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REVIEW ARTICLE

Cost effectiveness of endoscopic gallbladder drainage to treat acute cholecystitis in poor surgical candidates

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Abstract

Background Endoscopic gallbladder drainage (GBD) is an alternative to percutaneous GBD (PGBD) to treat acute cholecystitis, yielding similar success rates and fewer adverse events. To our knowledge, no cost-effectiveness analysis has compared these procedures. We performed an economic analysis to identify clinical and cost determinants of three treatment options for acute cholecystitis in poor surgical candidates.

Methods We compared three treatment strategies: PGBD, endoscopic retrograde cholangiographic transpapillary drainage (ERC-GBD), and endosonographic GBD (EUS-GBD). A decision tree was created over a 3-month period. Effectiveness was measured using hospital length of stay, including adverse events and readmissions. Costs of care were calculated from the National Inpatient Sample. Technical and clinical success estimates were obtained from the published literature. Cost effectiveness was measured as incremental cost effectiveness and compared to the national average cost of one hospital bed per diem.

Results Analysis of a hypothetical cohort of poor candidates for cholecystectomy showed that, compared to PGBD, ERC-GBD was a cost-saving strategy and EUS-GBD was cost effective, requiring $1312 per hospitalization day averted. Additional costs of endoscopic interventions were less than the average cost of one hospital bed per diem. Compared to ERC-GBD, EUS-GBD required expending an additional $8950 to prevent one additional day of hospitalization. Our model was considerably affected by lumen-apposing metal stent cost and hospital length of stay for patients managed conservatively and those requiring delayed surgery.

Conclusions Endoscopic GBD is cost effective compared to PGBD, favoring ERC-GBD over EUS-GBD. Further efforts are needed to make endoscopic GBD available in more medical centers, reduce equipment costs, and shorten inpatient stay.

Keywords Acute cholecystitis · Cost-effectiveness analysis · Endoscopic retrograde cholangiopancreatography · Endoscopic ultrasound · Gallbladder drainage

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Background

Acute cholecystitis is the cause of many emergency department consultations and hospitalizations [1, 2]. A noteworthy percentage of patients are not candidates for cholecystectomy at their initial presentation. Patients with multiple comorbidities or hemodynamic instability or those who are elderly may benefit from antibiotics and gallbladder drainage (GBD) prior to or as an alternative to surgery. Similarly, patients with altered anatomy, intraabdominal malignancy, or other terminal diseases may not be considered for cholecystectomy and will also require GBD [3, 4].

Traditionally, percutaneous GBD (PGBD) is used with good technical (97–100%) and moderate, but variable, clinical success (56–100%) [5, 6]. Over the last 20 years more patients are being treated with PGBD followed by interval laparoscopic cholecystectomy [7]. However, adverse events are common. Periprocedural adverse events, such as pain, bleeding, infection, and tube dislodgement, are seen in 4.1% cases, and increase to 14% to 74.6% after 3 to 4 months of follow-up [5, 6, 8]. Hospital readmissions are frequent (19.8–71.2% of cases), mostly related to adverse events with the external cholecystostomy tube [6, 8].

Endoscopic GBD has been refined and is now considered an alternative treatment with similar success rates and fewer adverse events. Multiple studies, including 5 meta-analyses, have shown that endoscopic retrograde cholangiographic transpapillary drainage (ERC-GBD) and endosonographic GBD (EUS-GBD) are effective and safe alternatives to PGBD [5, 6, 9–12]. However, no economic analysis has been published comparing these different interventions.

The objective of our study was to compare the cost effectiveness of three available interventions (PGBD, ERC-GBD, and EUS-GBD) in the treatment of acute cholecystitis in poor surgical candidates. Our secondary goal was to identify the different clinical and cost determinants, under which individual procedures become cost effective.

Methods

Our cost-effectiveness analysis focused on patients presenting with acute cholecystitis who are deemed to be poor operative candidates for cholecystectomy in a hospital setting in the United States. Acute cholecystitis was defined using the Tokyo Guidelines [13]. We evaluated a hypothetical cohort of patients considered poor surgical candidates based on comorbidities. We attempted to imitate the largest published cohort, in which approximately 70% of patients had calculous cholecystitis and 30% had acalculous cholecystitis (e.g., in the setting of intensive care hospitalization or malignant biliary obstruction) [6].

We created a decision tree that compared three nonoperative strategies to provide GBD (Fig. 1):

- Strategy I: PGBD (also called percutaneous cholecystostomy tube).
- Strategy II: ERC-GBD (also called endoscopic retrograde transpapillary stenting).
- Strategy III: EUS-GBD (also called endosonographic transmural stenting). EUS-GBD was performed with lumen-apposing metal stents (LAMS) only. Technically, EUS-GBD can also be performed with plastic stents or self-expandable metallic biliary stents, but these two alternatives were excluded in our model.

Our main outcomes were incremental costs in United States dollars ($) and incremental effectiveness, using hospitalization days averted. The primary analysis was performed from the health care perspective and secondary analysis from the general societal perspective. The time period of the model was 3 months from hospital consultation with acute cholecystitis. Our study adheres to the latest recommendations for conduct, methodologic practices, and reporting of

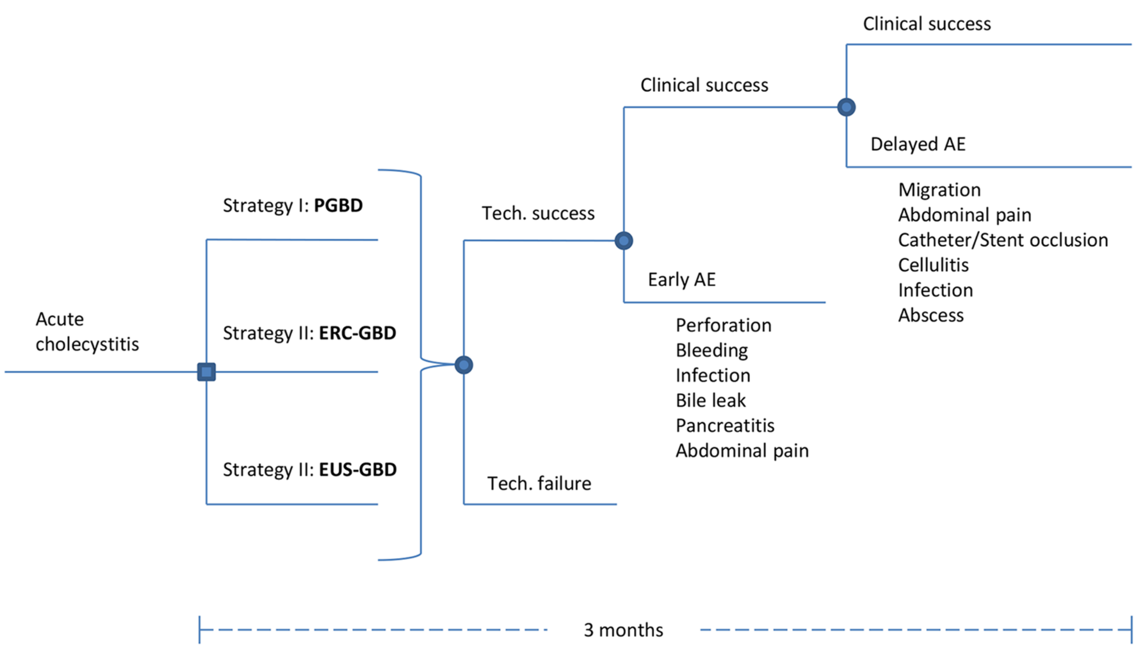

Fig. 1 Decision tree for gallbladder drainage in acute cholecystitis in poor surgical candidates. *AE* adverse events, *ERC-GBD* endoscopic retrograde transpapillary drainage, *EUS-GBD* endosonographic gallbladder drainage, *PGBD* percutaneous gallbladder drainage, *Tech.* technical

cost-effectiveness analyses [14]. IRB review was deemed not necessary for this study considering that no patients were contacted.

Study definitions and clinical probabilities

In our model, patients were assumed to be managed initially with bowel rest, intravenous fluids, and antibiotics, without improvement. The patients' clinical course was assumed to follow a recently published international multicenter cohort study, as this is the largest sample comparing all three interventions, providing clinical outcomes from 2010 to 2016 following standard methodology [6]. Technical success, clinical success, and adverse event rates are reported in Table 1. All patients were considered to be treated in the inpatient setting, and commonly accepted definitions for positive findings and adverse events were used.

According to the decision tree, patients would experience technical success (i.e., procedure completed with gallbladder decompression achieved) or technical failure (i.e., procedure aborted, requiring surgery or additional conservative monitoring). If technical success was achieved, patients would then progress to clinical success (resolution of disease after 3 months) or adverse events during the first 3 months. Clinical success required improvement in the overall clinical picture, without fever, leukocytosis, or abdominal pain, and tolerating oral diet [6]. For simplicity, clinical success and adverse events were deemed mutually exclusive. Readmissions within a 3-month period were included in the model on each arm of the decision tree and added to each arm's costs.

It was assumed that all procedures (PGBD, ERC-GBD, EUS-GBD, and laparoscopic cholecystectomy) would be performed by expert endoscopists, interventional radiologists, and surgeons in high-volume medical centers. In all strategies, repeated interventions were allowed, but not a combination of them (e.g., to a patient with failed ERC-GBD, PGBD could not be offered).

If surgery was required, patients would undergo laparoscopic exploration and a cholecystectomy. We did not include patients requiring conversion to open cholecystectomy in our model. When no estimates were available or considerable discrepancies were found in published literature, three authors (A.D., V.G., and M.B.W.) would discuss and agree on a final estimate.

Table 1 Probabilities used in decision analysis

Description of Probability	PGBD, %	ERC-GBD, %	EUS-GBD, %
Technical success, for baseline analysis[a]	97.9	87.9	94.1
Technical success, for Monte Carlo analysis[b]			
Siddiqui et al. [6]	97.95 (93.7–100.0)	87.90 (83.5–92.3)	94.12 (89.3–99.0)
Anderloni et al. [9]	NA	NA	91.50 (82.5–96.8)
Khan et al. [11]	NA	83.00 (78.2–86.8)	93.00 (86.9–96.4)
Final estimate	97.95 (93.7–100.0)	85.45 (78.2–92.3)	92.87 (82.5–99.0)
Need for surgery	49.7	11.4	4.0
Early adverse events			
Perforation	0.0	0.0	2.1
Bleeding	2.1	1.8	5.2
Early infection	0.7	0	1.0
Biliary leak	1.4	0	2.1
Pancreatitis	0.0	2.8	0.0
Persistent abdominal pain	0.0	3.7	2.1
Delayed adverse events			
Stent/tube migration	7.8	2.0	1.1
Readmission for abdominal pain	1.4	0.0	0.0
Stent/tube occlusion	2.8	4.0	0.0
Abdominal wall cellulitis	3.5	0.0	0.0
Late abdominal infection	3.5	0.0	1.1
Intraabdominal abscess	1.4	0.0	0.0

ERC-GBD endoscopic retrograde transpapillary drainage, *EUS-GBD* endosonographic gallbladder drainage, *NA* not available, *PGBD* percutaneous gallbladder drainage

[a]Included only Siddiqui et al. the largest sample study published to date

[b]Presumed to follow a normal distribution, with 25% standard deviation

Cost estimates

Cost estimates were measured in United States dollars ($) and were collected from different sources (Table 2). The majority of estimates were generated from a structured review of the National Inpatient Sample (NIS) dataset [15, 16]. To increase comparability between sources, the NIS database review only included Medicare beneficiaries, 18 years or older, admitted with acute cholecystitis, who did not receive a cholecystectomy between 2010 and 2014. Costs and charges were recorded and adjusted for inflation using the consumer price index.

If data were unavailable in the NIS, missing costs were obtained from Chen et al's [17] cost-effectiveness analysis of endoscopic drainage of pancreatic necrosis using billing claims or the 2017 National Average Ambulatory Procedure Classification Payments from the Centers for Medicare & Medicaid Services (CMS) [15]. Costs were selected for facility settings (hospital or urgent care centers) rather than office settings. Following the same protocol as the NIS review, costs were adjusted for inflation using the Consumer Price Index.

Effectiveness

Effectiveness was measured in hospital length of stay (i.e., hospitalization days averted). Prolonged hospitalizations due to adverse events (e.g., abdominal pain or infections) and readmissions (e.g., tube dislodgement at home) were included in the model and added to total hospitalization days. Hospitalization days were adapted from the international multicenter cohort manuscript [6]. Length of stay may seem prolonged for acute cholecystitis (i.e., 5 days in all-comers recorded in the Nationwide Readmissions Database vs 15+ days here) [18]. However, our estimates included inpatients admitted in a medical unit for nongastrointestinal reasons (e.g., heart failure or stroke) who developed acute cholecystitis. Based on the literature, PGBD required a median of two procedures and ERC-GBD and EUS-GBD each required only one procedure for clinical success [6]. No procedure-related deaths were reported during the 3-month follow-up [6].

Primary outcome and statistical analysis

The primary outcome of our study was incremental dollars per hospital day averted. Cost effectiveness was compared between the three strategies and against the national average cost of one hospital bed per diem as reference.

Traditionally, cost-effectiveness analyses use incremental cost-effectiveness ratios (ICERs) as a measure of added cost for additional life-years gained by treatment strategy. Considering the lack of studies proving that endoscopic intervention improves survival, we could not compute life-years gained or calculate ICERs. Cost of hospital beds per diem were used as reference, considering the lack of agreement on a *willingness to pay* definition for short-term cost-effectiveness analysis. The decision tree was analyzed using TreeAge Pro decision analysis software (TreeAge Software, Inc.).

Sensitivity analysis and Monte Carlo simulation

The robustness of the model was tested by performing sensitivity and threshold analyses with varying clinical probabilities and cost estimates. One-way sensitivity analyses evaluated the effect of variations of the price of LAMS in the model. Tornado diagrams were generated to evaluate the effect of other modifying variables.

We also performed probabilistic sensitivity analysis. A hypothetical cohort of 1000 patients with acute cholecystitis, unfit for cholecystectomy, was included in a second-order Monte Carlo simulation. This simulation used varying probabilities of technical success for each strategy. Probability distributions were extracted from three studies (1 multicenter cohort and 2 meta-analyses selected by authors) [6, 9, 11] and assumed to follow a normal distribution with 25% standard deviation (Table 1).

Monte Carlo simulation recalculates a model multiple times and incorporates uncertainties into an analysis simulating real-life situations [19]. By using technical success as a tracking variable, acceptability curves were created, requiring a preset value for willingness to pay. There is no convention of willingness to pay to prevent a 1-night stay in the hospital; therefore, willingness to pay was replaced by the average cost of a 1-night hospitalization in the United States for any cause.

Secondary analysis

Secondary analysis evaluated cost effectiveness of the same interventions from a societal perspective, including costs incurred by third-party payers. The added costs accounted for outpatient visits, home health care, over-the-counter medications, unpaid caregiver costs, transportation costs, and loss of productivity for both patient and employer. Costs were obtained from different sources (Supplement Table 1) and were adjusted for inflation during the 2016 and 2017 periods. Clinical probabilities and effectiveness estimates remained the same.

Results

Analysis of a hypothetical cohort of patients with acute cholecystitis who were considered poor candidates for cholecystectomy showed that the cost effectiveness of endoscopic

Table 2 Cost and clinical effectiveness estimates used in the decision analysis

Name	Source	Root definition (USD)	Low (USD)	High (USD)
Costs (USD)[a]				
Anesthesia per procedure	Chen et al. [17]	712	534	890
PGBD	Chen et al. [17], and Medicare (cms.gov)[b]	3860	2895	4825
ERC-GBD	Chen et al. [17], Das et al. [1], and Medicare (cms.gov)[b]	2002	1514	2490
EUS-GBD	Chen et al. [17], and Medicare (cms.gov)[b]	5237 (insertion) + 4930 (stent)	7625	12,709
Hospitalization costs at baseline (without procedure)	NIS 2010–2014[c]	35,248	26,436	44,060
Hospitalization complicated by abscess	NIS 2010–2014[c]	171,906	128,929	214,882
Hospitalization complicated by bile leak	NIS 2010–2014[c]	180,000	135,000	225,000
Hospitalization complicated by bleeding	NIS 2010–2014[c]	109,249	81,936	136,561
Hospitalization complicated by cellulitis	NIS 2010–2014[c]	142,049	106,536	177,561
Hospitalization with conservative management	NIS 2010–2014[c]	36,000	27,000	45,000
Hospitalization complicated by early infection	NIS 2010–2014[c]	142,049	106,536	177,561
Readmission due to infection	NIS 2010–2014[c]	142,049	106,536	177,561
Hospitalization complicated by stent/tube migration	NIS 2010–2014[c]	Hospital baseline + 4687		
Hospitalization complicated by stent/tube occlusion	NIS 2010–2014[c]	Hospital baseline + 2000		
Hospitalization complicated by abdominal pain	NIS 2010–2014[c]	35,248	26,436	44,060
Readmission due to abdominal pain	NIS 2010–2014[c]	35,248	26,436	44,060
Hospitalization complicated by pancreatitis (only in ERC-GBD)	NIS 2010–2014[c]	60,223	45,167	75,278
Hospitalization complicated by perforation	NIS 2010–2014[c]	187,061	140,295	233,826
Hospitalization not improving, requiring surgery	NIS 2010–2014[c]	Hospital baseline + 714		
Effectiveness (hospitalization days)				
PGBD	Siddiqui et al. [6]	19	14.25	23.75
	Kedia et al. [22]	16.3	12.22	20.37
ERC-GBD	Siddiqui et al. [6]	18	13.5	22.5
EUS-GBD	Siddiqui et al. [6]	16	12	20
	Kedia et al. [22]	7.6	5.7	9.5
Additional days if abscess develops	NIS 2010–2014[c]	+11.6	8.7	14.5
Additional days if bile leak	Authors estimate	+12	9	15
Additional days with bleeding	NIS 2010–2014[c]	+6.6	4.95	8.25
Additional days if cellulitis	NIS 2010–2014[c]	+2	1.5	2.5
Additional days if technical failure, but conservative approach	NIS 2010–2014[c]	+5	3.75	6.25
Additional days if infection develops	NIS 2010–2014[c]	+3	2.25	3.75
Additional days if readmitted with infection	Authors estimate	+5	3.75	6.25
Additional days if stent/tube migration	NIS 2010–2014[c]	+5	3.75	6.25
Additional days if stent/tube occlusion	NIS 2010–2014[c]	+5	3.75	6.25

Table 2 (continued)

Name	Source	Root definition (USD)	Low (USD)	High (USD)
Additional days if severe abdominal pain	NIS 2010–2014[c]	+2	1.5	2.5
Additional days if readmitted for abdominal pain	Authors estimate	+3	2.25	3.75
Additional days if develops pancreatitis	NIS 2010–2014[c]	+5	3.75	6.25
Additional days if develops perforation	NIS 2010–2014[c]	+12	9	15
Additional days if technical failure, but requires surgery	Authors estimate	+12	9	15

ERC-GBD endoscopic retrograde transpapillary drainage, *EUS-GBD* endosonographic gallbladder drainage, *NIS* National Inpatient Sample Database, *PGBD* percutaneous gallbladder drainage, *USD* United States dollars

[a]Costs used for secondary analysis (societal perspective) in Supplement

[b]Procedures were selected only for facility setting and include both facility and physician fees

[c]Hospitalization charges for Medicare patients only. Average 2010–2014 adjusted for inflation

therapies was superior to PGBD. Compared to PGBD, ERC-GBD was a cost-saving strategy and EUS-GBD was cost effective, requiring $1312 per hospitalization day averted (Fig. 2 and Table 3). Both interventions were acceptable under the cost of one hospital bed per diem ($2338 national average). Compared to ERC-GBD, EUS-GBD required spending $8950 more per hospitalization day averted.

Sensitivity and threshold analyses

Sensitivity analyses showed that our model was notably affected by LAMS price, length of stay for patients managed conservatively, and length of stay for patients requiring laparoscopic cholecystectomy (i.e., those with technical or clinical failure after drainage attempt). Cost effectiveness was minimally affected by variations in technical success rates of endoscopic procedures (Fig. 3). One-way sensitivity analysis showed that a decrease of LAMS price (to $780) could potentially make EUS-GBD the dominant treatment strategy.

The Monte Carlo simulation included a variable range of therapeutic success rates for each intervention. ERC-GBD was cost effective in the majority of simulation trials, and was well under the cost of 1 hospitalization day (average cost of a 1-day hospital stay in the United States was $2338 in 2016) [20]. ERC-GBD ceased being cost effective when willingness to pay for a new intervention was greater than $10,000, approximately the cost of 4 nights in the hospital. ERC-GBD remained more cost effective than EUS-GBD in the Monte Carlo simulation (Fig. 4).

Secondary analysis

From our literature review, the cost analysis from a societal perspective added $6264 for PGBD, $4659 for ERC-GBD, and $4543 for EUS-GBD over 3 months (Supplement Table 1). Loss of productivity days represented approximately 60% of the additional costs for the societal perspective in all arms. Cost-effectiveness results did not change from primary analysis (Fig. 2 and Table 4). EUS-GBD was cost effective, with $762 per hospital day averted compared to PGBD.

Discussion

Endoscopic GBD is an effective and safe strategy to treat acute cholecystitis in patients who are unfit for cholecystectomy [8, 10, 12]. To our knowledge, this is the first economic analysis evaluating endoscopic drainage of the gallbladder in this population. We found that endoscopic alternatives for acute cholecystitis are more cost effective than PGBD. Comparing both alternatives, ERC-GBD was favored over EUS-GBD.

The advantages in cost effectiveness seen in endoscopic procedures can be explained using two main factors: (1) patients are hospitalized for a shorter period, and (2) they have lower readmission rates caused by technical problems associated with percutaneous catheters (e.g., infection and tube migration). The initial cost benefits of PGBD were reduced notably after considering that patients in the PGBD arm required a median of 2 procedures to achieve clinical success [6].

Between both endoscopic alternatives, ERC-GBD is marginally less expensive than EUS-GBD, likely due to the lower cost of plastic biliary stents compared to using LAMS in EUS-GBD. A fundamental consideration is that ERC-GBD will certainly require removal or replacement of the plastic stent. Our 3-month analysis does not capture this and limits comparisons to definitive EUS-GBD, which may also require LAMS removal. There are no clear recommendations on indications to remove LAMS, the best time frame to do

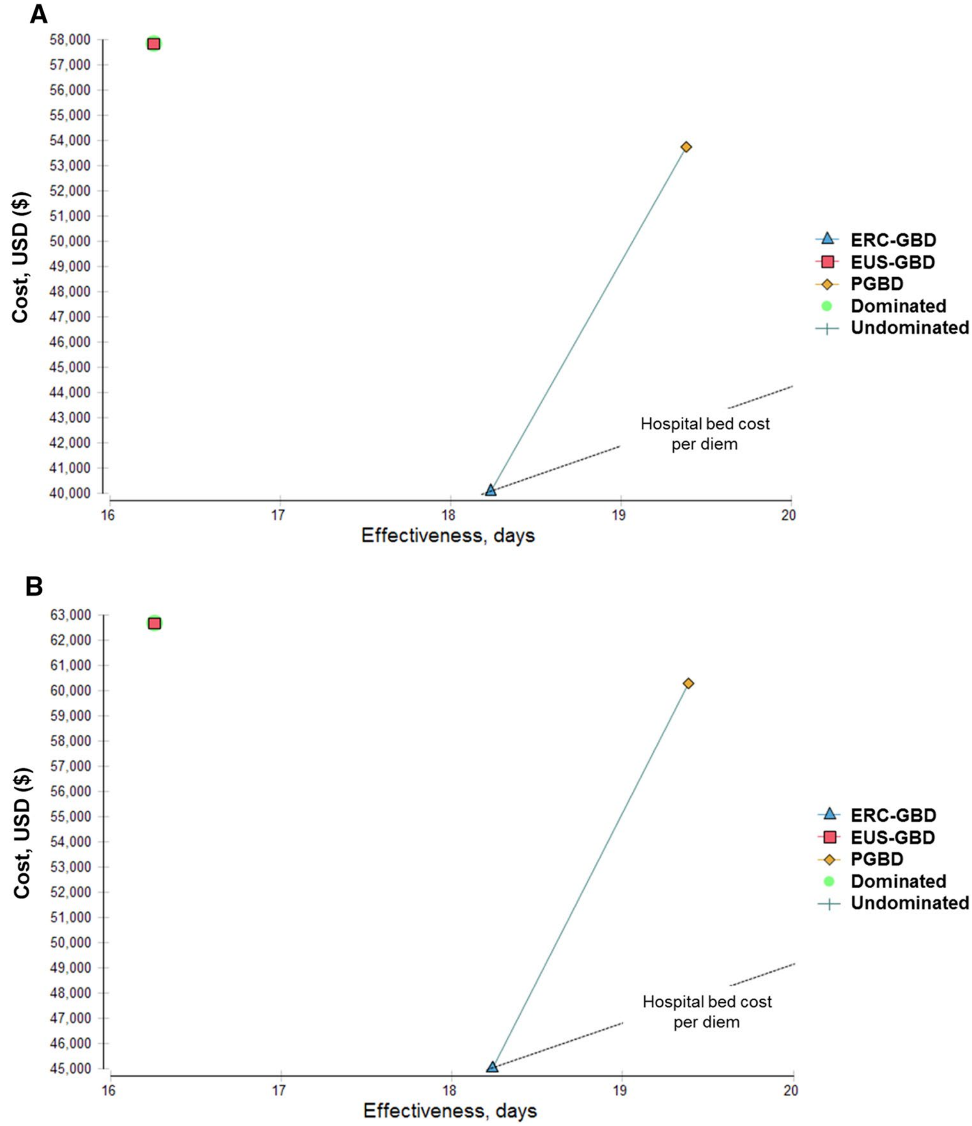

Fig. 2 Cost-effectiveness diagrams comparing three strategies for gallbladder drainage. **A** Health care perspective. **B** Society perspective. *ERC-GBD* endoscopic retrograde transpapillary drainage, *EUS-GBD* endosonographic gallbladder drainage, *PGBD* percutaneous gallbladder drainage, *USD* United States dollars

Table 3 Incremental cost effectiveness for acute cholecystitis treatment, health care perspective

Strategy	Cost (USD)	Incremental cost (USD)	Effectiveness (total hospital days)	Incremental effectiveness (hospital days averted)
PGBD as reference				
PGBD	53,712	Ref	19.38	Ref
ERC-GBD	40,086	− 13,626	18.24	1.14
EUS-GBD	57,808	4096	16.26	3.12
ERC-GBD as reference				
EUS-GBD	57,808	17,722	16.26	1.98

ERC-GBD endoscopic retrograde transpapillary drainage, *EUS-GBD* endosonographic gallbladder drainage, *PGBD* percutaneous gallbladder drainage, *USD* United States dollars

it, and the implications of a chronic, potentially beneficial fistula.

Our decision tree attempts to replicate a complex real-life scenario with a point intervention over a 3-month period. The decision to proceed with PGBD versus endoscopic GBD is multimodal and cannot be based solely on cost and price. Hospital resources, expertise, availability, patient preference, and anatomic factors must all be

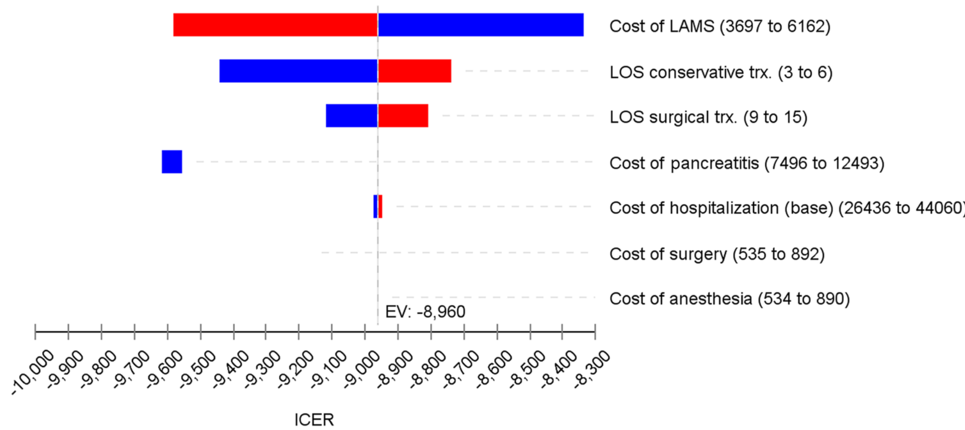

Fig. 3 Tornado diagram comparing ICERs and modifying variables (EUS-GBD Vs. ERC-GBD). *ERC-GBD* endoscopic retrograde transpapillary drainage, *EUS-GBD* endosonographic gallbladder drainage, *EV* expected value, *ICERs* incremental cost-effectiveness ratios, *LAMS* luminal apposing metal stent, *LOS* length of stay

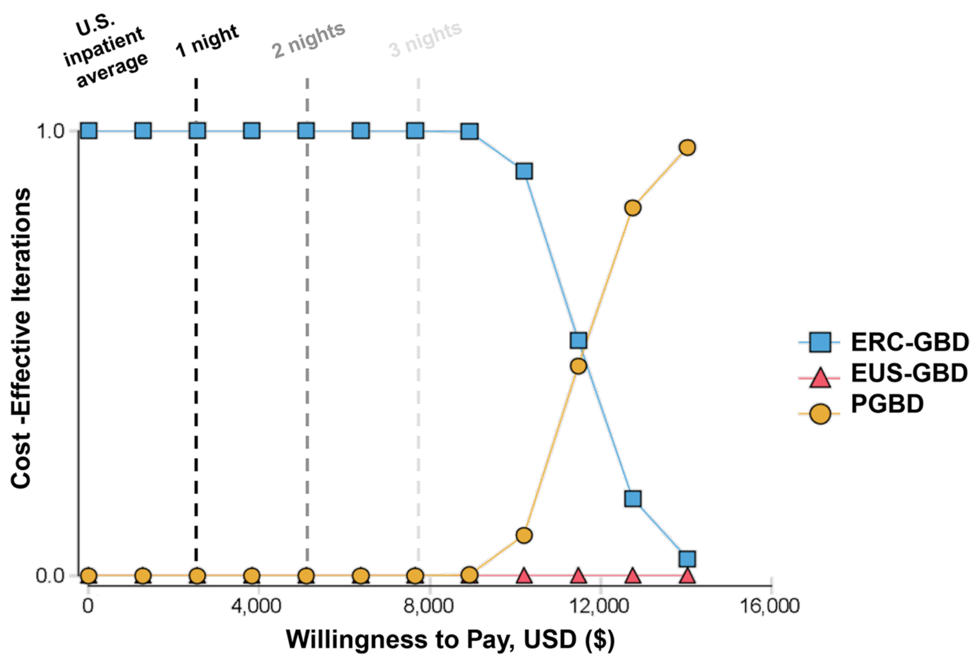

Fig. 4 Acceptability Curves for three Treatment Strategies Over a Broad Range of Willingness to Pay. *ERC-GBD* endoscopic retrograde transpapillary drainage, *EUS-GBD* endosonographic gallbladder drainage, *PGBD* percutaneous gallbladder drainage, *USD* United States dollars

Table 4 Incremental cost effectiveness for acute cholecystitis treatment, societal perspective

Strategy	Cost (USD)	Incremental cost (USD)	Effectiveness (total hospital days)	Incremental effectiveness (hospital days averted)
PGBD as reference				
PGBD	60,266	Ref	19.38	Ref
ERC-GBD	45,036	−15,230	18.24	1.14
EUS-GBD	62,643	2377	16.26	3.12
ERC-GBD as reference				
EUS-GBD	62,643	17,607	16.26	1.98

ERC-GBD endoscopic retrograde transpapillary drainage, *EUS-GBD* endosonographic gallbladder drainage, *PGBD* percutaneous gallbladder drainage, *USD* United States dollars

considered. Patient selection is particularly determinant in this process. Multiple individual characteristics might suggest or prevent a certain strategy. For example, biliary obstruction due to a pancreatic or biliary malignancy might prevent ERC-GBD and, instead, make EUS-GB more favorable.

Traditionally, most critically ill patients (e.g., requiring vasopressors and intensive care) are treated with PGBD.

These patients tend to have prolonged hospitalizations compared to those considered good candidates for endoscopic drainage. No randomized controlled trials have yet compared ERC-GBD to EUS-GBD; therefore, our estimates are subject to selection bias. This is suggested in Table 1, which shows a higher surgical rate in patients undergoing PBGD. The diversity of patient subgroups requiring different approaches is difficult to depict in any economic model.

This study supports that an endoscopic approach is cost-effective over a broad range of conditions, including varying technical success rates. By including an analysis from the societal perspective and hospitalization cost comparisons, we suggest that endoscopic GBD is not only cost effective, but can add social value in the United States. Analysis under the societal perspective allows all parties involved in health care (including patients' employers and social support system) to contribute to the decision on best treatment [21].

Our model was influenced by the hospitalization length of stay on each strategy. Our estimates are more conservative than other studies that report a shorter length of stay after endoscopic therapy and a larger difference compared to PGBD (7.6 days with EUS-GBD vs 16.3 with PGBD) [22]. We opted for this approach, as we considered that patients who have failed antibiotic therapy and supportive measures are the ideal population for endoscopic drainage. By including both patients with calculous and acalculous cholecystitis, we believe our model is generalizable to commonly encountered real-life clinical scenarios. We emphasize that this study assumed that treatment would be performed in high-volume centers. This has proved to increase success rates and reduce procedure-related adverse events [23].

Implications and future directions

The most recent Tokyo Guidelines for management of acute cholangitis and cholecystitis recommend endoscopic treatment as part of their treatment bundles [24]. Our results suggest a shift of resources from radiology to endoscopy departments in an already restrained health care system. Changing practice patterns from PGBD to endoscopic GBD affects inpatient treatment, but also subsequent encounters, follow-up visits, and surgical approaches. Data are still limited on further management of LAMS and biliary stents after 3 months. Preliminary evidence shows no limitations for these patients to receive an elective cholecystectomy [25]. As endoscopic procedures become more sophisticated (e.g., using puncture anchor traction devices), we presume endoscopic therapies will become safer and eventually more cost effective [26].

Our results and expert opinions advocate for a combined approach during endoscopy, where ERC-GBD is attempted first (especially if the common bile duct needs to be explored and stones removed), and, if not feasible, EUS-GBD is attempted during the same procedure. This combined approach can potentially reduce the need for a second round of anesthesia for the sick patient. This 2-step approach also requires having endoscopists proficient in both procedures.

EUS-GBD is a relatively new method, facilitated by the availability of LAMS. As this method is more frequently performed as a first-line procedure, technical success will become more predictable. Other potential advantages of EUS-GBD include shorter procedure duration; potential for monitored anesthesia care, given the more favorable left lateral decubitus (not prone) positioning; and nonradiating ultrasound versus fluoroscopy guidance. Furthermore, ERC-GBD carries the unique concern for postendoscopic retrograde cholangiopancreatography pancreatitis, which is less of an issue with EUS-GBD. Future research comparing ERC-GBD with EUS-GBD will facilitate individualized procedure selection.

Identifying patients at higher risk for technical failure, enhanced visualization, and selection of best endoscopic approach (e.g., transgastric vs transduodenal access to the gallbladder) are areas of ongoing research [27]. The ultimate challenge for scaling up endoscopic interventions will reside in dissemination of endoscopic alternatives among general practitioners, increasing availability of therapeutic endoscopic services and support from third-party payers.

Strengths and limitations

In any decision analysis, the quality of the input data is critical. In our analysis, most of the important probabilities were obtained from a large multicenter cohort study and a structured review of the NIS [15, 16]. This allowed using real costs of hospitalizations. Bothe the NIS estimates and the multicenter cohort, were obtained from an overlapping period of 5 years [28]. We have accounted for clinical uncertainties with a sensitivity analysis and a second-order Monte Carlo simulation. We adhered to recommendations of the Second Panel on Cost-Effectiveness in Health and Medicine [14].

Effectiveness in this economic model was a composite value. By including readmissions and adverse events in our model, we were able to add granularity on the effectiveness of each strategy (i.e., compared to length of stay during index admission). This is an important part of the study because the patients receiving PGBD require more readmissions than those receiving endoscopic GBD.

To increase comparability between specific costs, NIS estimates, and other sources (e.g., Centers for Medicare & Medicaid services), only Medicare beneficiaries were included. Estimating the cost of LAMS was challenging. When a patient undergoes procedures as an inpatient, all billable charges are included under the diagnosis-related group–associated facility and administrative fee, and a LAMS device cannot be billed separately. C-codes are used to track use, but are not reimbursable in the inpatient setting. With only limited data available, we opted to use estimates from Chen et al. [17], a retrospective review of procedures billed between 2012 and 2016.

This study has limitations inherent to any economic modeling study. Our results are limited by the lack of long-term cost and effectiveness estimates. Limited assumptions can be made on repeated interventions over the study window. Based on published information, we assumed that patients receiving PGBD will require more consultations, interventions (e.g., internalization of tubes performed after a 3-month period), and costs.

Authors attempted to include all the nuances of an external percutaneous drain into patient-related outcomes by accounting for additional hospital visits, outpatient consultations, and days missed from work. However, the impact on quality of life as an outpatient was difficult to estimate. We did not include quality-of-life adjustments or utility values in our model.

Conventionally, cost-effectiveness analyses use life-years saved to measure effectiveness and willingness to pay, usually based on recommendations from the United States Panel on Cost-Effectiveness studies or the World Health Organization CHOICE (CHOosing Interventions that are Cost-Effective) project, traditionally in relation to the country's annual gross domestic product [29]. For this analysis, no differences in mortality were noticed over a 3-month period, preventing any calculation of quality- or disability-adjusted life-years. This limits comparing our results with other cost-effectiveness analyses, and ultimately, reduces external validity. Currently, there is no agreement on willingness to pay to prevent a hospital day. Even though our findings might be applicable to other high-income countries, local practice, and costs variations should be accounted for (e.g., Japan and many European countries have prolonged hospitalizations across all admissions) [30].

Finally, the authors acknowledge that there are other alternatives to providing endoscopic GBD, such as endosonographic placement of plastic stents or self-expandable metallic biliary stents. These alternatives are not considered standard of care and were excluded from analysis, as they have higher adverse event rates [9].

Conclusion

Our economic analysis showed that endoscopic GBD is more cost effective compared to PGBD, favoring ERC-GBD over EUS-GBD. Further efforts are needed to ensure that these procedures are available in more medical centers, so that they reduce equipment costs, and that they shorten inpatient care duration. Larger-scale implementation of endoscopic therapies into clinical practice will depend on dissemination among general practitioners (e.g., general surgeons and internal medicine physicians), increasing the number of advanced endoscopists across the country, and securing reimbursement from third-party payers, while in parallel, procedure performance and technology get refined.

Compliance with ethical standards

Disclosures Drs Corral, Das, Kröner, Gomez, and Wallace have no conflicts of interest or financial ties to disclose.

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