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Review Article

Evolving Strategies for the Optimal Management of Common Bile Duct Stones

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Management of common bile duct (CBD) stones has evolved substantially with the advent of endoscopic techniques and dedicated high-end devices. Endoscopic retrograde cholangiopancreatography (ERCP) has become a widespread essential technique for managing CBD stones, with high success rates in standard cases. However, for patients with large stones, stones in an impacted state, and stones in anatomically challenging regions, advanced strategies using various dedicated devices may be needed. Although mechanical lithotripsy and endoscopic papillary large balloon dilation are effective techniques for managing giant stones, temporary biliary stenting with interval stone extraction, commonly referred to as two-stage ERCP, is a valuable approach, particularly in patients with sepsis or significant comorbidities. Digital single-operator cholangioscopy (DSOC) combined with electrohydraulic or laser lithotripsy has significantly transformed the endoscopic treatment strategy for managing difficult-to-extract stones by enabling direct visualization of stones and real-time targeted fragmentation. In very difficult situations where conventional ERCP is unsuccessful, percutaneous transhepatic cholangioscopy may be an effective solution, with DSOC enhancing both efficacy and safety. Advances in endoscopic technology, including integrated laser systems and next-generation retrieval devices, are expected to further improve procedural outcomes. Artificial intelligence is also gaining traction, with potential applications in diagnostic imaging interpretation, intraprocedural decision support, and prediction of stone recurrence. In conclusion, optimal management of CBD stones requires a patient specific, resource-sensitive approach. The integration of cutting-edge technologies and data-driven strategies is expected to improve the precision, efficiency, and overall quality of endoscopic CBD stone management. **(Gut Liver, 2025;19:665-676)**

Key Words: Choledocholithiasis; Endoscopic retrograde cholangiopancreatography; Lithotripsy; Cholangioscopy

INTRODUCTION

Common bile duct (CBD) stones, or choledocholithiasis, may occasionally present clinical challenges and occur in approximately 11% to 25% of patients with gallbladder stones as well as *de novo* primary stones, particularly in Asian populations.[1-3] Their incidence increases with age and is notably associated with female sex, anatomical variations, or metabolic factors.[4,5] CBD stones contribute substantially to hospital admissions and healthcare costs related to biliary tract diseases.[5-7]

The clinical course of CBD stones is variable. While some stones remain asymptomatic, others lead to significant morbidity, including biliary pain, obstructive jaundice, cholangitis, and gallstone pancreatitis.[8-11] Cholangitis, in particular, remains life-threatening, with mortality rates historically around 50%, now reduced to 10%–30% with timely intervention.[10] If left untreated, CBD stones may also cause long-term progressive complications, such as biliary strictures, liver abscesses, secondary biliary cirrhosis, or even cholangiocarcinoma.[12-14] Thus, complete ductal clearance is essential. While laparoscopic bile duct

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exploration performed during cholecystectomy offers improved outcomes, it is limited to high-volume centers and requires general anesthesia.[15-18] In current practice, endoscopic retrograde cholangiopancreatography (ERCP) is the standard method for CBD stone removal, offering broad applicability with a wide range of techniques and accessories.[17,19] The success rate of ductal clearance is recognized as a key quality indicator of the procedure.[20] Achieving prompt and effective stone clearance is therefore critical not only for symptom relief but also for preventing disease progression.[21,22] Continued technological advancements have further expanded endoscopic capabilities, particularly for managing difficult-to-extract stones.

This review focused on evidence-based endoscopic strategies for managing CBD stones in patients without a surgically altered anatomy, highlighting evolving technologies and practical insights to inform clinical decision-making and guide future directions.

ENDOSCOPIC TECHNIQUES FOR STONE REMOVAL

1. Sphincter management strategies for bile duct stone extraction

Following successful selective cannulation of the bile duct, secure and effective access must be established for subsequent CBD stone removal. Endoscopic sphincterotomy (EST) and endoscopic papillary balloon dilation (EPBD) are the standard methods used to facilitate stone extraction. The choice should be individualized based on the stone characteristics, patient comorbidities, and complication risks.

EPBD offers the potential advantage of preserving the sphincter of Oddi function and is associated with a lower bleeding risk (<0.1% vs 3.0%) but a higher incidence of post-ERCP pancreatitis (PEP) (approximately 10% vs 3%) compared with EST.[23] However, EPBD alone may result in lower complete stone clearance rates and higher lithotripsy needs, particularly for larger and multiple stones.[23,24] Both techniques are generally effective for stones <10 mm and fewer than three in number.[25]

Combined EST and EPBD have been increasingly adopted for bile duct stone removal. A network meta-analysis has been published that compared the clinical outcomes of stone removal using EST, EPBD, and the combination of EST and EPBD (EST+EPBD).[26] EPBD alone was less effective than EST alone in achieving same-session stone clearance (odds ratio, 0.59), while EST+EPBD showed comparable efficacy to EST alone. The need for mechanical lithotripsy was significantly lower with EST+EPBD than with EST alone (odds ratio, 0.49). Although the risk of bleeding was slightly higher with EST+EPBD than with EPBD alone, the overall bleeding rates were similar across the three groups (EST: 3.0%, EPBD: 1.1%, and EST+EPBD: 2.0%). Perforation rates were also similar at approximately 1% in all groups.[26] Based on these findings, EST+EPBD is considered a reasonable first-line approach for stones ≤15 mm, but technically difficult to extract due to anatomical or technical challenges, such as a narrow distal bile duct or impacted stones.[27,28]

2. Stone extraction using baskets or balloons

Metal baskets and balloon catheters are the most commonly used devices for endoscopic CBD stone extraction. Given the inconsistent findings from comparative studies, device selection is primarily influenced by clinical circumstances and the endoscopist's judgment.[29-31] Baskets offer stronger traction and are preferred for large stones, whereas balloon catheters are better suited for small stones or sludge.[22]

Regional practice patterns vary: baskets are more commonly used in Japan and Europe, while the American Society of Gastrointestinal Endoscopy guidelines favor balloon catheters due to concerns about basket impaction and entrapment at the papilla.[29,32,33] If standard baskets fail to extract small stones, switching to a balloon or helical (8-wire) basket is a reasonable approach.

Stone removal should proceed distally to proximally to avoid simultaneous engagement of multiple stones, which may complicate passage through the distal CBD and papilla and increase the risk of impaction or ductal injury. Two main techniques are used to manipulate baskets or balloon catheters: (1) retraction through the working channel to apply pulling force, and (2) advancement of the endoscope toward the distal side with rightward torque and downward angulation to align with the bile duct axis.[34]

In cases where stones are trapped within a pocket created by distal CBD dilatation, conventional baskets or balloons may fail to extract the stone. In such scenarios, pushing the stone proximally using a contrast injection or balloon pressure may improve retrieval. Alternatively, dedicated retrieval devices, such as the single-use no-tip nitinol basket (e.g., VorticCatch V, Olympus Medical Systems, Japan), may be considered as they are specifically designed to capture stones within challenging anatomical pockets.[34,35]

MANAGEMENT IN DIFFICULT SITUATIONS

1. Defining difficult-to-extract CBD stones

Difficult-to-extract CBD stones were defined as those

Table 1. Factors Contributing to Difficult-to-Extract Common Bile Duct Stones

Stone factors	Bile duct factors	Access factors
Size ≥15 mm	Sigmoid duct shape	Postoperative anatomy change
Multiple stones	Short duct length	Periampullary diverticulum
Barrel-shaped stones	Acute angulation	Luminal narrowing of duodenum
Unusual hardness	Duct stricture	Papillary stenosis
Cystic duct stone & Mirizzi syndrome	Duct diverticulum	Redundant papilla
Impacted ampullary stone	Downstream narrowing	Recessed or obscured papilla

that required advanced techniques beyond the standard ERCP technique for successful removal due to various contributing factors (Table 1). A stone diameter >15 mm is a well-established predictor of difficulty.[36,37] Other contributing factors include unfavorable stone shapes, impacted locations, and anatomical variations of the bile duct or papilla.[28] Pre-procedural identification through clinical history and imaging is essential for anticipating technical challenges and selecting the appropriate strategy.

2. Mechanical lithotripsy

Mechanical lithotripsy is widely used for fragmenting bile duct stones that cannot be removed intact. The system consists of a reinforced wire basket, a metal sheath, and a lithotripsy handle. After the stone is captured, the basket is pulled into the sheath, and a compressive force is applied to crush the stone.[38]

Two main approaches are used: out-of-the-scope and through-the-scope lithotripsy. The out-of-the-scope method, which is largely reserved for salvage situations, involves cutting the basket handle and withdrawing the endoscope, followed by fluoroscopy-guided application of the crushing force.[22] In contrast, through-the-scope devices allow in-scope lithotripsy without scope removal and are now widely available in integrated forms from different manufacturers.[39]

During the procedure, attention to the alignment of the basket and sheath is critical to prevent kinking and ensure effective force transmission. Reported success rates range from 76% to 91%, though repeat sessions are often needed.[22] Predictors of mechanical lithotripsy failure include impacted stones, stone sizes ≥3 cm, and a stone-to-CBD diameter ratio of ≥1.[40] Impacted stones are the most significant risk factor, with an OR of 17.83.

Potential complications include equipment failure or basket impaction. In a retrospective study of 643 cases, 29 lithotripsy-related complications were reported, including basket impaction or fracture (n=11), traction wire breakage (n=8), handle malfunction (n=7), and bile duct injury or perforation (n=3).[41] In the event of basket impaction, initial management should involve careful manipulation to release the stone. If this approach fails, endoscopic options, such as salvage lithotripsy, extended sphincterotomy, or temporary biliary stenting, may be employed. Surgical extraction should be considered only when all endoscopic rescue strategies are unsuccessful.[41]

3. Endoscopic papillary large balloon dilation

Endoscopic papillary large balloon dilation (EPLBD) is a widely accepted technique for managing large CBD stones and is defined as dilation of the distal bile duct and papilla using a balloon ≥12 mm in diameter. The balloon size should be selected according to the stone size and bile duct diameter. To optimize the efficacy of biliary stone extraction and minimize the risk of PEP, balloon inflation is generally maintained for at least 1 minute after the disappearance of the balloon waist at the level of the papilla.[22,42] Using an excessively large balloon relative to the bile duct caliber or forcibly inflating the balloon before the complete disappearance of the waist may increase the risk of perforation.

EPLBD is usually performed after limited EST, and EPLBD with full EST has been associated with an increased risk of complications, particularly bleeding.[43,44] As summarized in Table 2, EPLBD offers several advantages in managing large or technically difficult bile duct stones, such as improved stone clearance rates and reduced need for mechanical lithotripsy. However, careful patient selection, appropriate balloon sizing based on distal CBD diameter, and adherence to standard techniques are essential to minimize the risk of complications such as perforation and PEP.[45-55] A meta-analysis comparing limited EST+EPLBD to EST alone found no significant difference in stone clearance rates (98% vs 95%, p=0.60), but demonstrated a significant reduction in the need for mechanical lithotripsy (15% vs 32%, p=0.0008) and lower adverse event rates (11% vs 18%, p=0.001).[56] Nonetheless, the risk of PEP should be carefully considered.[26]

Compared to mechanical lithotripsy, which can be technically demanding and often requires multiple steps, EPLBD enables *en bloc* extraction of large stones after adequate dilation, thereby simplifying the procedure. However, attention to the potential adverse events, particularly bleeding, perforation, and pancreatitis, is essential. Based on the current evidence, European guidelines recommend limited EST combined with EPLBD as a first-line approach for large CBD stones.[22]

Table 2. Clinical Benefits and Technical Considerations of Endoscopic Papillary Large Balloon Dilation for Bile Duct Stone Management

Aspect	Summary
Indications	· Large CBD stones (≥10–15 mm) · Multiple stones · Difficult stone extraction with EST or EPBD · High bleeding risk (use with limited EST) · Accessible post-surgical anatomy
Advantages	· Higher stone clearance rate for large/difficult stones · Reduced need for mechanical lithotripsy · Shorter procedure time compared to lithotripsy · Lower risk of bleeding than full EST (with limited EST) · Preserves more sphincter function than full EST · Comparable or lower overall complication rates
Technical considerations	· Perform limited EST before dilation · Select balloon diameter based on distal CBD size (12–20 mm) · Inflate balloon across the papilla · Avoid dilation if distal CBD stricture is present
Potential complications	· Pancreatitis (reduced with prior limited EST) · Perforation (risk increases with oversized balloon or distal CBD stricture) · Bleeding (lower than with full EST when limited EST is used) · Cholangitis (due to incomplete stone clearance) · Stone impaction (from inadequate balloon positioning or dilation)
Contraindications	· Distal CBD stricture · Known or suspected malignancy involving the distal CBD or ampullary region (e.g., cholangiocarcinoma, ampullary tumor, pancreatic head cancer) · Acute pancreatitis · Coagulopathy or uncontrolled bleeding tendency

CBD, common bile duct; EST, endoscopic sphincterotomy; EPBD, endoscopic papillary balloon dilation

4. Extracorporeal shock wave lithotripsy

Extracorporeal shock wave lithotripsy (ESWL) utilizes externally generated shock waves to fragment bile duct stones and was first applied to biliary lithiasis in 1986.[57] Under fluoroscopic guidance, stones are localized using contrast injected through an endoscopic nasobiliary drainage catheter or T-tube. Shock waves are then transmitted through the soft tissues to the targeted stone. Continuous saline irrigation facilitates the clearance of stone fragments into the duodenum via the papilla.[58,59]

The stone clearance rate with ESWL ranges from 84.4% to 90.2%, although multiple sessions are often required.[60,61] General anesthesia or epidural anesthesia is typically necessary, representing a key limitation of ESWL.[61] Post-ESWL complications occur in 9.1% to 15.9% of cases and include abdominal pain, cholangitis, pancreatitis, sepsis, hematoma, hematuria, and hemobilia. Predictors of incomplete clearance include stone sizes ≥2 cm (p=0.021), incarcerated stones (p=0.020), and pre-procedural leukocytosis (p=0.047).[62]

In a randomized trial, ESWL was inferior to cholangioscopy-guided laser lithotripsy in terms of bile duct clearance (73% vs 97%, p<0.05), number of sessions (3.0 vs 1.2, p<0.001), and treatment durations (3.9 days vs 0.9 days, p<0.001).[63] Accordingly, European guidelines recommend ESWL only when conventional and cholangioscopy-assisted methods are unavailable or unsuccessful.[22]

5. Temporary biliary stenting and two-stage ERCP

In patients with acute cholangitis, sepsis, or significant comorbidities, immediate and complete extraction of CBD stones during the initial ERCP may be impractical and potentially hazardous. In such cases, a staged therapeutic strategy involving temporary biliary stenting, followed by delayed stone removal, commonly called two-stage ERCP, is a widely accepted and effective solution (Fig. 1). This approach allows for early biliary decompression and infection control and facilitates subsequent stone clearance through mechanical and physiological changes induced by the indwelling stent. The mechanism underlying this strategy relies on continuous bile flow and stent-induced mechanical interactions, which may lead to the softening, fragmentation, or even dissolution of stones. As a result, stone extraction during the second ERCP is often simplified and can be accomplished with a reduced need for complex interventions, such as mechanical lithotripsy.

One of the most compelling demonstrations of stent-mediated stone modulation was provided by Horiuchi *et al.*,[64] who prospectively evaluated 40 patients with large (≥20 mm) or multiple (≥3) CBD stones. All patients un-

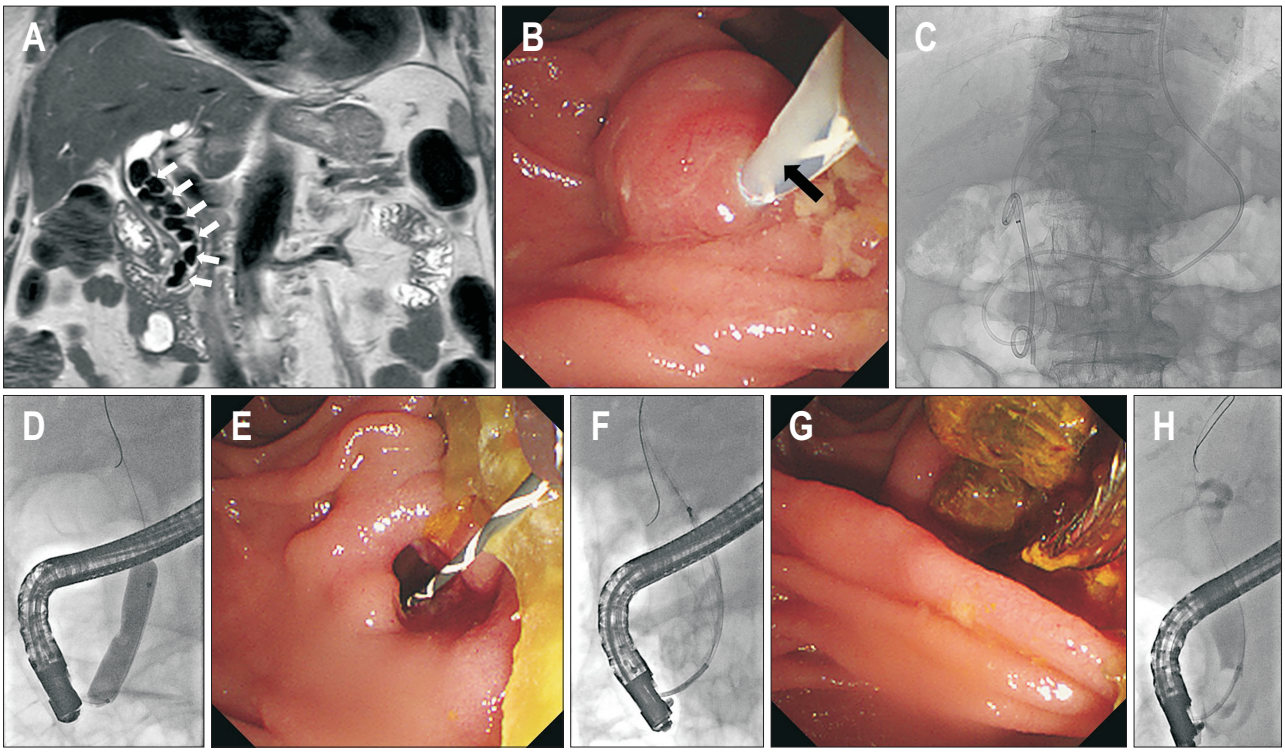


Fig. 1. Endoscopic management of a difficult-to-extract common bile duct (CBD) stone using a two-stage approach. (A) Magnetic resonance cholangiopancreatography shows multiple filling defects (white arrows) completely occupying the CBD, consistent with choledocholithiasis. (B) Pus drainage (black arrow) is observed from the bile duct during selective cannulation on endoscopic retrograde cholangiopancreatography, indicating suppurative cholangitis. (C) Endoscopic nasobiliary drainage and endoscopic retrograde biliary drainage were performed, resulting in symptomatic improvement and discharge. (D) On follow-up endoscopic retrograde cholangiopancreatography 1 month later, a 12-mm large balloon was used to dilate the ampulla of Vater. (E) Endoscopic view demonstrates a widely opened ampullary orifice. (F) CBD stones were extracted using a mechanical basket. (G) Endoscopic view reveals the passage of multiple large stones from the CBD. (H) Final balloon-occlusion cholangiogram confirms complete ductal clearance without residual filling defects. All images were provided by the authors.

derwent placement of a 7-Fr double-pigtail stent without initial stone extraction. After an average duration of 65 days, significant reductions in the stone size and number were observed. The median stone count per patient decreased from 4.0 to 2.0 ($p<0.0001$), whereas the stone index, a novel metric combining stone diameter and count, decreased from 4.6 to 2.0 ($p<0.0001$). Importantly, complete ductal clearance was achieved in 93% of the cases during the second ERCP, and no stent-related complications or 180-day mortality were reported. The authors proposed that the stent's mechanical contact with the stones, along with the maintenance of continuous bile drainage, may contribute to stone softening and disintegration.

These findings align with the meta-analysis by Nie *et al.*,[65] who compared the outcomes between single-stage and two-stage ERCP. The two-stage approach was associated with significantly lower rates of postprocedural pancreatitis and cholangitis and improved overall ductal clearance rates, despite requiring longer procedural times and delayed definitive management.

Similarly, a more recent study by Terada *et al.*[66] reported that in patients with small CBD stones (≤5 mm), spontaneous stone clearance occurred in over half of the cases following temporary plastic stent placement without any stone extraction attempts. This finding supports the hypothesis that, in selected cases, stent-induced microfragmentation and changes in biliary dynamics may be sufficient to achieve complete ductal clearance.

In a comprehensive, retrospective, multicenter cohort study, Jang *et al.*[67] analyzed 85 patients with difficult-to-extract stones who underwent initial biliary stenting using 7-Fr double-pigtail plastic stents. Multivariate analysis identified male sex, advanced age (>80 years), and initial stone size of >25 mm as negative predictors of successful clearance. Conversely, stent use resulting in >5 mm reductions in stone size significantly improved outcomes, emphasizing the therapeutic contribution of stenting beyond mere drainage.

While plastic stents are the preferred initial choice due to their cost-effectiveness and ease of placement, fully covered self-expandable metal stents may be used when prolonged drainage (>4–6 weeks) is anticipated or in anatomi-

cally challenging cases. These stents offer superior luminal patency and may promote the spontaneous passage of small residual fragments; however, their use is associated with important considerations, including the risk of migration, post-placement pancreatitis, and high cost.

6. Percutaneous transhepatic cholangioscopy

Percutaneous transhepatic cholangioscopy (PTCS) is an established therapeutic option for the management of difficult-to-extract CBD stones, particularly when conventional ERCP fails due to impacted or excessively large stones. By providing direct intraductal visualization, PTCS enables targeted interventions, such as lithotripsy, and facilitates effective stone clearance in technically challenging cases (Fig. 2).

A systematic review and meta-analysis by Papaefthymiou *et al.*[68] demonstrated a pooled stone clearance rate of 91.6% and an adverse event rate of 8.2%, supporting PTCS as an effective and relatively safe alternative when conventional endoscopic stone removal fails.

Traditional PTCS uses reusable fiberoptic cholangioscopes introduced through a percutaneously dilated tract. While offering good maneuverability and compatibility with standard lithotripsy devices, this procedure often requires stepwise tract dilation to 16–18 Fr, which necessitates multiple sessions. This results in prolonged treatment duration, increased patient discomfort, and greater procedural burden.

Recent advances have enabled the use of digital single-operator cholangioscopy (DSOC), such as the SpyGlass DS Direct Visualization System (SpyDS) (Boston Scientific, Natick, MA, USA), for percutaneous procedures with tract dilation limited to 12 Fr. Originally designed for transpapillary access, the SpyDS offers high-resolution imaging and single-operator control, enhancing both diagnostic and therapeutic capabilities. In a retrospective pilot study by Chon *et al.*,[69] SpyDS-assisted PTCS achieved 100% technical and 92.3% clinical success, with no significant complications, supporting its safety and feasibility even in anatomically complex cases.

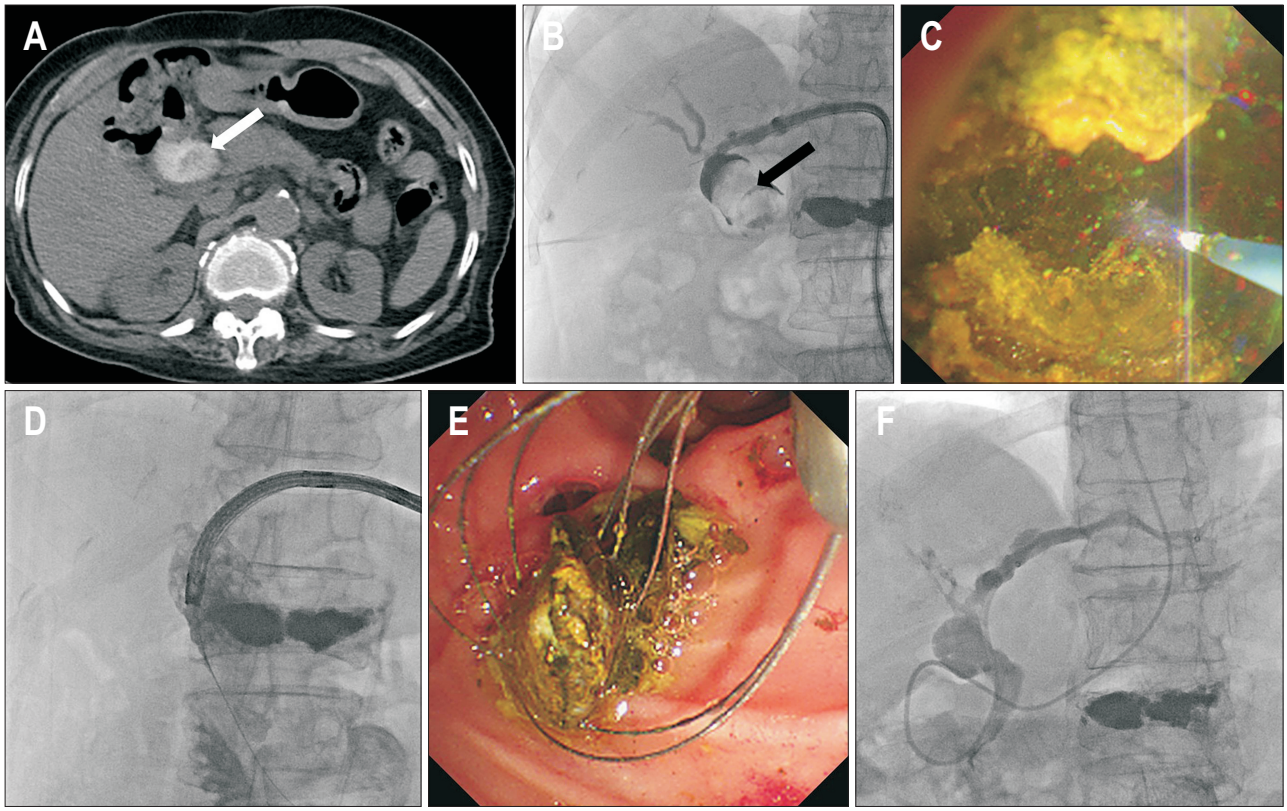


Fig. 2. Percutaneous transhepatic cholangioscopy (PTCS) for the management of a large, impacted common bile duct (CBD) stone. (A) Abdominal computed tomography reveals a large, dense stone (white arrow) impacted in the CBD, measuring approximately 4.5 cm. (B) After tract dilation via percutaneous transhepatic biliary drainage (PTBD), tube cholangiography demonstrates a large filling defect (black arrow) in the CBD. (C) PTCS-guided laser lithotripsy is performed to fragment the stone. (D) Cholangiogram during PTCS shows multiple fragmented filling defects within the CBD. (E) Endoscopic image during subsequent endoscopic retrograde cholangiopancreatography shows removal of the fragmented stones. (F) Tube cholangiogram after endoscopic nasobiliary drainage placement shows no residual filling defects after PTBD removal. All images were provided by the authors.

In a comparative meta-analysis, Mohamed *et al.*[70] reported that SpyDS-assisted PTCS achieved higher stone clearance rates and fewer complications than conventional PTCS, highlighting the clinical benefits of enhanced visualization and improved ergonomics. A recent multicenter study by Pérez-Cuadrado-Robles *et al.*[71] evaluated a novel short single-operator cholangioscope designed for percutaneous use, demonstrating high clinical success and acceptable safety, thereby supporting ongoing advances in PTCS device design. Both conventional and SpyDS-assisted PTCS are effective for managing difficult-to-extract CBD stones, with modality selection guided by institutional expertise, equipment availability, and patient-specific anatomy.

7. Peroral cholangioscopy and intraductal lithotripsy

Difficult-to-extract CBD stones characterized by large sizes, impaction, or anatomical challenges often require advanced therapeutic interventions beyond conventional endoscopic techniques. DSOC, such as the SpyDS, enables direct intraductal visualization and facilitates targeted lithotripsy using electrohydraulic lithotripsy or laser lithotripsy.

In a prospective study, Wong *et al.*[72] reported a 94% stone clearance rate with DSOC-guided laser lithotripsy, with minimal adverse events in managing complex biliary calculi. Similarly, a randomized controlled trial by Bang *et al.*[73] showed higher success with DSOC-guided lithotripsy (93.9%) compared to large balloon sphincteroplasty (72.7%) in challenging cases. Brewer Gutierrez *et al.*[74] further confirmed these findings in a multicenter study of 407 patients, achieving a 97.3% clearance rate. A systematic review and meta-analysis by Korrapati *et al.*[75] reported a pooled stone clearance rate of 88% and an adverse event rate of 7%, supporting the utility of cholangioscopy-guided lithotripsy in complex biliary stone management.

Collectively, these data highlight the efficacy and safety of DSOC-guided lithotripsy, suggesting it as a key modality in the management of difficult-to-extract CBD stones.

FUTURE DIRECTION IN CBD STONE MANAGEMENT

1. Endoscopic innovations

Endoscopic management of CBD stones has advanced significantly; however, challenges remain, particularly in complex, large, or impacted stones and patients with altered anatomy. Future developments aim to enhance visualization, improve device maneuverability, and integrate multifunctional therapeutic capabilities.

DSOC has improved intraductal visualization and enabled targeted lithotripsy using electrohydraulic lithotripsy or laser modalities, especially in cases refractory to standard techniques.[76] However, its limitations include a steep learning curve, large device diameter, limited image enhancement, and high costs.

Next-generation cholangioscopic platforms are expected to incorporate higher-resolution imaging, slimmer and more flexible designs, and artificial intelligence (AI)-assisted diagnostics for real-time stone detection and lesion characterization. The integration of steerable laser probes and optimized irrigation systems may enhance therapeutic efficacy. Advances in lithotripsy devices include the development of holmium:YAG and thulium fiber lasers, which offer improved energy efficiency and reduced collateral injury.[77] However, laser lithotripsy systems often require separate setups and costly fibers and may pose a risk of thermal injury or ductal perforation in inexperienced hands. The development of integrated laser units within compact cholangioscopic systems may streamline the procedures and reduce equipment-related delays.

Mechanical retrieval devices represent another area of innovation. Basket and balloon catheters are the standard; however, they show limited efficacy in tortuous ducts and when dealing with sludge and small fragments. Next-generation baskets with enhanced radial expansion, self-expanding meshes, or integrated suction may improve fragment retrieval and reduce procedure times. Furthermore, smart catheter systems capable of adjusting grip strength or orientation based on intraductal feedback may offer a more tailored and safer retrieval experience.

2. AI and data-driven innovation

AI has emerged as a novel adjunct for optimizing the management of CBD stones. Although still in early clinical translation, AI-based models have demonstrated promising applications in key aspects of CBD stone care, including diagnosis, intraprocedural decision support, and recurrence risk prediction.

During the diagnostic phase, deep-learning algorithms have demonstrated high accuracy in detecting CBD stones on imaging studies. Convolutional neural networks trained on magnetic resonance cholangiopancreatography have achieved expert-level performance in identifying ductal dilation and filling defects.[78] Although no pilot studies have specifically validated AI-assisted detection of CBD stones using endoscopic ultrasound, emerging research suggests its potential for future application in biliary stone evaluation. The integration of such tools into clinical workflows may assist non-specialist clinicians in early diagnosis, reduce inter-observer variability, and facilitate timely referral for endoscopic intervention.

AI has the potential to enhance procedural decision-

making during stone removal. Prototype systems have been developed to assess fluoroscopic images in real time, offer guidance on device selection (e.g., basket vs lithotripsy), predict the likelihood of stone impaction, and suggest optimal retrieval angles. Early AI models have shown feasibility in supporting ERCP procedures by localizing the ampulla and predicting cannulation difficulty, which may assist endoscopists in complex anatomical settings.[79]

Post-procedurally, CBD stone recurrence remains a significant clinical issue, particularly in patients with bile duct dilation, periampullary diverticula, or metabolic comorbidities. Machine-learning models have been trained to predict recurrence risk based on a combination of imaging features, laboratory markers, and procedural details. One such model demonstrated robust performance in stratifying recurrence probability, potentially informing individualized follow-up strategies and preventive measures.[80]

Although early results are encouraging, the implementation of AI in CBD stone management faces several challenges. These include the requirements for large annotated datasets, real-time data processing capabilities, and validation across diverse clinical environments. Moreover, integration with existing endoscopic systems and interpretability of AI outputs remain critical hurdles. Nonetheless, data-driven innovation has substantial potential to refine CBD stone removal by enhancing diagnostic accuracy, optimizing procedural choices, and guiding long-term surveillance strategies.

CONCLUSIONS

The management of CBD stones has evolved substantially with advancements in endoscopic techniques and accessory devices. Although ERCP remains the primary treatment modality, strategies such as EPLBD, two-stage ERCP with temporary stenting, and DSOC-guided lithotripsy have significantly improved the success rate of ductal clearance, particularly in difficult cases. PTCS offers a valuable alternative when endoscopic access is limited, and newer digital platforms have further enhanced their safety and efficiency. We propose a structured treatment algorithm for the management of CBD stones by integrating

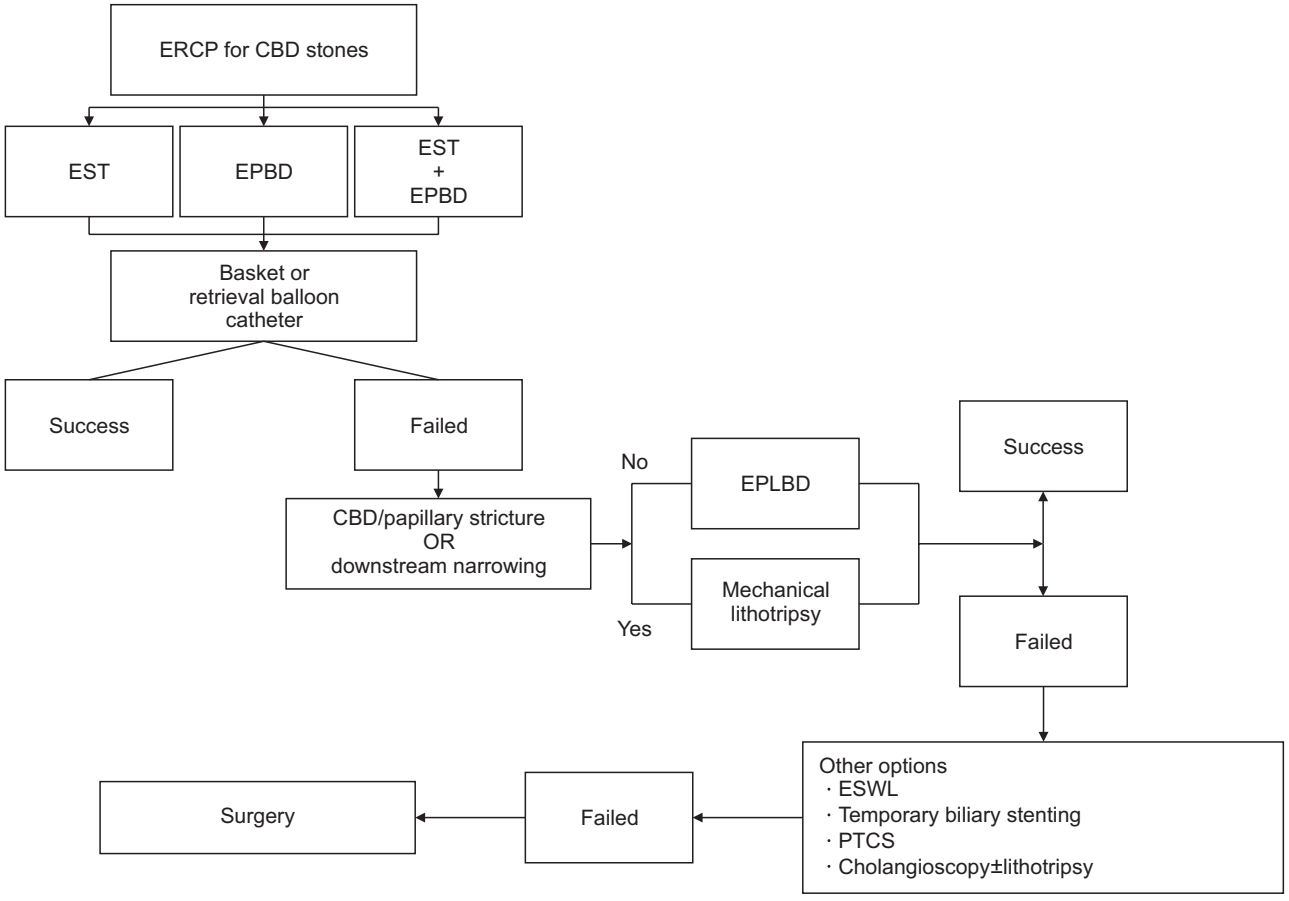


Fig. 3. Proposed endoscopic treatment algorithm for CBD stones. ERCP, endoscopic retrograde cholangiopancreatography; CBD, common bile duct; EST, endoscopic sphincterotomy; EPBD, endoscopic papillary balloon dilation; EPLBD, endoscopic papillary large balloon dilation; ESWL, extracorporeal shock wave lithotripsy; PTCS, percutaneous transhepatic cholangioscopy.

recent techniques and strategies into a practical framework, as outlined in Fig. 3. Innovations in device technology, including integrated laser systems and advanced retrieval tools, along with the application of AI in diagnostic support and procedural planning, are poised to further refine and personalize CBD stone management.

In conclusion, selecting the optimal approach requires consideration of the stone characteristics, anatomical complexity, patient comorbidities, and available expertise. Continued clinical research and technological innovations will play a pivotal role in enhancing procedural outcomes and shaping the future of biliary stone therapy.

CONFLINTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

AUTHOR CONTRIBUTIONS

Study concept and design: H.K.C., I.H.J. Data acquisition: H.K.C., I.H.J. Data analysis and interpretation: H.K.C., I.H.J. Drafting of the manuscript: H.K.C., I.H.J. Critical revision of the manuscript for important intellectual content: all authors. Statistical analysis: H.K.C., I.H.J. Obtained funding: C.H.P. Administrative, technical, or material support; study supervision: H.K.C., I.H.J., C.H.P. Approval of final manuscript: all authors.

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