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Cost-Effective Treatment of Patients with Symptomatic Cholelithiasis and Possible Common Bile Duct Stones

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Abstract

Background—Clinicians must choose a treatment strategy for patients with symptomatic cholelithiasis without knowing whether common bile duct (CBD) stones are present. The purpose of this study was to determine the most cost-effective treatment strategy for patients with symptomatic cholelithiasis and possible CBD stones.

Study Design—Our decision model included five treatment strategies: (1) laparoscopic cholecystectomy (LC) alone followed by expectant management, (2) preoperative endoscopic retrograde cholangiopancreatography (ERCP) followed by LC, (3) LC with intraoperative cholangiography (IOC) ± common bile duct exploration (CBDE), (4) LC followed by postoperative ERCP, and (5) LC with IOC ± postoperative ERCP. The rates of successful completion of diagnostic testing and therapeutic intervention, test characteristics (sensitivity and specificity), morbidity, and mortality for all procedures are from current literature. Hospitalization costs and lengths of stay are from the 2006 National CMS data. The probability of CBD stones was varied from 0% to 100% and the most cost-effective strategy was determined at each probability.

Results—Across the CBD stone probability range of 4% to 100%, LC with IOC ± ERCP was the most cost-effective. If the probability was 0%, LC alone was the most cost-effective. Our model was sensitive to one health input: specificity of IOC, and three costs: cost of hospitalization for LC with CBDE, cost of hospitalization for LC without CBDE, and cost of LC with IOC.

Conclusions—The most cost-effective treatment strategy for the majority of patients with symptomatic cholelithiasis is LC with routine IOC. If stones are detected, CBDE should be forgone and the patient referred for ERCP.

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INTRODUCTION

Approximately ten percent of patients who undergo cholecystectomy for symptomatic cholelithiasis also have common bile duct (CBD) stones [1-3]. Although the diagnosis of symptomatic cholelithiasis (biliary colic and acute cholecystitis) is usually straightforward, determining whether CBD stones are present is more challenging. To estimate the probability of CBD stones, physicians rely on clinical clues such as jaundice, ultrasound findings of CBD or intrahepatic ductal dilation, or laboratory abnormalities including bilirubin and/or alkaline phosphatase elevation. These parameters can only provide an estimate. Usually the clinician must choose a treatment strategy without knowing for certain whether a patient has CBD stones.

Both laparoscopic common bile duct exploration (CBDE) and endoscopic retrograde cholangiopancreatography (ERCP) with sphincterotomy are safe and effective methods of clearing stones from the CBD [4, 5]. Randomized controlled trials comparing ERCP with laparoscopic CBDE have demonstrated similar efficacy for removal of CBD stones [6, 7]. If these two treatments are equally efficacious, then it is worthwhile to determine which costs less. Prior cost-effectiveness analyses have yielded mixed results, with one study concluding that preoperative ERCP followed by laparoscopic cholecystectomy (LC) is the most cost-effective strategy [8] and others concluding that LC with CBDE is the most cost-effective [7, 9]. Our aim was to determine the most cost-effective treatment strategy for patients with symptomatic cholelithiasis and possible CBD stones.

METHODS

DECISION MODEL

We developed a decision model that included the five most commonly used treatment strategies for patients with symptomatic cholelithiasis and possible CBD stones (Figure 1): (1) LC alone followed by expectant management (Figure 2, online only), (2) preoperative ERCP followed by LC (Figure 3, online only), (3) LC with intraoperative cholangiography (IOC) ± CBDE depending upon whether stones were detected during IOC (Figure 4, online only), (4) LC followed by postoperative ERCP (Figure 5, online only), and (5) LC with IOC ± postoperative ERCP depending upon whether stones were detected during IOC (Figure 6, online only).

The probabilities of morbidity and mortality associated with ERCP, LC with IOC ± CBDE, and LC alone were included in the model (Table 1). Only complications that required prolonged hospital stay, readmission, or additional procedures were considered for our analysis. The rate of successful completion of diagnostic testing, test characteristics (sensitivity and specificity), and the rate of successful therapeutic intervention were considered for ERCP and LC with IOC ± CBDE.

The base case scenario for our analysis is a 65 year old woman who presents to the emergency department with symptomatic cholelithiasis. She has a 10% probability of having CBD stones in addition to gallstones, and when choosing a treatment strategy it is uncertain whether she has CBD stones. Each strategy was carried out until the patient was found not to have CBD stones, was found to have CBD stones and underwent removal, or died. The pretest probability of CBD stones was varied from 0% to 100% and the most cost-effective treatment strategy was determined at each probability.

MODEL ASSUMPTIONS

Within each treatment strategy the same assumptions were used to ensure consistent clinical judgment between strategies. If ERCP or laparoscopic CBDE failed because the CBD could

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not be cannulated or CBD stones could not be removed, the other therapy served as the rescue therapy. If a patient underwent ERCP but the CBD could not be cannulated or CBD stones could not be removed, we assumed this patient would undergo successful non-endoscopic CBD stone removal via either an open CBDE, laparoscopic CBDE, or transhepatic approach. Similarly, if a patient underwent IOC but the CBD could not be cannulated, or underwent CBDE but CBD stones could not be removed, we assumed this patient would undergo successful ERCP stone removal. In all patients who underwent ERCP, we assumed that it might take more than one ERCP to ensure successful diagnosis and/or removal of CBD stones; the probability for this was based on published literature.

Our model takes into account patients who may experience signs and symptoms of retained CBD stones after a hospitalization that included either a false negative ERCP or IOC. We acknowledge that some patients with retained CBD stones will not seek medical care because their symptoms are very mild, the stones pass spontaneously, or the stones are too small to lead to symptoms. However, we assumed the worst-case scenario: every patient with either a false negative ERCP or IOC would present with evidence of retained CBD stones. We also assumed these patients were readmitted to the hospital and underwent ERCP with successful CBD stone removal. In addition, in the LC alone strategy, we assumed that patients who were discharged and then presented with signs and symptoms of retained CBD stones were readmitted and underwent an ERCP attempt at CBD stone removal.

We did not include patient preferences (health state utilities) in our model because there are no published data for patient preferences for choledocholithiasis and we did not want to include invalidated data in the model. In addition, we assumed that choledocholithiasis, either symptomatic or asymptomatic, would not cause long-term changes in quality of life.

HEALTH INPUTS

Endoscopic Retrograde Cholangiopancreatography

ERCP Cannulation: There are many recent randomized controlled trials investigating new ERCP cannulation techniques. The techniques and equipment used for diagnostic and therapeutic ERCP have evolved over time. Therefore the most recent data best represents the methods currently used for selective cannulation of the common bile duct. The overall success rate of ERCP biliary cannulation in expert hands is 94.4%. This was determined by taking a weighted average of the most recent ERCP cannulation randomized controlled trials [10-15].

ERCP Sensitivity and Specificity: A study by Stabuc and co-workers [16] determined the sensitivity and specificity of ERCP for detecting CBD stones to be 96% and 92%, respectively. In 38 consecutive patients with acute biliary pancreatitis EUS and ERCP were done. If either the EUS or ERCP (or both) was positive for CBD stones, an endoscopic sphincterotomy was done. The final diagnosis regarding whether or not the patient had CBD stones was based on extraction of stones after sphincterotomy. If both EUS and ERCP were negative, then it was assumed that the patient did not have stones.

ERCP Stone Removal: Two recent randomized controlled trials investigating new ERCP cannulation techniques [17, 18] combined with eight randomized controlled trials from the 1990s [6, 7, 19-24] provided the summary estimate of 94% for ERCP stone removal.

ERCP Complications: The estimated ERCP complication rate is 11.3%. This estimate is based on two large studies that prospectively determined the complication rate for ERCP. The first study is a landmark article by Freeman and co-workers [25] detailing the complications following ERCP with endoscopic sphincterotomy in 2,347 patients. The

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second study [26] included 1,177 patients undergoing diagnostic ERCP, some of whom also underwent endoscopic intervention for attempted CBD stone removal.

ERCP Mortality: The probability of mortality associated with ERCP is 0.7%. This estimate is based on the same two large prospective studies used to determine the ERCP complication estimate [25, 26] and two randomized controlled trials comparing ERCP with surgical removal of CBD stones [19, 23].

Laparoscopy

Intraoperative Cholangiography Cannulation: The largest and most recent series of IOC determined the sensitivity and specificity of IOC for detecting CBD stones [27]. This study enrolled 1,171 patients undergoing laparoscopic cholecystectomy. Routine IOC could not be completed in 48 patients. Therefore, the success rate of IOC was 95.9%. All cholangiograms in this study used dynamic real-time intraoperative fluoroscopy using a C-arm, 10-40ml of Omnipaque as contrast, and Glucagon to prevent papillary spasm.

Intraoperative Cholangiogram Sensitivity and Specificity: This same study [27] determined the sensitivity and specificity of IOC to be 97% and 99% respectively. If a patient had a negative IOC with no postoperative biliary symptoms, this was a true negative. If a patient developed biliary symptoms after a negative IOC, this was a false negative IOC. A positive IOC followed by a CBD exploration and/or postoperative ERCP, MRCP, or postoperative cholangiography revealing stones was a true positive. A positive IOC followed by a CBD exploration, postoperative ERCP, MRCP, or postoperative cholangiography that revealed no stones was a false positive.

Laparoscopic CBDE Stone Removal: The summary estimate of 91.1% for CBD stone removal by laparoscopic CBDE was determined by seven recent studies [1, 27-32] from 2003-2009 and two randomized controlled trials [6, 7] from the late 1990s.

Laparoscopic Cholecystectomy Complications: The complication rate for laparoscopic cholecystectomy is 2.6%. This estimate is based on 9 studies [33-41]. Four of these studies are randomized controlled trials and all compared the outcomes of ambulatory versus overnight stay laparoscopic cholecystectomy or reported outcomes of laparoscopic cholecystectomy in a large series of patients.

Laparoscopic Cholecystectomy and CBDE Complications: The complication rate for laparoscopic cholecystectomy and CBDE is 3.2%. This is a summary estimate of five studies [1, 7, 28, 29, 42]. The largest series retrospectively analyzed one surgeon's 12-year experience with laparoscopic CBDE in 3,544 patients [1].

Surgical Mortality—The mortality estimate for laparoscopic cholecystectomy with or without CBDE is 0.3%. This estimate is based on a large cohort study (3544) of laparoscopic outcomes [1] in addition to three other studies [6, 29, 42].

Costs—The perspective of this analysis is that of a third-party payer, the Center for Medicare and Medicaid Services (CMS). Although CMS generally dictates health care reimbursement for enrollees ≥65 years of age, their costs can also be used to estimate reimbursements for other populations because they represent a national standard followed by most other health care insurers. We classified hospitalizations according to Diagnosis Related Groups (DRGs) and International Classification of Diseases, Ninth Revision (ICD-9) codes. The median cost of hospitalization for each DRG and ICD-9 code was derived from the 2006 national CMS data found on the US Department of Health and

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Human Service's Healthcare Cost and Utilization Project website. Professional fees for each procedure are coded using Current Procedural Terminology (CPT) codes. All procedures were assumed to occur in the inpatient setting; therefore, outpatient costs were not used. The CPT codes we used were identified from the website of the American Medical Association (AMA). Professional fees for each procedure done within a treatment strategy were included in the total cost for that particular strategy.

For patients who underwent an ERCP without successful CBD cannulation, the cost of a diagnostic ERCP was used. For patients with CBD stones regardless of whether stone removal was successful, the cost of an ERCP with stone removal was used. Patients who returned to the hospital with evidence of retained CBD stones after discharge were assumed to have CBD stones and the cost of an ERCP with stone removal was used. Finally, in the LC alone strategy, if patients presented with symptoms of retained CBD stones, but no stones were identified on ERCP, the cost of an ERCP with sphincterotomy was used.

For patients who underwent an unsuccessful ERCP followed by rescue non-endoscopic stone removal (via either an open CBDE, laparoscopic CBDE, or transhepatic approach), the cost of an open CBDE was used. The cost of open CBDE is more expensive than either laparoscopic CBDE or transhepatic stone removal.

If a patient experienced complications during a hospitalization, the hospital DRG reflected this; there are two DRGs for each type of hospitalization, one with complications and co-morbidities and one without. Furthermore, micro costing was done to reflect the additional cost of complications for each procedure. For ERCP, LC, and LC with CBDE, the cost of complications was determined by taking a weighted average of the cost of managing the most common complications for a particular procedure (*ERCP:* pancreatitis, hemorrhage, cholangitis, and bowel perforation. *LC:* bile leak, wound hematoma/infection, intraabdominal hemorrhage, intraabdominal abscess, and need for reoperation. *LC with CBDE:* bile leak, wound hematoma/infection, intraabdominal hemorrhage, and intraabdominal abscess).

Length of Stay—The mean length of stay (LOS) for each DRG and ICD-9 code was used when available from the 2006 CMS data. The DRG for a cholecystectomy with CBDE includes pooled data from both open and laparoscopic approaches. Therefore, for the LC with CBDE strategy we used LOS data from a recently published clinical trial [43]. In that trial 61 patients were randomized to laparoscopic LC with CBDE and the average LOS was 5.3 days. This estimate was used for an uncomplicated hospital stay. For a complicated stay, 8.0 days was used as the estimated LOS because this would make the difference between a complicated and uncomplicated stay for LC with CBDE similar to the difference in length of stay for LC alone (2.7 days).

If a patient was discharged from the hospital after either a false-negative ERCP or IOC, and presented to the ED with signs and symptoms of retained CBD stones, the estimated LOS of 4.9 days was obtained from data on hospitalizations for the ICD-9 code for choledocholithiasis. For each uncomplicated ERCP, an additional day was added to the entire LOS and for each ERCP with complications, an additional 4 days was added.

The primary outcome of our analysis was the incremental cost-effectiveness ratio, defined as the ratio between the difference in costs and the difference in hospital LOS between competing strategies. If a strategy were both less costly and associated with a shorter LOS it was termed cost-saving and defined as a dominant strategy. If one strategy were more costly, but had a shorter length of stay, we calculated the cost per hospital day averted compared to a strategy that was less costly and associated with a longer length of stay. We

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used a one-way sensitivity analysis to observe the effect of changing the pretest probability of CBD stones on cost-effectiveness. The pretest probability of CBD stones was varied from 0-100% and the cost and LOS of each of the five strategies were compared at each pretest probability. One-way sensitivity analyses were done by varying the health input estimates and the costs (Table 1) while keeping the probability of CBD stones at 10%. For the health inputs, the lowest estimate and the highest estimate from current published literature were used. When empiric data are not available, standard sensitivity analyses double and half any given input. Therefore, for the costs, each was doubled and halved and the sensitivity and specificity of IOC were halved and 100% was used as the upper estimate. The secondary outcome was a comparison of total costs of each strategy (cost-minimization).

RESULTS

Cost Minimization and Cost-Effectiveness

For the base case scenario, the LC with IOC ± ERCP strategy was cost-saving; it had was the least costly and had the shortest LOS (Table 2, Fig. 7A). Across the CBD stone probability range of 1%-100%, the LC with IOC ± ERCP strategy was least costly (Figure 8), and across the probability range of 4%-100% was also cost-saving.

If the probability of CBD stones was 0%, the LC alone strategy was cost-saving (Table 3). When the probability of CBD stones was 1%-3%, the LC alone strategy had the shortest LOS, but the LC with IOC ± ERCP strategy was the least costly. The cost per hospital day averted using the LC alone strategy increased as the probability of CBD stones increased from 1%-3%.

As the probability of CBD stones increased beyond 90%, the preoperative ERCP and the postoperative ERCP strategies had costs and LOS similar to the LC with IOC ± ERCP strategy (Table 4). The LC with IOC ± ERCP strategy dominated the other two strategies up to and including a probability of 100%. However, the cost difference between these two strategies and the LC with IOC ± ERCP strategy decreased as the probability of CBD stones increased.

Sensitivity Analyses

When the health inputs for ERCP, LC, and LC with CBDE were varied according to the range of values found in the literature (Table 1), LC with IOC ± ERCP was consistently cost-saving except for one scenario. If the specificity of IOC was halved, the LC with IOC ± ERCP was the least costly, but had a slightly longer LOS ($7988, LOS 3.8 days) than the LC alone strategy ($8243, LOS 3.1 days) (Fig. 7B). Cost-effectiveness was determined by calculating the cost per hospital day averted for LC alone compared to LC with IOC ± ERCP. The cost per hospital day averted with the LC alone strategy was $364 (Fig. 7B).

In addition, three costs determined which strategy was the least expensive: cost of hospitalization for LC with CBDE without complications (DRG 196), cost of hospitalization for LC without CBDE without complications (DRG 494), and cost of LC with IOC (CPT 47563). If the cost of hospitalization for LC with CBDE without complications (DRG 196) is halved, then LC with IOC ± CBDE became the least costly. However, this strategy had the longest LOS (Fig. 7C). Cost-effectiveness was determined by calculating the cost per hospital day averted for each of the other strategies compared to LC with IOC ± CBDE. The cost per hospital day averted was $472 for LC with IOC ± ERCP, $768 for LC alone, $2,437 for preoperative ERCP, and $2,443 for postoperative ERCP.

If the cost of hospitalization for LC without CBDE without complications (DRG 494) is doubled, the LC with IOC ± CBDE strategy was the least costly, but had the longest LOS

(Fig. 7D). Accordingly, the cost per hospital day averted was $965 for LC with IOC ± ERCP, $1,348 for LC alone, $3,211 for preoperative ERCP, and $3,217 for postoperative ERCP.

The third cost that affected which strategy was most cost-effective was the cost of LC with IOC (CPT 47563). If this cost was doubled, but the cost of LC (without IOC or CBDE) remained unchanged, the LC alone strategy became the least expensive ($8,243, 3.1 days) (Fig. 7E). However, the LC with IOC ± ERCP was also inexpensive and had a slightly shorter LOS ($8,307, 2.9 days). The cost per hospital day averted with LC with IOC ± ERCP was $319.50.

DISCUSSION

We found that the most cost-effective treatment for patients with symptomatic cholelithiasis when the probability of CBD stones is 4%-100% is LC with IOC and postoperative ERCP if stones are detected on IOC. If the probability of CBD stones is 0%, LC alone is the most cost-effective approach. However, at the extremes of CBD stone probabilities, the differences in cost and LOS between the LC with IOC and postoperative ERCP strategy and some of the other strategies were small, and therefore may not be financially meaningful, rendering these strategies essentially equivalent. In addition to the probability of CBD stones, our model was sensitive to one health input: specificity of IOC, and three costs: cost of hospitalization for LC with CBDE (without complications), cost of hospitalization for LC without CBDE (without complications), and cost of LC with IOC.

The NIH state-of-the-science statement on ERCP for diagnosis and therapy supports the use of IOC for patients with suspected CBD stones [4]. In patients with CBD stones, this statement indicates that laparoscopic CBDE and postoperative ERCP are comparable in safety and clearing stones from the CBD duct [4]. However, the consensus panel proposes that postoperative ERCP appears to be associated with greater health care cost and longer LOS, and suggests that laparoscopic CBDE is more efficient and preferable when surgical proficiency is available [4]. In our analysis, a key determinant of treatment strategy cost was the cost of hospitalization. From the third party payer perspective taken by our analysis, the cost of hospitalization for patients undergoing CBDE in addition to cholecystectomy is much higher than for those undergoing cholecystectomy without CBDE. The cost difference between these two DRGs was large enough to render the laparoscopic CBDE approach not cost-effective. In addition, laparoscopic CBDE is unavailable at many institutions because it requires advanced surgical expertise, whereas expertise in ERCP is more readily available in most US hospitals [44].

Our results suggest that IOC should be used across a wide range of CBD stone probabilities. This finding has two implications. First, many studies have tried to devise clinical scoring systems to determine the probability of CBD stones in patients with cholelithiasis [45-50]. However, our results suggest that it is cost-effective to use IOC across almost the entire probability range (4%-100%) of CBD stones. At a 2% probability of CBD stones, the LC alone strategy would cost $746 per hospital day averted compared to LC with IOC ± ERCP. Similarly, at a 3% probability, it would cost $1,421. Perhaps the additional cost may not be worth the decrease in LOS, and LC with IOC ± ERCP may be preferred if the probability of CBD stones is 2%-3%. According to our analysis, it is important to identify those patients with a 0%-1% probability of CBD stones so that these patients can avoid IOC and can undergo LC alone followed by expectant management. Jaundice, abnormal liver chemistries, and ductal dilatation seen on ultrasound are indicators of common bile duct stones. If none of these are present, then it is highly unlikely that CBD stones are present[4]. One study of biochemical predictors of the absence of CBD stones reported that patients with a normal

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serum gamma glutamyl transferase (GGT) had a 2.1% risk of CBD stones (negative predictive value of 97.9%)[49]. Therefore, perhaps patients with a normal GGT may be best treated with LC followed by expectant management. Additional studies of predictors of the absence of CBD stones are needed to help to determine which patients should undergo LC followed by expectant management and which should undergo LC with IOC ± ERCP.

The second implication of our findings is that surgeons striving for the most cost effective care should routinely perform IOC. However, in a recent survey of members of the American College of Surgeons, only 381 surgeons out of 1,411 (27%) considered themselves routine (versus selective) IOC users [51]. Some surgeons do not use IOC because they believe it adds too much time to the operation or is too costly, and that this is not worth the potential benefit. Two prospective studies reported that it takes about 15 minutes to perform an IOC [52, 53], and surgeons who used IOC routinely reported faster IOC completion times than selective IOC users [51]. From a cost perspective, two studies found that routine use of IOC during LC was cost-effective for preventing CBD injury [54, 55]. In our study, the use of IOC in addition to LC added little extra cost. However, the use of CBDE in addition to LC added significantly more cost because the use of CBDE changes the DRG for the hospitalization.

One major advantage of using IOC routinely is that the sensitivity (97%) and negative predictive value (99%) are high [27]. Therefore, if CBD stones are present they should be detected on IOC and a normal IOC almost always means that the CBD is clear. A negative IOC can prevent patients from undergoing unnecessary attempts at CBD clearance [56] and patients can be reassured that the risk of complications from retained CBD stones is extremely low.

The natural history of CBD stones is not well-defined [3, 57]. The results of one study suggest that not all patients with CBD stones found at the time of IOC will need to be removed via postoperative ERCP because some CBD stones will pass spontaneously [58]. However, there is no way to predict which CBD stones will pass and which will lead to costly complications such as pancreatitis or cholangitis.

We did not include patient preferences (health state utilities) in our model for three reasons. First, we assumed that asymptomatic choledocholithiasis would not cause long-term changes in quality of life. Second, we assumed the disability incurred by each treatment strategy, including missed diagnoses of choledocholithiasis, would be included in the denominator of the cost-effectiveness analysis where the cost per hospital day averted was examined. Third, there are no published data for patient preferences for choledocholithiasis, symptomatic or asymptomatic, and we did not want to include invalidated data in the model. Health state utilities would likely impact this analysis and further research on this topic is needed.

Our analysis provides a unique evaluation of the therapeutic options for patients with possible CBD stones because it differs from prior studies in three important ways. First, prior studies modeled scenarios that are not as widely applicable as ours. One study compared ERCP with laparoscopic CBDE for incidentally discovered CBD stones on IOC at the time of LC [8]. Since most surgeons do not use IOC routinely, that study represents a small proportion of all patients undergoing LC [51]. Another study compared several strategies, but each was modeled for two different scenarios, one in which CBD stones were present, and one in which they were absent [9]. Our study examines the decision-making process more broadly than these studies because we started with the more common clinical scenario of a patient with symptomatic cholelithiasis who may or may not have CBD stones. Second, one previous study assumed that there were no procedural deaths and the only complications considered were pancreatitis after ERCP and bile leak after laparoscopic

CBDE [8]. We included the risk of death and any complication that increased cost or LOS for each diagnostic and therapeutic procedure in our model. This is important because clinicians decide which procedures to use by considering the associated risks and benefits. Finally, most of these studies used institution costs or costs from the provider perspective [8, 59, 60]. Only one study [9], in addition to ours, used a third-party payer perspective. Using national Medicare data for the costs makes our results more generalizable across the United States.

The only analysis besides ours to vary the probability of CBD stones found that LC followed by expectant management was the most cost-effective strategy at a CBD stone risk between 0 and 11%; above 55%, ERCP was the most cost-effective [59]. If the risk was between 12% and 54%, endoscopic ultrasound (EUS) was the most cost-effective. If EUS was not available, IOC became the most cost-effective if the risk was between 17% and 34% [59]. Both EUS and magnetic resonance cholangiopancreatography (MRCP) are accurate for detecting CBD stones[61, 62]. However, we excluded these modalities from our model because we only included modalities that could be used to both diagnose and treat CBD stones. In addition, that study stated that ERCP was superior to IOC and therefore used a higher sensitivity and specificity for ERCP than IOC. Whereas, in our study, we used test characteristics from current literature and the sensitivity and specificity of IOC are higher than that of ERCP. Finally, in that study the cost perspective is that of the provider and in our study the cost perspective is that of a third party. The most cost-effective diagnostic and therapeutic strategies from the provider perspective may not be the same as those from a third party perspective.

In conclusion, the most cost-effective treatment strategy for the majority of patients with symptomatic cholelithiasis (4%-100% probability of CBD stones) is LC with routine IOC. If stones are detected, CBDE should be forgone and the patient referred for ERCP. For those patients with a 0% probability of CBD stones, LC alone followed by expectant management is the most cost-effective strategy.

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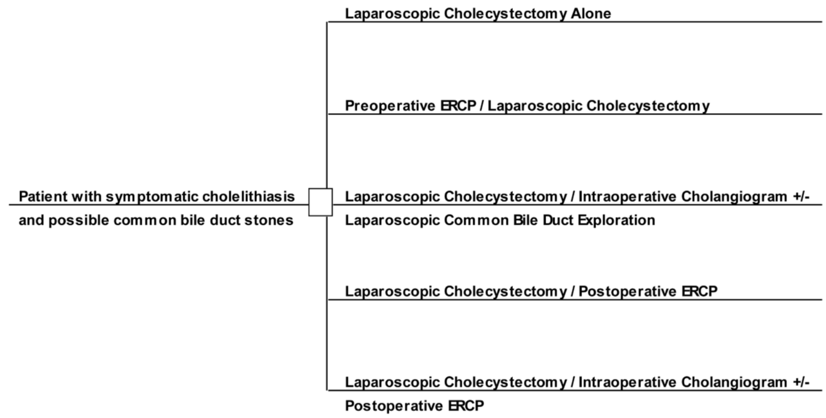

Figure 1.
Decision model including five treatment strategies for patients with symptomatic cholelithiasis and possible common bile duct stones.

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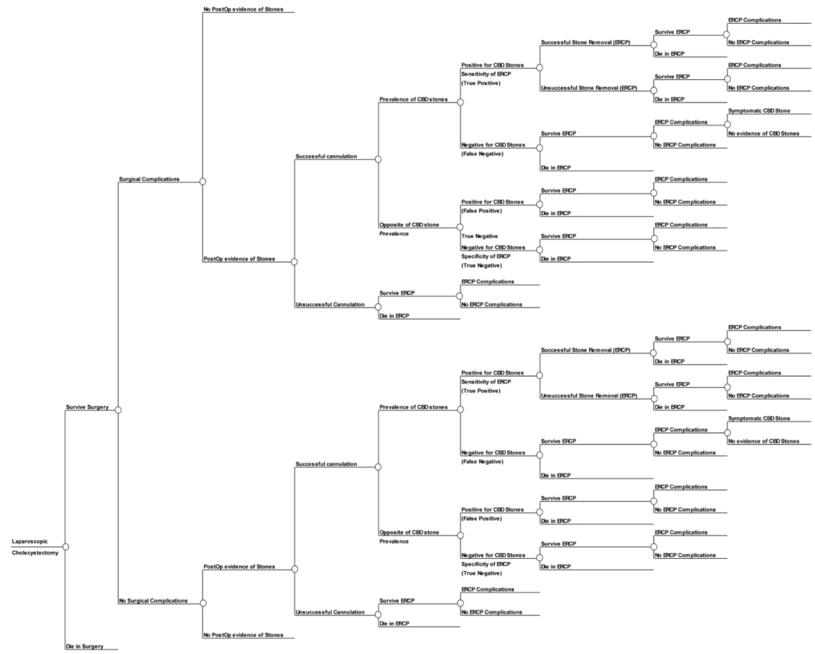

Figure 2.

Laparoscopic cholecystectomy alone followed by expectant management (online only).

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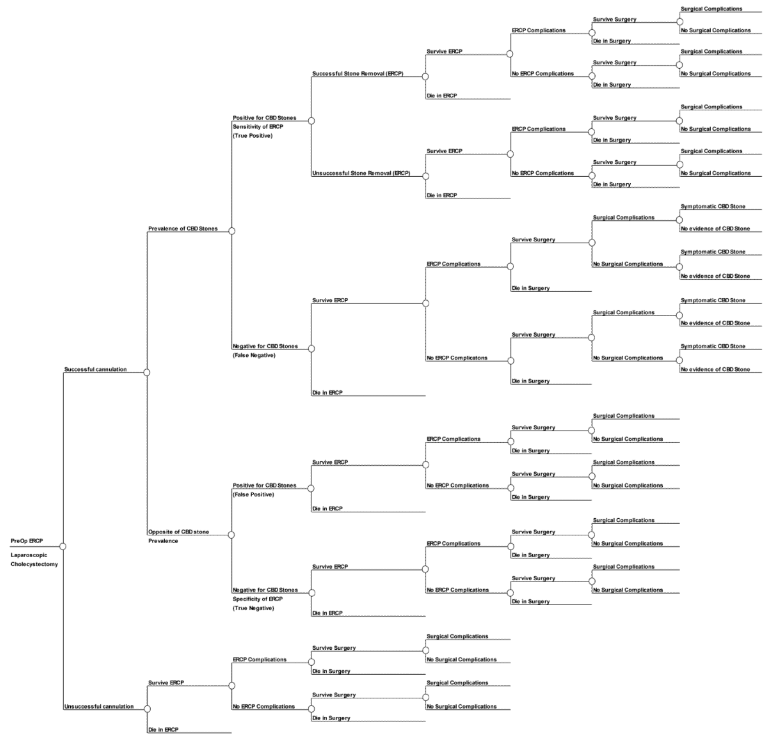

Figure 3.
Preoperative ERCP followed by laparoscopic cholecystectomy (online only).

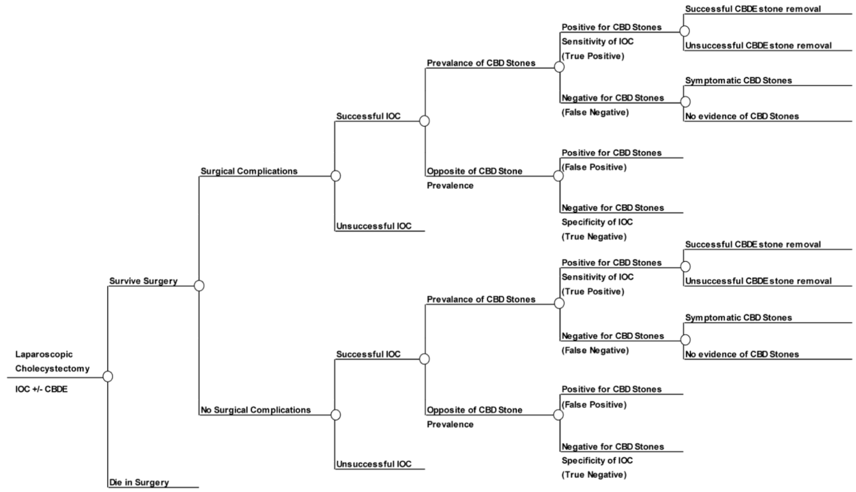

Figure 4.
Laparoscopic cholecystectomy and intraoperative cholangiogram ± laparoscopic CBDE (online only).

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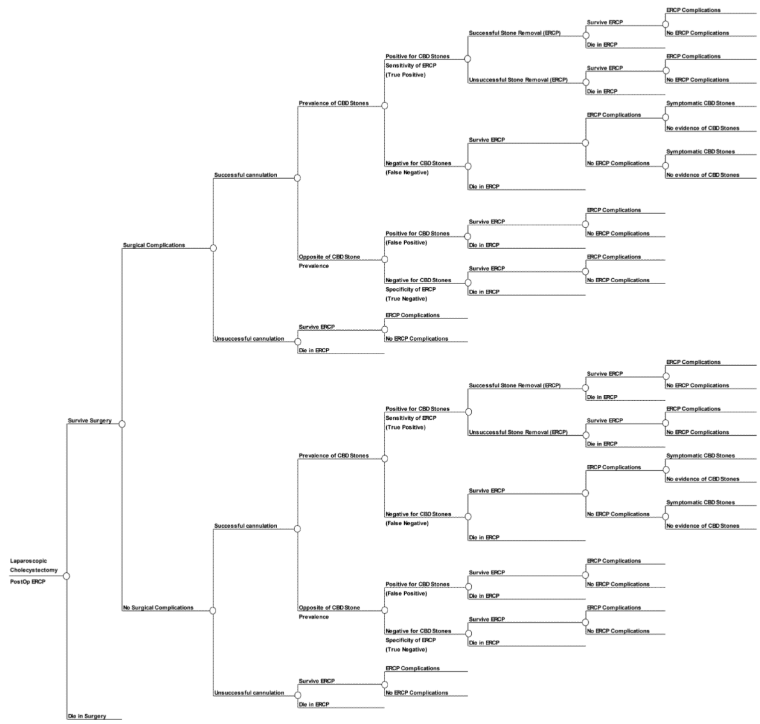

Figure 5.
Laparoscopic cholecystectomy followed by postoperative ERCP (online only).

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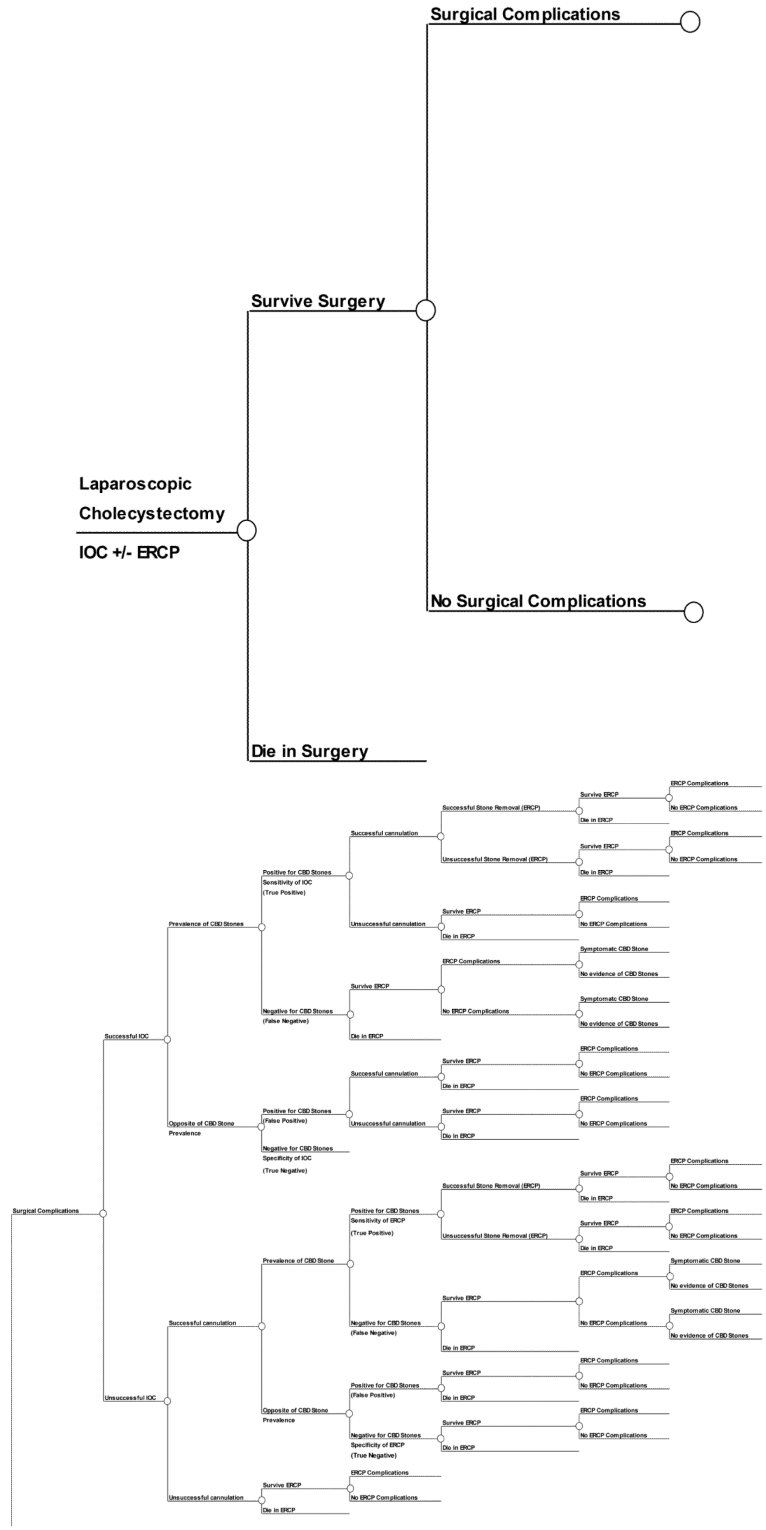

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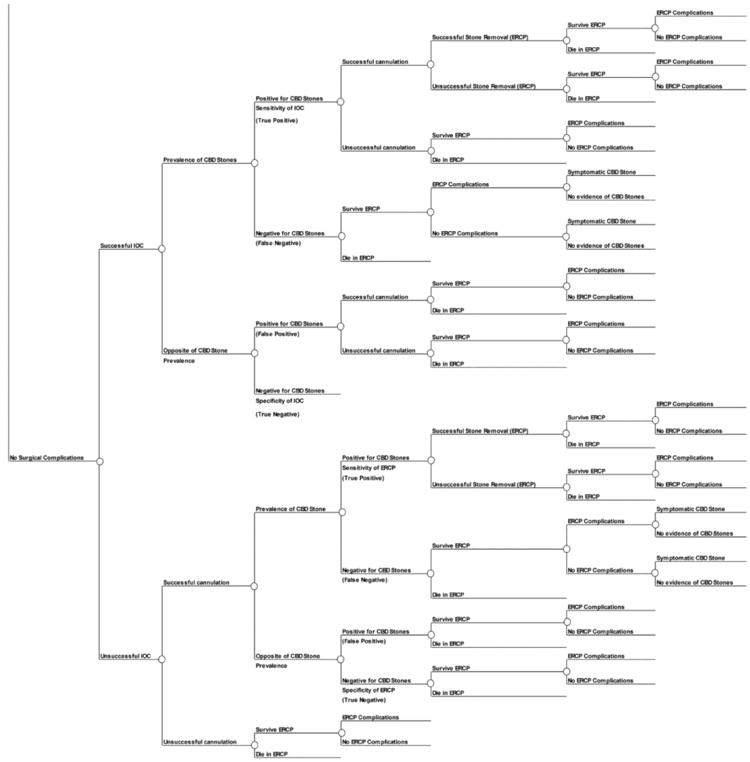

Figure 6.
Laparoscopic cholecystectomy and intraoperative cholangiogram ± postoperative ERCP (online only).

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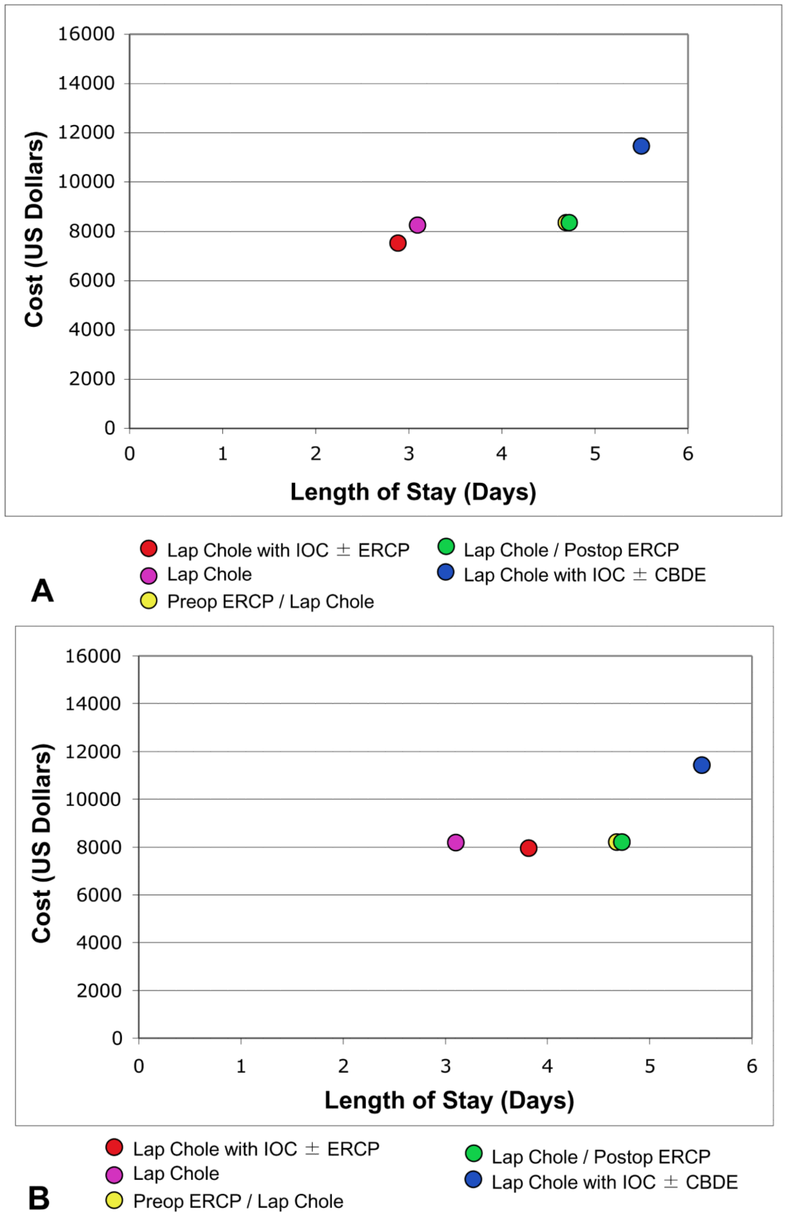

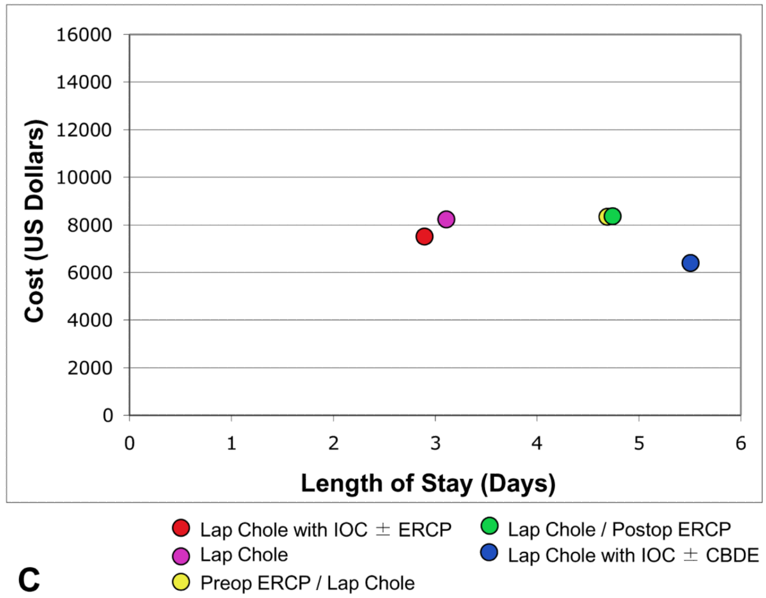

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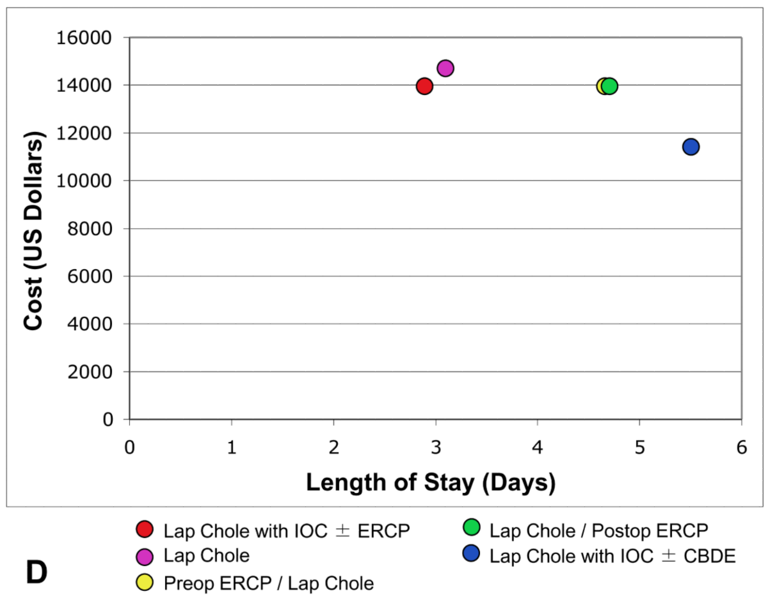

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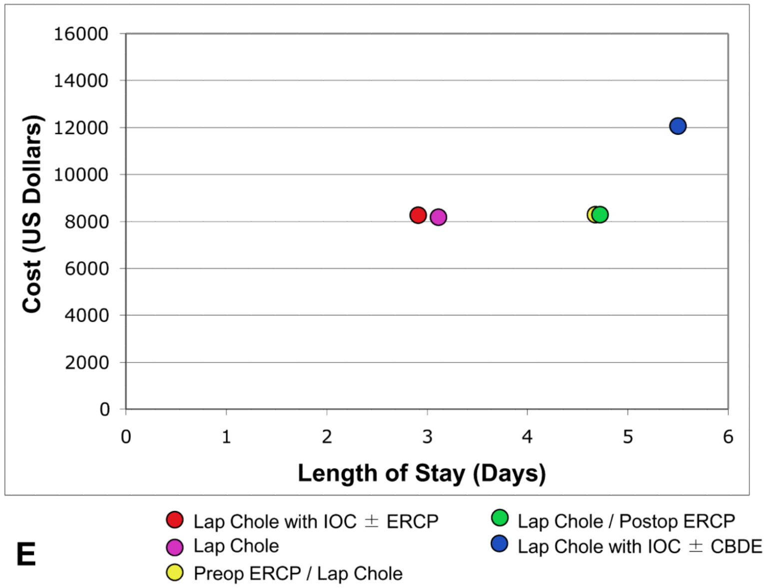

Figure 7.

(A) Cost and length of stay for the five treatment strategies at a common bile duct stone pretest probability of 10%. The costs and lengths of stay for preoperative ERCP / laparoscopic cholecystectomy and laparoscopic cholecystectomy / postoperative ERCP are similar, therefore these circles overlap in each of these figures. (B) Cost and length of stay for the five treatment strategies with the specificity of IOC halved. (C) Cost and length of stay for the five treatment strategies with the diagnosis-related group (DRG) cholecystectomy with CBDE without complications and co-morbidities halved. (D) Cost and length of stay for the five treatment strategies with the DRG laparoscopic cholecystectomy without CBDE without complications and co-morbidities doubled. (E) Cost and length of stay for the five treatment strategies with the cost of laparoscopic cholecystectomy with IOC doubled.

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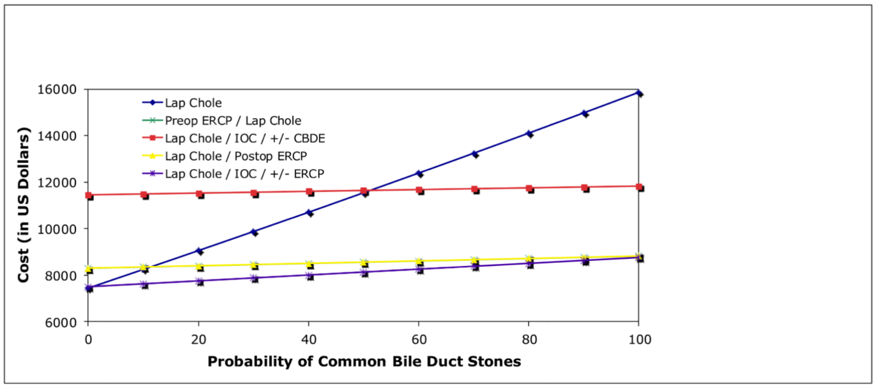

Figure 8.
Cost of five treatment strategies by probability of common bile duct stones. The costs of Preop ERCP / Lap Chole and Lap Chole / Postop ERCP are similar, therefore these two lines overlap.

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Table 1

Health Inputs, Costs, and Lengths of Stay for the Cost-Effectiveness Model

	Base	Low	High
Prevalence of CBD stones	10%	0%	100%
ERCP			
Cannulation[10-15]	94.4%	83%	99.5%
Sensitivity[16]	96.0%	Not varied	Not varied
Specificity[16]	92.0%	Not varied	Not varied
Stone removal[6, 7, 17-24]	94.0%	71%	98%
Complications[25, 26]	11.3%	10.2%	13.5%
Mortality[19, 23, 25, 26]	0.7%	0.4%	1%
Laparoscopic cholecystectomy with IOC and CBDE			
Cannulation[27]	95.9%	Not varied	Not varied
Sensitivity[27]	97.0%	48.5%	100%
Specificity[27]	99.0%	49.5%	100%
Stone Removal[1, 6, 7, 27-32]	91.1%	75%	97.3%
Complications[1, 7, 28, 29, 42]	3.2%	1.4%	15.8%
Mortality[1, 6, 29, 42]	0.3%	0.2%	0.9%
Laparoscopic cholecystectomy			
Complications[33-41]	2.6%	1.3%	7.1%
Mortality[1, 6, 29, 42]	0.3%	0.2%	0.9%
Costs			
Diagnostic Related Groups			
Chole with CBDE with complications and co-morbidities (195)	$15,732	$7,866	$31,464
Chole with CBDE without complications and co-morbidities (196)	$10,554	$5,277	$21,108
Lap Chole without CBDE with complications and co-morbidities (493)	$9,696	$4,848	$19,392
Lap Chole without CBDE without complications and co-morbidities (494)	$6,678	$3,339	$13,356
Choledocholithiasis (ICD-9 code 574.51)	$7,411	$3,705.50	$14,822
Current procedural terminology (CPT) codes			
ERCP			
ERCP, diagnostic (43260)	$403.80	$201.90	$807.60
ERCP, with sphincterotomy/papillotomy (43262)	$498.59	$249.30	$997.18
ERCP, with endoscopic removal of calculus/calculi from biliary ducts (43264)	$598.56	$299.28	$1,197.12
Laparoscopy			
Lap Chole (47562)	$663.99	$332.00	$1,327.98
Lap Chole with IOC (47563)	$680.58	$340.29	$1,301.16
Lap Chole with CBDE (47564)	$786.97	$393.49	$1,573.94
Non-endoscopic stone removal			
Open Chole with exploration of the common duct (47610)	$1,129.25	$564.63	$2,258.50
Lap Chole with exploration of the common duct (47564)	$786.97	Not varied	Not varied
Biliary endoscopy, percutaneous via T-tube or other tract; with removal of calculus/calculi (47554)	$485.82	Not varied	Not varied

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	Base	Low	High
Complications			
ERCP complications	$273.60	$136.80	$547.20
Lap Chole complications	$384.30	$192.15	$656.62
Lap Chole with CBDE complications	$328.31	$164.16	$656.62
Costs of individual complications			
Pancreatitis			
Resection or debridement of pancreas and peripancreatic tissue for acute necrotizing pancreatitis (48105) Intraabdominal hemorrhage/abscess	$2,570.11	Not varied	Not varied
Exploration of the abdomen for postoperative hemorrhage, thrombosis, or infection (35840)	$622.15	Not varied	Not varied
Cholangitis			
ERCP, wtih sphincterotomy/papillotomy (43262)	$415.49	Not varied	Not varied
Bowel perforation			
Suture of small bowel for injury, single perforation (44602)	$1,237.81	Not varied	Not varied
Bile leak			
Introduction of percutaneous transhepatic catheter for biliary drainage (47510)	$481.13	Not varied	Not varied
ERCP with insertion of stent into bile duct (43268)	$498.80	Not varied	Not varied
Wound infection/hematoma			
Incision and Drainage, complex, postoperative wound infection (10180)	$161.58	Not varied	Not varied
Length of stay, d			
Diagnostic related groups			
Chole with CBDE with complications and co-morbidities (195)	8		
Chole with CBDE without complications and co-morbidities (196)	5.3		
Lap Chole without CBDE with complications and co-morbidities (493)	5.2		
Lap Chole without CBDE without complications and co-morbidities (494)	2.5		
ICD-9 Code			
Choledocholithiasis (574.51)	4.9		
Additional length of stay for specific procedure, d			
ERCP	1		
ERCP with complications and co-morbidities	4		
Non-endoscopic stone removal (Open CBDE, Lap CBDE, or transhepatic stone removal)	5.1		

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Table 2

Base Case Analysis: 10% Probability of Common Bile Duct Stones

Treatment strategy	Cost, US $	Length of stay, d	Incremental cost-effectiveness ratio, US $
Lap Chole / IOC ± ERCP	7,626	2.9	
Lap Chole Alone	8,243	3.1	Dominated*
Preop ERCP / Lap Chole	8,349	4.7	Dominated
Lap Chole / Postop ERCP	8,354	4.7	Dominated
Lap Chole / IOC ± LCBDE	11,492	5.5	Dominated

*Dominated, the strategy is both more costly and is associated with a longer LOS than another strategy.

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Table 3

Cost, Length of Stay, and Cost per Hospital Day Averted for Two Treatment Strategies by Probability of Common

Probability of CBD Stones, %	Lap Chole alone		Cost per hospital day averted* (US $)	Lap Chole / IOC ± ERCP	
	Cost, US $	LOS, d		Cost, US $	LOS, d
0	7,440	2.6	Lap Chole / IOC ± ERCP Strategy Dominated	7,500	2.7
1	7,520	2.6	72	7,513	2.7
2	7,600	2.7	746	7,526	2.8
3	7,680	2.7	1,421	7,538	2.8
4	7,760	2.8	Lap Chole Alone Strategy Dominated	7,551	2.8

* Cost per hospital day averted using the Lap Chole Alone strategy.

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Table 4

Cost, Length of Stay, and Cost Difference for Three Treatment Strategies by Probability of Common Bile Duct

Probability of CBD stones, %	Preop ERCP / LC		(Preop ERCP/LC Cost) - (LC/IOC ± ERCP Cost) , US $	LC/ IOC ± ERCP		(LC/Postop ERCP Cost) - (LC/IOC ± ERCP Cost), US $	LC / Postop ERCP	
	Cost, US $	LOS, d		Cost, US $	LOS, d		Cost, US $	LOS, d
90	8,767	5.1	133	8,634	4.8	137	8,771	5.1
92	8,777	5.1	118	8,659	4.8	122	8,781	5.1
94	8,787	5.1	103	8,685	4.9	107	8,792	5.1
96	8,798	5.1	88	8,710	4.9	92	8,802	5.1
98	8,808	5.1	73	8,735	5.0	78	8,813	5.1
100	8,819	5.1	59	8,760	5.0	63	8,823	5.1