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A comparative study between single-operator pancreatoscopy with intraductal lithotripsy and extracorporeal shock wave lithotripsy for the management of large main pancreatic duct stones

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Abstract

Background and aims—Endoscopic management of large main pancreatic ductal (MPD) stones often require treatment with lithotripsy. Extracorporeal shock wave lithotripsy (ESWL) has been the mainstay therapy, and single-operator pancreatoscopy with intraductal (intracorporeal) lithotripsy (SOPIL) is an emerging technique. However, no comparative studies between these techniques exist. We therefore aimed to compare ESWL to SOPIL for the treatment of large MPD stones.

Methods—This is a retrospective cohort study comparing patients who were treated with ESWL or SOPIL from September 2013 to September 2019 at a single tertiary center. Logistic regression was performed to identify factors associated with technical success and efficient stone clearance (≤ 2 procedures to clear stones).

Results—There were 240 patients who were treated with ESWL and 18 treated with SOPIL. The overall technical success rate of stone clearance was 224/258 (86.8%), which was similar between the ESWL and SOPIL groups (86.7% vs 88.9%, $p = 1.000$). A SOPIL approach required fewer total procedures (1.6 ± 0.6 vs 3.1 ± 1.5, $p < 0.001$) and less aggregate procedure time (101.6

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Disclosures Dr. Jeffrey J. Easier reports that he is a consultant for Boston Scientific (Marlborough, MA). Dr. Glen Lehman reports that he is a consultant for Cook Medical (Bloomington, IN). Dr. Stuart Sherman reports that he is a consultant for Cook Medical (Bloomington, IN), Olympus America (Center Valley, PA), and Boston Scientific (Marlborough, MA). Drs. Benjamin L. Bick, Feenalie Patel, Yan Tong, James L. Watkins, Lee McHenry, Evan L. Fogel, and Mark A. Gromski have no conflicts of interest or financial ties to disclose.

± 68.2 vs 191.8 ± 111.6 min, $p = 0.001$). Adverse event rates were similar between the groups (6.3% vs 5.6%, $p = 1.000$). The use of SOPIL was independently associated with greater efficiency compared to ESWL (OR 5.241 [1.348–20.369], $p = 0.017$). Stone size > 10 mm was associated with less efficient stone clearance (OR 0.484 [0.256–0.912], $p = 0.025$).

Conclusion—Both ESWL and SOPIL are safe and effective endoscopic adjunct modalities for treating large pancreatic duct stones. SOPIL is an emerging alternative to ESWL that is potentially more efficient for lithotripsy and MPD stone clearance.

Keywords

Endoscopic retrograde cholangiopancreatography; Extracorporeal shock wave lithotripsy; Electrohydraulic shock wave lithotripsy; Chronic pancreatitis; Pancreatic duct stones

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Chronic pancreatitis (CP) is a progressive fibroinflammatory disease of the pancreas that can lead to pain, exocrine pancreatic insufficiency, and endocrine pancreatic dysfunction [1]. Pancreatic duct obstruction is a complication of CP and can be caused by main pancreatic duct (MPD) strictures or stones. Obstructing MPD stones can often lead to severe abdominal pain due to increased intraductal pressure, parenchymal tissue pressure, and ischemia [2, 3]. Endoscopic removal of MPD stones has been shown to improve MPD drainage and relieve pain attributable to pancreatic duct obstruction [4–6].

Current endoscopic options for treatment of MPD stones include lithotripsy techniques applied in conjunction with endoscopic retrograde cholangiopancreatography (ERCP) [7–9]. Smaller MPD stones (< 5 mm) can often be removed by ERCP techniques alone following pancreatic sphincterotomy. Large MPD stones may be more difficult to extract and require fragmentation utilizing lithotripsy [10–12]. Options for lithotripsy include extracorporeal shock wave lithotripsy (ESWL) and single-operator pancreatoscopy with intraductal (intracorporeal) lithotripsy (SOPIL). The principle of ESWL is based on focusing shock wave energy to MPD stones either through electromagnetic or piezoelectric forces [9]. A recent systematic review and meta-analysis of the use of ESWL for symptomatic pancreatic duct stones demonstrated a high rate of stone fragmentation/clearance and relief from symptoms [13]. SOPIL is a novel technique that relies on direct visualization of MPD stones utilizing pancreatoscopy. Lithotripsy is performed within the pancreatic duct using either electrohydraulic shocks or a laser. The feasibility of SOPIL has been enhanced by recent improvements in pancreatoscopy technologies such as single-operator cholangiopancreatoscopy platforms that utilize digital imaging technologies. A multicenter retrospective analysis of SOPIL has demonstrated high efficacy and safety [14]

Current guidelines that address lithotripsy for chronic pancreatitis recommend using ESWL as first-line therapy for MPD stones larger than 5 mm and reserving SOPIL only when ESWL is not available or ineffective for stone clearance [10]. However, this is based on little to no comparative data. Importantly, there are several theoretical advantages of SOPIL over ESWL including more accurate targeting of MPD stones through direct visualization, visualization of non-calcified or minimally calcified stones that cannot be targeted with ESWL, and decreased collateral injury to surrounding tissue. Additionally, lithotripsy can be combined with ERCP for same session fragmentation and extraction of pancreatic duct stone fragments with successful clearance of stones as a single procedure. ESWL requires a separate, subsequent ERCP procedure to clear fragments from the main pancreatic duct. To date, there are no studies that directly compare ESWL to SOPIL for the management of obstructing symptomatic MPD stones. The aim of this study is to compare ESWL and SOPIL for the treatment of large MPD stones.

Materials and methods

Study design and patient selection

This is a retrospective study of consecutive patients with symptomatic MPD stones who received either SOPIL or ESWL. This study was approved by the Institutional Review Board at the Indiana University School of Medicine. Patients were identified from a prospectively maintained database of all patients undergoing ESWL and ERCP from September 2013 to September 2019. Patient-related data and outcomes were collected from the electronic medical record. Inclusion criteria included all adult patients > 18 years old, who had symptomatic large MPD stones (≥ 5 mm in greatest dimension). Definite indications for treatment included the presence of abdominal pain, and relative indications included symptomatic exocrine pancreatic insufficiency. Excluded patients included those without clear symptomatic indications for treatment.

The number and diameter of pancreatic duct stones and size of pancreas ducts were assessed by pre-treatment computed tomography (CT) scan or intraprocedural ERCP prior to lithotripsy. The baseline stone count included all large MPD stones that were targeted for lithotripsy and stone clearance. In patients with multi-focal stones, the downstream stones (head of pancreas) were typically treated first to assess for clinical response. In some cases, additional upstream stones (tail of pancreas) were treated if symptoms persisted. In other cases, stones in the pancreatic tail did not require treatment if symptoms resolved. Treating physicians determined which stones required lithotripsy and which technology to use (ESWL vs SOPIL).

Lithotripsy methods

ESWL (Fig. 1) was performed using an electrohydrau-lic spark gap lithotripter (HealthTronics, Austin, TX) by gastroenterologists who had dedicated training for ESWL (L.M. and J.W.) in conjunction with a dedicated radiology technician (S.H.). Most patients underwent an abdominal X-ray (Kidney–ureter–bladder with oblique series) prior to ESWL to ensure whether the stone was localizable on fluoroscopy. Patients were treated under general anesthesia with continuous monitoring. MPD stone(s) were localized under fluoroscopic guidance. Intravenous secretin (ChiRhoStim™, Bell-More Labs, Inc., Hampstead, MD) was administered 5–10 min after the initial shock wave and given via slow injection over 1 min[15]. Shock waves were then continued until the stone was adequately fragmented per physician discretion based on serial fluoroscopic images or until a maximum of 11,000 shock waves were achieved. Patients typically underwent ERCP either on the same day of ESWL after adequate stone fragmentation was achieved or within 14 days of ESWL. Pancreatic sphincterotomy was performed at the time of post-ESWL ERCP if not already present, and standard balloons or baskets were used to extract stone fragments.

If satisfactory stone fragmentation was not achieved at index ESWL, patients returned for additional ESWL sessions prior to ERCP. While ESWL alone without ERCP has been demonstrated to successfully treat large MPD stones [16, 17], we along with most centers perform both to ensure complete stone clearance and to minimize the number of ESWL sessions required to completely fragment stones.

SOPIL (Fig. 2) was performed using the SpyGlass™ Direct Visualization System (Boston Scientific, Natick, MA) before 2015 and the SpyGlass™ DS Direct Visualization System (Boston Scientific) after 2015. Lithotripsy was performed with electrohydraulic lithotripsy using the AUTOLITH® Generator (Northgate Technologies Inc., Elgin, IL) and AUTOLITH® Touch Electrohydraulic Lithotripter Probe (Northgate Technologies Inc.). Pancreatic sphincterotomy was performed (if not already present) at ERCP prior to advancement of the pancreatoscope catheter. Intraductal lithotripsy was then performed in an aqueous environment until the stone was adequately fragmented based on direct visualization. If partial but incomplete stone fragmentation was achieved, a pancreatic stent was placed and patients returned for additional treatment sessions.

Study outcomes and adverse events

Technical success was defined as complete or near-complete (> 90%) stone fragmentation and clearance based on procedure reports and subsequently measured on the final pancreatogram at the time of ERCP or on subsequent CT scans if available. Patients who had to cross over to the other lithotripsy modality were considered technical failures. The total procedures required to clear stones included any discrete lithotripsy sessions and subsequent ERCP procedures performed to clear MPD stones. Each ESWL and ERCP were considered discrete procedures. Same session SOPIL and ERCP were considered one procedure. Efficient MPD stone clearance was defined as the use of 2 or fewer procedures to clear the MPD stones. Pain improvement was defined as any patient reported improvement in pain at follow-up clinic visits, phone calls, or procedures. Adverse events were assessed by their frequency and severity graded per ASGE criteria (mild, moderate, severe, or fatal) [18].

Statistical procedures

Patient demographics, baseline history, stone characteristics, outcomes, and adverse events were compared between patients who underwent ESWL and SOPIL. Continuous variables were described by means and standard deviations and were compared between groups using Student's *t* tests or Wilcoxon rank-sum tests. Categorical variables were described as frequencies and percentages and were compared between groups using Chi-square tests or Fischer exact tests. Univariate and multivariable logistic regression models were fit to assess factors associated with technical success and efficient stone clearance. All categorical variables were included and clinically relevant continuous variables were dichotomized to include in the logistic regression. In the logistic regression analyses, risk factors with a p value < 0.25 obtained from the univariate logistic regression models were included in a subsequent multivariable logistic regression model. A p value < 0.05 was considered statistically significant. Data analysis was performed using SAS 9.4 (SAS Inc., Cary, NC, USA).

Results

There were 258 patients who underwent lithotripsy for management of large MPD stones (ESWL = 240 and SOPIL = 18, Table 1). Patient demographics, baseline symptoms, and etiology of chronic pancreatitis were similar between groups. Chronic symptoms associated with ductal obstruction included abdominal pain in 91.5% and exocrine pancreatic insufficiency in 50.4% of patients treated. Patients in the SOPIL group had a higher stone burden at baseline including more large MPD stones (1.7 ± 1.0 vs 1.3 ± 0.7, $p = 0.036$) and more often had 3 or more large MPD stones present (22.2% vs 4.6%, $p = 0.014$). Additionally, patients in the SOPIL group more often had a prior unsuccessful attempt at stone extraction with basic ERCP techniques (38.9% vs 7.5%, $p \leq 0.0001$) and more often had prior failed lithotripsy attempts (38.9% vs 2.9%, $p \leq 0.0001$).

Outcomes and adverse events are summarized in Table 2. The overall technical success rate of stone clearance was 224/258 (86.8%), which was similar between the ESWL and SOPIL groups (86.7% vs 88.9%, $p = 1.000$). The reason for failure in the 2 SOPIL patients was partial but incomplete stone fragmentation. These 2 SOPIL failures were then treated successfully with ESWL. Of the 32 ESWL failures, 2 were successfully treated with SOPIL, 13 received surgical drainage, 2 had symptom improvement without stone removal, and 15 were lost to follow-up.

Overall, 83.5% of patients experienced improvement in pain after treatment, which was similar between patients who received ESWL and SOPIL (82.7% vs 93.8%, $p = 0.483$). SOPIL achieved successful clearance of MPD stones with fewer total procedures (1.6 ± 0.6 vs 3.1 ± 1.5, $p < 0.001$) and a shorter aggregate procedure time (101.6 ± 68.2 vs 191.8 ± 111.6 min, $p = 0.001$). Adverse events, including those at the time of lithotripsy and subsequent related ERCPs, occurred in 6.2% of patients, and rates were similar between the groups (6.3% vs 5.6%, $p = 1.000$). All adverse events were mild ($n = 15$) or moderate ($n = 1$).

A univariate and multivariable logistic regression model was created looking for predictors of technical success (Table 3). On univariate analysis, a prior pancreatic sphincterotomy (OR 2.402 [1.060–5.443], $p = 0.036$) and presence of a pancreatic duct stricture (OR 2.418 [1.107–5.282], $p = 0.027$) were significant. However, no factors were found to be significant on multivariable analysis. Of those with successful stone clearance, efficient (2 or fewer procedures) MPD stone clearance was achieved in 114/224 (50.9%). A univariate and multivariable logistic regression analysis was performed to identify predictors for efficient stone clearance (Table 4). The use of SOPIL rather than ESWL was associated with greater efficiency compared to ESWL on both univariate and multivariable (OR 5.241 [1.348–20.369], $p = 0.017$) analysis. A large stone was associated with lesser efficiency (or a greater procedure burden) on both univariate and multivariable (OR 0.484 [0.256–0.912], $p = 0.025$) analysis.

Discussion

Endoscopic management of large MPD stones is challenging. While smaller stones (<5 mm) are reliably removed with standard ERCP techniques alone, large stones require adjunct interventions for endoscopic management or surgery. Lithotripsy is often deployed for the fragmentation of large MPD stones prior to extraction. Options for lithotripsy include mechanical lithotripsy, extracorporeal lithotripsy, and intraductal direct lithotripsy. The most common adverse event of mechanical lithotripsy for MPD stones is a trapped or broken basket [19]. Considered an emergent severe endoscopic complication, this event often results in the need for surgical resection and consequently this technique is not favored by the majority of experts. While ESWL is a well-studied and established therapy for lithotripsy of MPD stones, novel advances in cholangiopancreatoscopy have greatly enhanced the capabilities of intraductal lithotripsy. The advent and refinement of single-operator ductoscopy platforms include slim, agile catheters with digital imaging and therapeutic applications [20]. SOPIL is now much more feasible for MPD stone therapy. It is in the absence of large cases series and comparative data on the efficacy and safety of SOPIL that current guidelines do not emphasize SOPIL as a preferred therapy for management of symptomatic MPD stones clearance. While ESWL is the recommended first-line therapy for MPD stones greater than 5 mm in size by many societies, access to ESWL equipment, experienced operators, and the number of programs with experience are severely limited [10, 21]. To better define the role of ESWL and SOPIL for lithotripsy of MPD stones, studies that explore the comparative efficacy between the two techniques are needed.

There is currently a large body of evidence supporting the efficacy of ESWL for large MPD stones. An updated metaanalysis recently published included 22 studies and 3868 patients with symptomatic calcific chronic pancreatitis that underwent ESWL [13]. Complete stone fragmentation was achieved in 86.3% (95% CI 76.0–94.0) and complete ductal clearance was achieved in 69.8% (95% CI 63.8–75.5). Complete pain relief was achieved in 64.8% (95% CI 57.5–70.6), while partial pain relief was not assessed due to heterogeneity. The rate of technical success (86.7%) and relief of pain (82.7%) in our study is comparable with this meta-analysis. However, the literature supporting SOPIL is based on small, non-comparative case series. A systematic review of 10 studies with 87 patients assessing the efficacy and safety of SOPIL demonstrated a ductal clearance rate of 43–100% and an adverse event rate of 0–13.5% [7]. This wide range of success rate is likely due to an early learning curve with SOPIL and the gradual advances in cholangiopancreatos-copy platforms over time. Since then, a multicenter study including 109 patients with calcific pancreatitis treated with the current state of the art digital single-operator pancreatoscopy platform demonstrated a complete ductal clearance rate of 89.9%, an adverse event rate of 10.1%, and symptom improvement in 88.4% [14]. The findings of our study are comparable to the findings of this large, multicenter case series (88.9% rate of stone clearance; 93.8% rate of pain improvement).

Our findings demonstrated that SOPIL and ESWL were similar in terms of both technical success ($p = 1.000$) and symptomatic improvement ($p = 0.483$). Despite similar rates of technical and clinical success with ESWL and SOPIL, there may be several potential advantages of SOPIL in appropriately selected patients. Pancreatoscopy allows for direct visualization of stones, which therefore results in accurate targeting for fragmentation. Accurate targeting of stones is a significant challenge during ESWL as stones may move in and out of held during the respiratory cycle resulting in shocks delivered away from the stone to the pancreatic parenchyma. Furthermore, non-calcihed radiolucent stones cannot be seen with huoroscopically-guided ESWL, yet are evident with direct visualization at SOPIL. ESWL has the added disadvantage of rare adverse events unique to the ESWL maneuvers including injury to surrounding organs (including renal injury, splenic rupture, liver injury, and bowel perforation) and cardiac arrhythmias [7, 22]. There have been no reports of these adverse events with SOPIL.

Moreover, we found that SOPIL has the technical advantage of fewer procedures required to clear stones and a lower procedure duration compared to ESWL. This is because SOPIL is incorporated into ERCP, while ESWL requires subsequent ERCP procedures to clear stones. While the European Society of Gastrointestinal Endoscopy suggests restricting the use of ERCP after ESWL only in patients where spontaneous clearance of MPD stones does not occur, we routinely perform ERCP after ESWL to decrease the risk of steinstrasse (acute stone fragment impaction at the papilla) which occurs up to 6% of the time in some series but did not occur at all in this study [10, 22]. Additional ERCPs performed after ESWL incur additional costs and extra anesthesia time for patients. On the other hand, the use of SOPIL during ERCP allows for stone clearance at the same session.

The main limitation of SOPIL is that the 10 Fr delivery catheter of the pancreatoscopy platform needs to be advanced to the level of the stone in the pancreatic duct for lithotripsy, while ESWL can target stones throughout the pancreas. Specifically, the pancreatoscope can be difficult to advance across downstream MPD strictures (or small diameter pancreatic ducts) or around other anatomical issues (e.g., ansa loop, surgically altered anatomy). Furthermore, stones that are located upstream (i.e., toward the body/tail) may be difficult to treat since the pancreatoscope may be difficult to navigate around the genu in some patients. This is reflected in Brewer-Gutierrez's study demonstrating that the most commonly cited reasons for failure included an inability to advance the lithotripsy probe or the pancreatoscope to the stone (6/11, 54.5%) [14]. Nevertheless, the population treated with SOPIL in the current study had downstream MPD strictures present in 38.9% of patients and MPD stones in the body/tail 38.9% of the time, demonstrating that SOPIL is still a feasible technique to consider in these situations. Another limitation of SOPIL is that it cannot target stones that are impacted at the ampulla, since direct visualization of the stone is not feasible in this setting and the pancreatoscope typically requires a short segment (up to 1 cm) of pancreatic duct to rest on while performing lithotripsy. Patients meeting any of these criteria may benefit from attempting ESWL first.

The main limitations of this study pertain to its retrospective design. First, there is significant potential for selection bias between ESWL and SOPIL in this population. Patients treated with SOPIL were chosen at the discretion and expertise of the physicians caring for the patient. Therefore, selection bias was introduced and baseline characteristics differed between the groups. Patients treated with SOPIL had more MPD stones at baseline. SOPIL also appeared to be utilized more often as a rescue therapy following failed ESWL.

These baseline differences suggest that the patients treated with SOPIL may have had more difficult stones to treat, but this did not negatively impact the efficacy of SOPIL. In fact, despite a seemingly more difficult baseline stone burden in the SOPIL group (including larger stone size, greater number of stones, and more frequent prior treatment failures), patients treated in this group were still successfully treated at a high rate. This suggests that SOPIL may be used earlier in the treatment algorithm of large MPD stones that are accessible by pancreatoscopy. Secondly, the technique and technology of SOPIL improved during the course of this study period. With more experience and improved imaging, SOPIL evolved into an alternative first-line choice for lithotripsy of large MPDs. Including the early experience of SOPIL in the study did not seem to negatively affect the results. Thirdly, definitions of technical success were based on procedures' reports and review of subsequent imaging, but the degree of clearance may not be accurate when imaging was unavailable. Finally, as with many institutions, our experience with SOPIL is continuing to grow. We report significantly fewer patients managed with SOPIL than those treated with ESWL. It is possible that our study is underpowered to detect differences in relatively infrequent events (e.g., post-ERCP pancreatitis) and rates of success may vary with more SOPIL patients. However, our Endings are on par with larger, multicenter case series. Furthermore, we offer one of the largest single center series in the USA for lithotripsy of large MPD stones and the only study directly comparing both. Given the potential heterogeneity in factors that impact decision-making across centers (e.g., patient selection, follow-up, assessment of outcomes) for lithotripsy and MPD stone clearance in the setting of CP, it is important that a comparative retrospective study should be performed at centers that perform both lithotripsy techniques. A randomized controlled trial directly comparing ESWL and SOPIL techniques is the next step to identify the optimal approach for patients.

In conclusion, both ESWL and SOPIL are safe and effective modalities for lithotripsy of large pancreatic duct stones. SOPIL is a promising alternative to ESWL that may achieve similar rates of success with a lower procedure burden in carefully selected patients. A randomized controlled trial directly comparing ESWL and SOPIL would offer significant insights into the optimal management strategy for patients with symptomatic large MPD stones.

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References

1. Steer ML, Waxman I, Freedman S (1995) Chronic pancreatitis. N Engl J Med 332:1482–1490 [PubMed: 7739686]
2. Bradley EL 3rd (1982) Pancreatic duct pressure in chronic pancreatitis. Am J Surg 144:313–316 [PubMed: 7114368]
3. Karanjia ND, Widdison AL, Reber HA (1992) Pancreatic tissue and ductal pressures in chronic pancreatitis. Br J Surg 79:469
4. Gabbrielli A, Pandolfi M, Mutignani M, Spada C, Perri V, Petruzziello L, Costamagna G (2005) Efficacy of main pancreatic-duct endoscopic drainage in patients with chronic pancreatitis, continuous pain, and dilated duct. Gastrointest Endosc 61:576–581 [PubMed: 15812411]

5. Rosch T, Daniel S, Scholz M, Huibregtse K, Smits M, Schneider T, Ell C, Haber G, Riemann JF, Jakobs R, Hintze R, Adler A, Neuhaus H, Zavoral M, Zavada F, Schusdziarra V, Soehendra N, European Society of Gastrointestinal Endoscopy Research G (2002) Endoscopic treatment of chronic pancreatitis: a multicenter study of 1000 patients with long-term follow-up. Endoscopy 34:765–771 [PubMed: 12244496]
6. Sherman S, Lehman GA, Hawes RH, Ponich T, Miller LS, Cohen LB, Kortan P, Haber GB (1991) Pancreatic ductal stones: frequency of successful endoscopic removal and improvement in symptoms. Gastrointest Endosc 37:511–517 [PubMed: 1936826]
7. Beyna T, Neuhaus H, Gerges C (2018) Endoscopic treatment of pancreatic duct stones under direct vision: revolution or resignation? Systematic review. Dig Endosc 30:29–37 [PubMed: 28656688]
8. Rios GA, Adams DB (2001) Does intraoperative electrohydrau-lic lithotripsy improve outcome in the surgical management of chronic pancreatitis? Am Surg 67:533–537 (discussion 537–538) [PubMed: 11409800]
9. Tandan M, Talukdar R, Reddy DN (2016) Management of pancreatic calculi: an update. Gut Liver 10:873–880 [PubMed: 27784844]
10. Dumonceau JM, Delhaye M, Tringali A, Arvanitakis M, Sanchez-Yague A, Vaysse T, Aithal GP, Anderloni A, Bruno M, Cantu P, Deviere J, Dominguez-Munoz JE, Lekkerkerker S, Poley JW, Ramchandani M, Reddy N, van Hooft JE (2019) Endoscopic treatment of chronic pancreatitis: European society of gastrointestinal endoscopy (ESGE) guideline—updated august 2018. Endoscopy 51:179–193 [PubMed: 30654394]
11. Lehman GA (2002) Role of ERCP and other endoscopic modalities in chronic pancreatitis. Gastrointest Endosc 56:S237–S240 [PubMed: 12447274]
12. Tandan M, Reddy DN, Santosh D, Vinod K, Ramchandani M, Rajesh G, Rama K, Lakhtakia S, Banerjee R, Pratap N, Venkat Rao G (2010) Extracorporeal shock wave lithotripsy and endotherapy for pancreatic calculi-a large single center experience. Indian J Gastroenterol 29:143–148 [PubMed: 20717860]
13. van Huijgevoort NCM, Veld JV, Fockens P, Besselink MG, Boer-meester MA, Arvanitakis M, van Hooft JE (2020) Success of extracorporeal shock wave lithotripsy and ERCP in symptomatic pancreatic duct stones: a systematic review and meta-analysis. Endosc Int Open 8:E1070–E1085 [PubMed: 32743061]
14. Brewer Gutierrez OI, Raijman I, Shah RJ, Elmunzer BJ, Webster GJM, Pleskow D, Sherman S, Sturgess RP, Sejpal DV, Ko C, Maurano A, Adler DG, Mullady DK, Strand DS, DiMaio CJ, Piraka C, Sharahia R, Dbouk MH, Han S, Spiceland CM, Bekkali NLH, Gabr M, Bick B, Dwyer LK, Han D, Buxbaum J, Zulli C, Cosgrove N, Wang AY, Carr-Locke D, Kerdsirichairat T, Aridi HD, Moran R, Shah S, Yang J, Sanaei O, Parsa N, Kumbhari V, Singh VK, Khashab MA (2019) Safety and efficacy of digital single-operator pancreatoscopy for obstructing pancreatic ductal stones. Endosc Int Open 7:E896–E903 [PubMed: 31281875]
15. Choi EK, McHenry L, Watkins JL, Sherman S, Fogel EL, Cote GA, Lehman GA (2012) Use of intravenous secretin during extracorporeal shock wave lithotripsy to facilitate endoscopic clearance of pancreatic duct stones. Pancreatology 12:272–275 [PubMed: 22687384]
16. Dumonceau JM, Costamagna G, Tringali A, Vahedi K, Delhaye M, Hittelet A, Spera G, Giostra E, Mutignani M, De Maertelaer V, Deviere J (2007) Treatment for painful calcified chronic pancreatitis: extracorporeal shock wave lithotripsy versus endoscopic treatment: a randomised controlled trial. Gut 56:545–552 [PubMed: 17047101]
17. Vaysse T, Boytchev I, Antoni G, Croix DS, Choury AD, Laurent V, Pelletier G, Buffet C, Bou-Farah R, Carbonnel F (2016) Efficacy and safety of extracorporeal shock wave lithotripsy for chronic pancreatitis. Scand J Gastroenterol 51:1380–1385 [PubMed: 27595309]
18. Cotton PB, Eisen GM, Aabakken L, Baron TH, Hutter MM, Jacobson BC, Mergener K, Nemcek A Jr, Petersen BT, Petrini JL, Pike IM, Rabeneck L, Romagnuolo J, Vargo JJ (2010) A lexicon for endoscopic adverse events: report of an ASGE workshop. Gastrointest Endosc 71:446–454 [PubMed: 20189503]
19. Thomas M, Howell DA, Carr-Locke D, Mel Wilcox C, Chak A, Raijman I, Watkins JL, Schmalz MJ, Geenen JE, Catalano MF (2007) Mechanical lithotripsy of pancreatic and biliary stones: complications and available treatment options collected from expert centers. Am J Gastroenterol 102:1896–1902 [PubMed: 17573790]

20. Committee AT, Komanduri S, Thosani N, Abu Dayyeh BK, Aslanian HR, Enestvedt BK, Manfredi M, Maple JT, Navaneethan U, Pannala R, Parsi MA, Smith ZL, Sullivan SA, Banerjee S (2016) Cholangiopancreatoscopy. Gastrointest Endosc 84:209–221 [PubMed: 27236413]

21. Gardner TB, Adler DG, Forsmark CE, Sauer BG, Taylor JR, Whitcomb DC (2020) ACG clinical guideline: chronic pancreatitis. Am J Gastroenterol 115:322–339 [PubMed: 32022720]

22. Li BR, Liao Z, Du TT, Ye B, Zou WB, Chen H, Ji JT, Zheng ZH, Hao JF, Jiang YY, Hu LH, Li ZS (2014) Risk factors for complications of pancreatic extracorporeal shock wave lithotripsy. Endoscopy 46:1092–1100 [PubMed: 25251205]

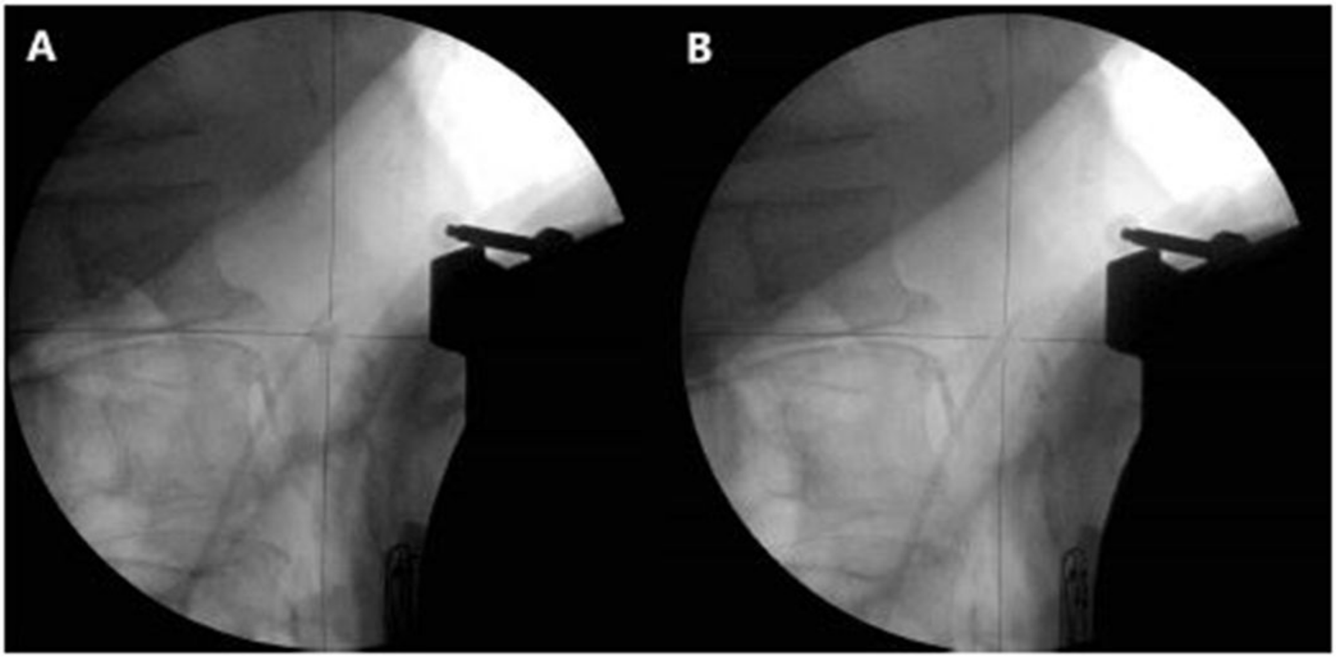

Fig. 1.
Fluoroscopic images of a patient with a pancreatic stent adjacent to a main pancreatic duct stone, with targeting of the stone during extracorporeal shock wave lithotripsy (**A**) followed by complete fragmentation of the stone (**B**)

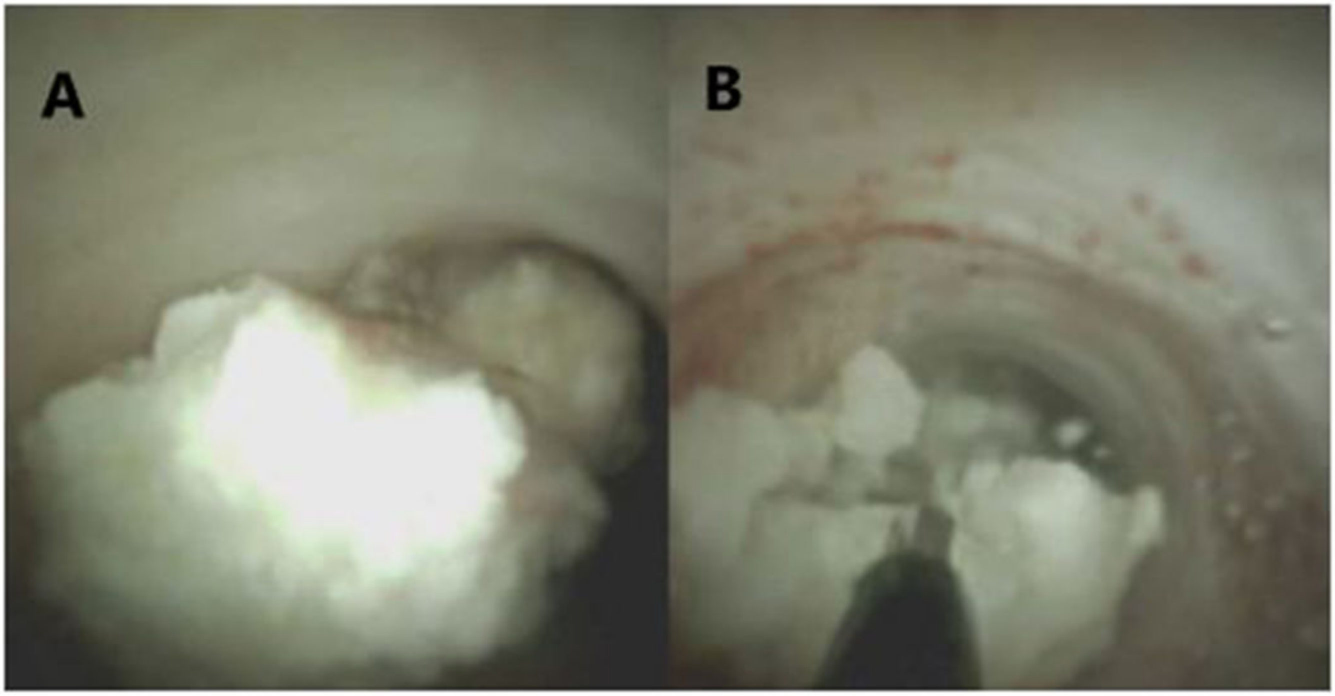

Fig. 2.

Pancreatoscopic images of a patient with a large main pancreatic duct stone before treatment (**A**) and fragmented stone debris following electrohydraulic lithotripsy (**B**)

Table 1

Baseline characteristics of patients with large main pancreatic duct stones who underwent extracorporeal shock wave lithotripsy (ESWL) or single-operator pancreatoscopy with intraductal lithotripsy (SOPIL) for treatment

	All patients (n = 258)	ESWL (n = 240)	SOPIL (n = 18)	p value
Demographics and baseline history				
Age, mean (SD)	58.0 (12.6)	57.8 (12.7)	61.3 (11.7)	0.255
Sex, F (%)	88 (34.1%)	79 (32.9%)	9 (50%)	0.196
Race, Caucasian (%)	227 (89.0%)	212 (88.3%)	17 (94.4%)	0.703
BMI, mean (SD)	25.1 (6.1)	25.1 (6.1)	24.9 (6.2)	0.891
Charlson comorbidity index, mean (SD)	2.7 (2.1)	2.7 (2.1)	2.9 (1.5)	0.646
Abdominal pain at baseline (%)	236 (91.5%)	220 (91.7%)	16 (88.9%)	0.657
Opioid medication usage at baseline (%)	142 (55.0%)	133 (55.4%)	9 (50%)	0.656
Exocrine insufficiency at baseline[a] (%)	130 (50.4%)	117 (48.8%)	13 (72.2%)	0.055
Endocrine insufficiency requiring insulin (%)	71 (27.5%)	67 (27.9%)	4 (22.2%)	0.602
Weight loss (%)	109 (42.4%)	101 (42.3%)	8 (44.4%)	0.856
Etiology[b]				
Alcohol (%)	137 (53.1%)	127 (52.9%)	10 (55.6%)	0.829
Tobacco (%)	181 (70.2%)	168 (70.0%)	13 (72.2%)	0.842
Hereditary (%)	9 (3.5%)	7 (2.9%)	2 (11.1%)	0.124
Hypertriglyceridemia (%)	13 (5.0%)	13 (5.4%)	0	0.608
Autoimmune (%)	1 (0.4%)	1 (0.4%)	0	1.000
Obstructive (%)	33 (12.8%)	32 (13.4%)	1 (5.6%)	0.484
Idiopathic (%)	40 (15.5%)	36 (15.0%)	4 (22.2%)	0.495
Stone and pancreas anatomy				
Stone location (%)[c]				
Head	213 (82.6%)	196 (81.7%)	17 (94.4%)	0.329
Neck	30 (11.6%)	28 (11.7%)	2 (11.1%)	1.000
Body	38 (14.7%)	32 (13.3%)	6 (33.3%)	***0.033***
Tail	9 (3.5%)	8 (3.3%)	1 (5.6%)	0.484
Number of large main duct stones treated, mean (SD)	1.3 (0.7)	1.3 (0.7)	1.7 (1.0)	***0.036***
Single stone (%)	198 (76.7%)	185 (77.7%)	11 (61.1%)	0.267
3 or more stones present (%)	15 (5.8%)	11 (4.6%)	4 (22.2%)	***0.014***
Largest stone size (mm), mean (SD)	10.0 (4.5)	10.0 (4.2)	10.3 (7.4)	0.770
Presence of parenchymal stones (%)	166 (64.3%)	152 (63.3%)	14 (77.8%)	0.217
Downstream pancreatic duct stricture (%)	140 (54.3%)	133 (55.4%)	7 (38.9%)	0.174
Largest pancreatic duct diameter (mm), mean (SD)	7.3 (2.8)	7.2 (2.8)	8.2 (2.6)	0.152
Procedure history				
Prior ERCP (%)	165 (64.0%)	151 (62.9%)	14 (77.8%)	0.120
Prior pancreatic sphincterotomy (%)	121 (46.9%)	107 (44.6%)	14 (77.8%)	***0.006***
Prior failed attempt at stone extraction (%)	25 (9.7%)	18 (7.5%)	7 (38.9%)	***<0.001***

	All patients (*n* = 258)	**ESWL (*n* = 240)**	**SOPIL (*n* = 18)**	***p* value**
PD stent prior to lithotripsy (%)	90 (34.9%)	77 (32.1%)	13 (72.2%)	***<0.001***
Prior failed lithotripsy (%)	14 (5.4%)	7 (2.9%)	7 (38.9%)	***<0.001***
Prior failed ESWL (%)	10 (3.9%)	3 (1.3%)	7 (38.9%)	***<0.001***
Prior failed SOPIL (%)	4 (1.6%)	4 (1.7%)	0	0.278

Bold italic indicates $p < 0.05$

SD standard deviation, *F* female, *BMI* body mass index, *ERCP* endoscopic retrograde cholangiopancreatography, *PD* pancreatic duct, *ESWL* extracorporeal shock wave lithotripsy, *SOPIL* single-operator pancreatoscopy with intraductal lithotripsy

[a]Exocrine insufficiency at baseline defined by pancreatic enzyme supplementation

[b]Total etiology proportion does not add up to 1 due to coexisting etiologies in patients

[c]Total stone location proportion does not add up to 1 due to patients with multiple main duct stones

Table 2

Clinical outcomes and adverse events in patients with main pancreatic duct stones who underwent extracorporeal shock wave lithotripsy (ESWL) or single-operator pancreatoscopy with intraductal lithotripsy (SOPIL) for treatment

	All patients (n = 258)	ESWL (n = 240)	SOPIL (n = 18)	p value
Clinical outcomes				
Technical success, stone clearance (%)	224 (86.8%)	208 (86.7%)	16 (88.9%)	1.000
Degree of lithotripsic stone fragmentation (%)				
None	21 (8.1%)	21 (8.8%)	0	0.079
Partial	33 (12.8%)	28 (11.7%)	5 (27.8%)	
Complete	204 (79.1%)	191 (79.6%)	13 (72.2%)	
Improvement in pain (%)[a]	197/236 (83.5%)	182/220 (82.7%)	15/16 (93.8%)	0.483
Efficient stone clearance (≤ 2 procedures to clear stones)	114/224 (50.9%)	99/208 (47.6%)	15/16 (93.8%)	<***0.001***
Number of procedures to clear stones, mean (SD)[b]	3.0 (1.6)	3.1 (1.5)	1.6 (0.6)	<***0.001***
Number of lithotripsy sessions, mean (SD)	1.5 (0.9)	1.5 (0.9)	1.3 (0.5)	0.321
Aggregate procedure duration (minutes), mean (SD)	185.5 (111.4)	191.8 (111.6)	101.6 (68.2)	***0.001***
Adverse events				
Adverse events related to any procedures (%)	17 (6.6%)	16 (6.7%)	1 (5.6%)	1.000
Post-ERCP/Post-ESWL pancreatitis	12 (4.7%)	11 (4.6%)	1 (5.6%)	
Ascending cholangitis	1 (0.4%)	1 (0.4%)	0	
GI bleeding	1 (0.4%)	1 (0.4%)	0	
Symptomatic intra-abdominal hematoma	1 (0.4%)	1 (0.4%)	0	
Ventricular arrhythmia	1 (0.4%)	1 (0.4%)	0	
Adverse events at index lithotripsy session (%)	6 (2.3%)	5 (2.1%)	1 (5.6%)	0.355
Post-procedure admission (%)	49 (19.0%)	45 (18.8%)	4 (22.2%)	0.755

Bold italic indicates $p < 0.05$

ESWL extracorporeal shock wave lithotripsy, *SOPIL* single-operator pancreatoscopy with intraductal lithotripsy, *SD* standard deviation, *ERCP* endoscopic retrograde cholangiopancreatography, *GI* gastrointestinal

[a] In 236 patients with baseline pain

[b] In 224 patients with technical success

Table 3

Univariate and multivariable logistic regression model assessing predictors of technically successful stone clearance in patients who underwent extracorporeal shock wave lithotripsy (ESWL) or single-operator pancreatoscopy with intraductal lithotripsy (SOPIL) for treatment

Predictor	Odds ratio (95% CI), univariate	*p* value	Odds ratio (95% CI), multivariable	*p* value
Procedure type, SOPIL vs ESWL	1.298 (0.287–5.875)	0.735	–	–
Sex, male vs female	1.014 (0.465–2.210)	0.973	–	–
Race, Caucasian vs non-Caucasian	1.185 (0.383–3.667)	0.769	–	–
Abdominal pain at baseline	1.127 (0.314–4.046)	0.855	–	–
Opioid medication usage at baseline	1.092 (0.520–2.294)	0.816	–	–
Exocrine insufficiency at baseline	0.660 (0.311–1.401)	0.280	–	–
Endocrine insufficiency requiring insulin	0.505 (0.235–1.085)	**0.080**	0.477 (0.205–1.109)	0.085
Weight loss	0.610 (0.290–1.284)	**0.193**	0.594 (0.269–1.309)	0.196
Etiology, alcohol	0.552 (0.255–1.199)	**0.133**	0.448 (0.193–1.040)	0.062
Etiology, tobacco	0.759 (0.325–1.772)	0.523	–	–
Etiology, idiopathic	1.892 (0.548–6.538)	0.313	–	–
Prior pancreatic sphincterotomy	2.402 (1.060–5.443)	***0.036***	1.911 (0.790—4.622)	0.151
PD stent prior to lithotripsy	1.637 (0.700–3.826)	0.255	–	–
Prior failed lithotripsy	1.637 (0.700–3.826)	0.255	–	–
Stone location downstream (head or neck)	0.871 (0.247–3.075)	0.830	–	–
Presence of pancreatic duct stricture	2.418 (1.107–5.282)	***0.027***	2.047 (0.897–4.669)	0.089
Presence of parenchymal stones	0.599 (0.256–1.400)	**0.237**	–	–
Single stone	0.576 (0.212–1.567)	0.280	–	–
3 or more large stones treated	2.047 (0.260–16.116)	0.496	–	–
Largest stone size > 10 mm	0.574 (0.272–1.212)	**0.146**	0.641 (0.283–1.449)	0.285
Pancreatic duct diameter[a]	0.960 (0.844–1.092)	0.535	–	–

Bold italic indicates $p < 0.05$. Bold indicates logistic regression model $p < 0.25$

CI confidence interval, *SOPIL* single-operator pancreatoscopy with intraductal lithotripsy, *ESWL* extracorporeal shock wave lithotripsy, *PD* pancreatic duct

[a]Odds of success with every 1 mm incremental increase in pancreatic duct diameter

Table 4

Univariate and multivariable logistic regression model assessing predictors of the ability to use 2 or fewer procedures to successfully clear stones in patients who underwent extracorporeal shock wave lithotripsy (ESWL) or single-operator pancreatoscopy with intraductal lithotripsy (SOPIL) for treatment

Predictor	**Odds ratio (95% CI), univariate**	***p* value**	**Odds ratio (95% CI), multivariable**	***p* value**
Procedure type, SOPIL vs ESWL	5.504 (1.547–19.581)	***0.0084***	5.241 (1.348–20.369)	***0.017***
Sex, male vs female	0.779 (0.449–1.353)	0.3756	–	–
Race, Caucasian vs non-Caucasian	0.679 (0.288–1.602)	0.3769	–	–
Abdominal pain at baseline	1.144 (0.446–2.930)	0.7797	–	–
Opioid medication usage at baseline	1.235 (0.730–2.088)	0.4310	–	–
Exocrine insufficiency at baseline	1.153 (0.684–1.943)	0.5932	–	–
Endocrine insufficiency requiring insulin	1.176 (0.646–2.138)	0.5960	–	–
Weight loss	0.734 (0.430–1.250)	0.2547	–	–
Etiology, alcohol	1.035 (0.614–1.744)	0.8969	–	–
Etiology, tobacco	0.984 (0.559–1.733)	0.9551	–	–
Etiology, idiopathic	1.044 (0.516–2.114)	0.9038	–	–
Prior pancreatic sphincterotomy	1.377 (0.816–2.323)	**0.2312**	0.949 (0.527–1.709)	0.861
PD stent prior to lithotripsy	1.322 (0.767–2.278)	0.3147	–	–
Stone location downstream (head or neck)	0.471 (0.193–1.150)	**0.0984**	0.446 (0.174–1.141)	0.092
Presence of pancreatic duct stricture	0.801 (0.473–1.358)	0.4100	–	–
Presence of parenchymal stones	1.068 (0.622–1.835)	0.8108	–	–
Single stone	0.600 (0.324–1.112)	**0.1049**	0.548 (0.282–1.065)	0.076
3 or more large stones treated	1.333 (0.447–3.974)	0.6057	–	–
Largest stone size > 10 mm	0.399 (0.225–0.706)	***0.0016***	0.484 (0.256–0.912)	***0.025***
Pancreatic duct diameter[a]	0.922 (0.832–1.021)	**0.1199**	0.922 (0.818–1.039)	0.181

Bold italic indicates $p < 0.05$. Bold indicates logistic regression model $p < 0.25$

CI confidence interval, *SOPIL* single-operator pancreatoscopy with intraductal lithotripsy, *ESWL* extracorporeal shock wave lithotripsy, *PD* pancreatic duct

[a]Odds of efficient clearance with every 1 mm incremental increase in pancreatic duct diameter