0.220			
Transhepatic approach	Left vs. right	6.400	2.007–20.406	0.002*	21.621	1.962–238.226	0.012*
Failed ERCP (fERCP)	Yes vs. no	4.062	1.371–12.035	0.011*	16.509	2.471–110.288	0.004*
Altered anatomy	Yes vs. no	0.335	0.108–1.037	0.058			
Interval between PTBD and PTSR (days)	< 6.4 vs. ≥ 6.4	2.122	0.635–7.089	0.221			

*Abbreviations:* OR odds ratio, CI confidence interval, CBD common bile duct, TG13 Tokyo guideline of severity for acute cholangitis, ERCP endoscopic retrograde cholangiopancreatography, PTBD percutaneous transhepatic biliary drainage, PTSR percutaneous transhepatic biliary stone removal

failure. We obtained a reasonable predictive accuracy in our multivariable model with a C-statistic of 0.913; therefore, when faced with a case with symptomatic CBD stones, the model would correctly assign the case as being at higher risk or benefit 91% of the time after stone removal.

## Discussion

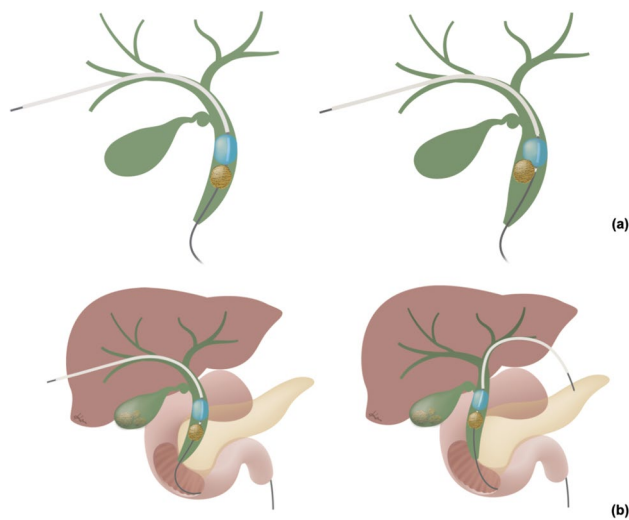
Bile duct stones account for 15% of patients with gallstones. Since the introduction of ERCP in 1974 [40], ERCP has become the preferred method for the treatment of CBD stones [2]. Its complication rates are 5–18% [41–43], and immediate complications include pancreatitis, hemorrhage, biliary sepsis, and perforation [44, 45]. Nevertheless, the scope of ERCP is limited in patients with surgically altered gastroduodenal or pancreatobiliary anatomy, biliary duct stricture, or juxtapaillary diverticulum [5, 8, 46]. Recent advanced approaches allow higher success in patients with surgically altered anatomy, though disadvantage exists: deep enteroscopy-assisted ERCP has adverse event of 0–12.5% [5–7]; ESCP has complication rate of 22% including bile leakage and pneumoperitoneum in transmural approach and 12–17% in rendezvous approach [8, 9]; and laparoscopy-assisted ERCP has risk for bowel injury in transgastric access [10–12, 47]. Due to limited availability of accessories/instruments and additional cost not covered by our countries' health insurance, however, PTSR can be an effective alternate for treatment. However, little information is available on the clinical or anatomic factors affecting the technical outcomes of transhepatic CBD stone extraction.

PTSR has a high success rate of 97.5–99% [21, 22]. The lower technical success rate in our study may be caused by older population than those of other studies by 13–15 years (mean age: 79 vs. 64 years) [21, 22]. The elderly are prone to higher TG18/TG13 grading for multi-organ dysfunction or morbidities.

Several studies have analyzed the factors affecting CBD stone removal through ERCP, such as CBD stone size, PAD, and distal CBD angle [33, 48, 49]. Lauri et al. reported that the success rate of endoscopic extraction decreased with an increase in stone size (successful clearance: median stone size of 10 mm; unsuccessful clearance: median stone size of ≥ 18 mm) [33]. In our study, large CBD stone size (> 13.5 mm) and CBD size (> 15.5 mm) were significant factors affecting technical failure in univariate analysis. In the multivariable analysis, only CBD size reached statistical significance, which has not been mentioned in previous studies. We hypothesized that a larger bile duct weakens uniform contact with a balloon catheter, and may release the pushing force of a balloon catheter on a floating stone (Fig. 4a). This corresponds with our experience that an embolectomy balloon catheter is more desirable to expel stones than a Gruentzig-type balloon due to its balloon shape providing static contact with bile ducts wall.

We reported fERCP to be a risk factor for technical failure. Anatomic difficulty in ERCP included large PAD, distal CBD narrowing or stricture, and duodenal bulb deformity. Nine (66.7%) patients in the fERCP group subsequently experienced failed PTSR: six with incomplete stone clearance (including four patients asymptotically), two with too-hard stones to crush, and one with extremely dilated





**Fig. 4** Illustration of the effect of dilated CBD and left-sided PTBD **a** The effect of dilated bile duct caliber on balloon flushing technique. A larger bile duct weakens uniform contact with a balloon catheter on the bile duct wall and may release the pushing force of a balloon catheter on a floating stone. **b** Left-sided PTBD usually has a more acute angle above the bifurcation of the common hepatic duct and is speculated to accumulate tension for pushing force

CBD and abrupt CBD angle for balloon sphincteroplasty flushing technique. Hu et al. reported that large PAD causes unidentified orifice of the papilla and lowers the rate of complete CBD stones removal in the first session by ERCP. PAD has a high prevalence of 50% in elderly patients [48]. We assumed that PAD leads to non-uniform mucosa contrast pooling indistinguishable from residual stones when facing CBD filling defects on cholangiogram.

Kim et al. revealed that a more acute distal CBD angle ( $\leq 135^\circ$ ) and a shorter distal CBD arm ( $\leq 36$  mm) were independent contributors for endoscopic clearance of bile duct stones. CBD angulation was measured as the sharpest angle along the CBD from 1 cm below the bifurcation to 1 cm above the papilla on an endoscopic cholangiogram [49]. In our study, aCBD was not conclusive as a risk factor. We presume that both distal CBD angulation and transhepatic route determine the access for the balloon catheter to push stones into the duodenum. Left-sided PTBD usually has a more acute angle between IHD entry site-common hepatic duct (CHD) and CBD axis, and thus may accumulate tension above CHD bifurcation (Fig. 4b). An acute angle reinforces the “edge effect” compared with obtuse or straight angles when stones are swept by balloon catheter. Current assessment of bile duct angulation is on a two-dimensional plane. This may have underestimated the CBD angulation compared with measuring it on a more accurate three-dimensional plane. Future studies should include a larger number of patients and advanced measurement methods for appropriate statistical analysis.

In conclusion, our findings suggest that PTSR is safe and efficacious for managing CBD stones in older adults and individuals with altered anatomy. Complete transhepatic removal of CBD stones is technically more challenging in patients with specific risk factors, such as fERCP, larger CBD size, left-sided PTBD, and worse TG18/TG13 severity grade. Patients with these risk factors may benefit from PTSR and may be considered high-risk patients requiring intensive postoperative surveillance.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s00330-023-09631-y>.

**Acknowledgements** Kan Ling contributed to the figure illustration (Fig. 4).

**Funding** This study has received funding by Wong Vung-Hau Radiology Foundation (WVH). The WVH Foundation had no role in the design, analysis or interpretation of the results in this study, or the decision to submit the manuscript for publication.

## Declarations

**Guarantor** The scientific guarantor of this publication is Chien-An Liu.

**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 obtained from all subjects (patients) in this study.

**Ethical approval** Institutional Review Board approval was obtained.

## Methodology

- retrospective
- prognostic study/observational
- performed at one institution

## References

1. Shah KN, Clary BM (2017) Chapter 36A - stones in the bile duct: clinical features and open surgical approaches and techniques. In: Jarnagin WR (ed) Blumgart's Surgery of the Liver, Biliary Tract and Pancreas, 2-Volume Set, 6th edn. Elsevier, Philadelphia, pp 585-603.e3
2. Manes G, Paspatis G, Aabakken L et al (2019) Endoscopic management of common bile duct stones. *Eur Soc Gastrointest Endosc (ESGE) Guide Endosc* 51(5):472–491
3. Li G, Pang Q, Zhai H et al (2021) SpyGlass-guided laser lithotripsy versus laparoscopic common bile duct exploration for large common bile duct stones: a non-inferiority trial. *Surg Endosc* 35(7):3723–3731
4. Costi R, Gnocchi A, Di Mario F, Sarli L (2014) Diagnosis and management of choledocholithiasis in the golden age of imaging, endoscopy and laparoscopy. *World J Gastroenterol* 20(37):13382–401

5. Morrell D, Pauli E, Juza R (2019) Endoscopy in surgically altered anatomy. *Annals Laparosc Endoscopic Surg* 4(41)
6. Ali MF, Modayil R, Gurrām KC, Brathwaite CEM, Friedel D, Stavropoulos SN (2018) Spiral enteroscopy-assisted ERCP in bariatric-length Roux-en-Y anatomy: a large single-center series and review of the literature (with video). *Gastrointest Endosc* 87(5):1241–1247
7. Committee AT, Chauhan SS, Manfredi MA et al (2015) Enterosc Gastrointest Endosc 82(6):975–990
8. Jirapinyo P, Lee LS (2016) Endoscopic ultrasound-guided pancreatobiliary endoscopy in surgically altered anatomy. *Clin Endosc* 49(6):515–529
9. Martin A, Kistler CA, Wrobel P, Yang JF, Siddiqui AA (2016) Endoscopic ultrasound-guided pancreaticobiliary intervention in patients with surgically altered anatomy and inaccessible papillae: a review of current literature *Endosc. Ultrasound* 5(3):149–156
10. Koggel LM, Wahab PJ, Robijn RJ et al (2021) Efficacy and safety of 100 laparoscopy-assisted transgastric endoscopic retrograde cholangiopancreatography procedures in patients with Roux-en-Y gastric bypass. *Obes Surg* 31(3):987–993
11. Saleem A, Levy MJ, Petersen BT, Que FG, Baron TH (2012) Laparoscopic assisted ERCP in Roux-en-Y gastric bypass (RYGB) surgery patients. *J Gastrointest Surg* 16(1):203–8
12. Lopes TL, Clements RH, Wilcox CM (2009) Laparoscopy-assisted ERCP: experience of a high-volume bariatric surgery center (with video). *Gastrointest Endosc* 70(6):1254–9
13. Lezoché E, Paganini AM (2000) Technical considerations and laparoscopic bile duct exploration: transcystic and choledochotomy. *Semin Laparosc Surg* 7(4):262–278
14. Shojaieard A, Esmailzadeh M, Ghafouri A, Mehrabi A (2009) Various techniques for the surgical treatment of common bile duct stones: a meta review. *Gastroenterol Res Pract* 2009:840208
15. Sharma A, Dahiya P, Khullar R, Soni V, Bajjal M, Chowbey PK (2012) Management of common bile duct stones in the laparoscopic era. *Indian J Surg* 74(3):264–269
16. Hongjun H, Yong J, Baoqiang W (2015) Laparoscopic common bile duct exploration: choledochotomy versus transcystic approach? *Surg Laparosc Endosc Percutan Tech* 25(3):218–222
17. Perez MR, Oleaga JA, Freiman DB, McLean GL, Ring EJ (1979) Removal of a distal common bile duct stone through percutaneous transhepatic catheterization. *Arch Surg* 114(1):107–109
18. Clouse ME (1983) Dormia basket modification for percutaneous transhepatic common bile duct stone removal. *AJR Am J Roentgenol* 140(2):395–397
19. Clouse ME, Falchuk KR (1983) Percutaneous transhepatic removal of common duct stones: report of ten patients. *Gastroenterology* 85(4):815–819
20. Centola CA, Jander HP, Stauffer A, Russinovich NA (1981) Balloon dilatation of the papilla of Vater to allow biliary stone passage. *AJR Am J Roentgenol* 136(3):613–614
21. Ozcan N, Kahrman G, Mavili E (2012) Percutaneous transhepatic removal of bile duct stones: results of 261 patients. *Cardiovasc Intervent Radiol* 35(3):621–7
22. Liu B, Ma J, Li S, et al (2021) Percutaneous transhepatic papillary balloon dilation versus endoscopic retrograde cholangiopancreatography for common bile duct stones: a multicenter prospective study. *Radiology* 300(2):470–478
23. Muglia R, Lanza E, Poretti D et al (2020) Percutaneous transhepatic endoscopic lithotripsy of biliary stones with holmium laser for the treatment of recurrent cholangitis. *Abdom Radiol (NY)* 45(8):2561–2568
24. Tripathi N, Mardini H, Koirala N, Raissi D, Emhmed Ali SM, Frandah WM (2020) Assessing the utility, findings, and outcomes of percutaneous transhepatic cholangioscopy with spyglass(TM) direct visualization system: a case series. *Transl Gastroenterol Hepatol* 5:12
25. Zhuo H, Chen Z, Lin R, et al (2020) Percutaneous transhepatic choledochoscopic lithotomy (PTCSL) is effective for the treatment of intrahepatic and extrahepatic choledocholithiasis. *Surg Laparosc Endosc Percutan Tech* 31(3):326–330
26. Wang P, Tao H, Liu C et al (2021) One-step percutaneous transhepatic cholangioscopic lithotripsy in patients with choledocholithiasis. *Clin Res Hepatol Gastroenterol* 45(2):101477
27. Jung GS, Kim YJ, Yun JH et al (2019) Percutaneous transcholangioscopic removal of common bile duct stones: case series in 114 patients. *Radiology* 290(1):238–243
28. Deal AK, Murthy S, Wason S, Vingan H, Fabrizio M (2016) Percutaneous transhepatic holmium laser lithotripsy of a large common bile duct stone. *Radiol Case Rep* 11(4):361–364
29. Herr A, Collins D, White M et al (2019) Percutaneous biliary endoscopy for stones. *Tech Vasc Interv Radiol* 22(3):127–134
30. Lamanna A, Maingard J, Bates D, Ranatunga D, Goodwin M (2019) Percutaneous transhepatic laser lithotripsy for intrahepatic cholelithiasis: a technical report. *J Med Imaging Radiat Oncol* 63(6):758–764
31. Tao H, Wang P, Sun B, Li K, Zhu C (2020) One-step multichannel percutaneous transhepatic cholangioscopic lithotripsy applied in bilateral hepatolithiasis. *World J Surg* 44(5):1586–1594
32. Gerges C, Vazquez AG, Tringali A, et al (2021) Percutaneous transhepatic cholangioscopy using a single-operator cholangioscope (pSOC), a retrospective, observational, multicenter study. *Surg Endosc* 35(12):6724–6730
33. Lauri A, Horton RC, Davidson BR, Burroughs AK, Dooley JS (1993) Endoscopic extraction of bile duct stones: management related to stone size. *Gut* 34(12):1718–1721
34. Kiriya S, Kozaka K, Takada T et al (2018) Tokyo Guidelines 2018: diagnostic criteria and severity grading of acute cholangitis (with videos). *J Hepatobiliary Pancreat Sci* 25(1):17–30
35. Skandalakis JE, Gray SW, Rowe JS (1983) Anatomical complications in general surgery 1st ed., McGraw-Hill. Book company. New York paris 130
36. Patel IJ, Rahim S, Davidson JC et al (2019) Society of Interventional Radiology Consensus Guidelines for the Periprocedural Management of Thrombotic and Bleeding Risk in Patients Undergoing Percutaneous Image-Guided Interventions-Part II: Recommendations: Endorsed by the Canadian Association for Interventional Radiology and the Cardiovascular and Interventional Radiological Society of Europe. *J Vasc Interv Radiol* 30(8):1168–1184 e1
37. Cotton PB, Eisen GM, Aabakken L et al (2010) A lexicon for endoscopic adverse events: report of an ASGE workshop. *Gastrointest Endosc* 71(3):446–454
38. Banks PA, Bollen TL, Dervenis C et al (2013) Classification of acute pancreatitis–2012: revision of the Atlanta classification and definitions by international consensus. *Gut* 62(1):102–111
39. Kim CW, Chang JH, Lim YS, Kim TH, Lee IS, Han SW (2013) Common bile duct stones on multidetector computed tomography: attenuation patterns and detectability. *World J Gastroenterol* 19(11):1788–1796
40. Kawai K, Akasaka Y, Murakami K, Tada M, Koli Y (1974) Endoscopic sphincterotomy of the ampulla of Vater. *Gastrointest Endosc* 20(4):148–151
41. Hallerback B, Enochsson L (2020) A prospective nationwide study on the impact of the level of sedation on cannulation success and complications of endoscopic retrograde cholangiopancreatography. *Ann Gastroenterol* 33(3):299–304
42. Simsek O, Simsek A, Ergun S, Velidedeoglu M, Saribeyoglu K, Pekmezci S (2017) Managing endoscopic retrograde cholangiopancreatography-related complications in patients referred to the surgical emergency unit. *Ulus Travma Acil Cerrahi Derg* 23(5):395–399

43. Neoptolemos JP, Carr-Locke DL, Fraser I, Fossard DP (1984) The management of common bile duct calculi by endoscopic sphincterotomy in patients with gallbladders in situ. *Br J Surg* 71(1):69–71
44. Dumonceau JM, Kapral C, Aabakken L et al (2020) ERCP-related adverse events: European Society of Gastrointestinal Endoscopy (ESGE) Guideline. *Endoscopy* 52(2):127–149
45. Plewka M, Rysz J, Kujawski K (2017) Complications of endoscopic retrograde cholangiopancreatography. *Pol Merkur Lekarski* 43(258):272–275
46. Karaahmet F, Kekilli M (2018) The presence of periampullary diverticulum increased the complications of endoscopic retrograde cholangiopancreatography. *Eur J Gastroenterol Hepatol* 30(9):1009–1012
47. Grimes KL, Maciel VH, Mata W, Arevalo G, Singh K, Arregui ME (2015) Complications of laparoscopic transgastric ERCP in patients with Roux-en-Y gastric bypass. *Surg Endosc* 29(7):1753–1759
48. Hu Y, Kou DQ, Guo SB (2020) The influence of periampullary diverticula on ERCP for treatment of common bile duct stones. *Sci Rep* 10(1):11477
49. Kim HJ, Choi HS, Park JH et al (2007) Factors influencing the technical difficulty of endoscopic clearance of bile duct stones. *Gastrointest Endosc* 66(6):1154–1160

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.