Optimizing Choledocholithiasis Management

A Cost-effectiveness Analysis

Benjamin K. Poulose, MD, MPH; Ted Speroff, PhD; Michael D. Holzman, MD, MPH

Hypothesis: Endoscopic retrograde cholangiopancreatography (ERCP) is more cost-effective for managing incidental choledocholithiasis (CDL) after laparoscopic cholecystectomy and intraoperative cholangiogram (LC/IOC) than laparoscopic common bile duct exploration (LCBDE).

Design: A cost-effectiveness analysis was performed to compare ERCP with LCBDE. Sensitivity analyses were performed to determine the key contributors to cost-effectiveness between the 2 treatment options.

Setting: Costs were approached from the institutional perspective considering a typical patient undergoing LC/IOC at a large referral center.

Patients: The base case patient evaluated was a woman 18 years of age or older with symptomatic cholelithiasis and incidental CDL discovered at the time of LC/IOC.

Interventions: Endoscopic retrograde cholangiopancreatography with drainage procedure performed after LC/IOC or LCBDE during LC/IOC.

Main Outcome Measures: Costs, quality-adjusted life years gained, mean cost-effectiveness ratios, and incremental cost-effectiveness ratios.

Results: In the base case analysis, ERCP was the optimal treatment choice with a cost of $24,300 for 0.9 quality-adjusted life years gained compared with $28,400 and 0.88 quality-adjusted life years for LCBDE. Endoscopic retrograde cholangiopancreatography remained the optimal strategy for CDL in multiway probabilistic sensitivity analysis. If LCBDE were performed and the cost of a potential operative case lost was $3100 or less and the cost of ERCP hospitalization was $18,000 or more, then LCBDE became the preferred treatment for CDL.

Conclusions: Endoscopic retrograde cholangiopancreatography was both less costly and more effective than LCBDE. Factors important to choosing the best strategy for CDL management included the cost of a potential case lost due to LCBDE performance and the cost of ERCP hospitalization.

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Both endoscopic retrograde cholangiopancreatography (ERCP) with drainage procedure and laparoscopic common bile duct exploration (LCBDE) have been deemed safe and reliable methods for treating choledocholithiasis (CDL) after laparoscopic cholecystectomy. Randomized controlled trials have shown differences in length of stay between these procedures without detectable differences in cost. However, these studies lack the power to make firm conclusions about cost. In addition, these studies do not account for the variations in costs, probabilities of ductal clearance, and complications in the published literature. These variations or this “uncertainty” ultimately describes a range of values within which the true value is assumed to exist. This uncertainty is implicit to the individual surgeon’s treatment choice and can be quantitatively incorporated into the decision-making process using cost-effectiveness analysis techniques. In this study, a cost-effectiveness analysis was performed to determine the best treatment of CDL from an institutional perspective while accounting for the uncertainty inherent to determining the optimal therapy.

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time of LC/IOC. Base case analysis with incremental cost-effectiveness determination was performed for a typical woman 18 years or older undergoing LC/IOC. One-way, 2-way, and multiway sensitivity analyses were undertaken to incorporate the uncertainty in model parameters and to determine the impact of key variables on cost-effectiveness. Guidelines set forth by the Panel on Cost-Effectiveness in Health and Medicine were followed for performance of cost-effectiveness analysis.5

**DECISION MODEL**

TreeAge Pro 2005 software (TreeAge Software Inc, Williams-town, Mass) was used to construct a decision model of CDL management. This model determined the optimal treatment strategy between ERCP (with bile duct drainage procedure) and LCBDE using costs, effectiveness measures, and probabilities of success and complications. To make modeling practicable, the following assumptions were made:

1. Patients underwent LC/IOC without complications.
2. No preoperative suspicion of CDL, pancreatitis, or cholangitis was present.
3. Procedural death (for all procedures) was not considered.
4. Laparoscopic common bile duct exploration was performed by the transcyrstic method.
5. Complications were limited to mild or severe pancreatitis (ERCP) and bile leak (LCBDE).
6. Rescue procedure for either strategy was ERCP with 100% success with similar risk of pancreatitis as nonrescue ERCP.
7. All patients survived through the total study time horizon of 1 year.

**PATIENT POPULATION AND BASE CASE**

The intended population for this analysis was a typical female patient 18 years of age or older with symptomatic cholelithiasis and incidental CDL discovered at the time of LC/IOC. Base case costs, health preferences, and probabilities are summarized in Table 1.

**COSTS**

Cost estimates from an institutional perspective were derived from 2 main sources: published data from cost-effectiveness analysis and cost estimates from the 2002 Nationwide Inpatient Sample (NIS). All monetary values were adjusted to 2004

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**Table 1. Variables and Sources**

<table>
<thead>
<tr>
<th>Source</th>
<th>Variable</th>
<th>Procedures</th>
<th>Complications</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Probability/Other</td>
<td>Cost, $*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>4074 (3000-6000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>1713 (600-2400)</td>
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<tr>
<td></td>
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<td>NA</td>
<td>2279 (1200-3600)</td>
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<tr>
<td></td>
<td></td>
<td>NA</td>
<td>16 978 (14 000-20 000)</td>
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<tr>
<td></td>
<td></td>
<td>0.91 (0.8-0.999)</td>
<td>NA</td>
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<td></td>
<td></td>
<td>NA</td>
<td>13 01 (600-2400)</td>
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<td></td>
<td></td>
<td>NA</td>
<td>12 82 (10 000-16 000)</td>
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<tr>
<td></td>
<td></td>
<td>0.81 (0.6-0.9)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NA</td>
<td>4074 (1000-7000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.04 (0.01-0.05)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.89</td>
<td>2169</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.11 (0.05-0.15)</td>
<td>6508 (2400-24 000)</td>
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<td></td>
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<td>0.01 (0.0-0.05)</td>
<td>1401 (600-3600)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5 (0.2-0.8)</td>
<td>NA</td>
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*Utilities describe the value of a given health state based on a scale of 0 (death) to 1 (perfect health).
†Utilities are reported in 2004 US dollars; costs for procedures represent cost in addition to LC/IOC cost.
‡Opportunity cost represents the amount of money lost to the institution for performing LC/IOC with LCBDE as opposed to LC/IOC alone; for the base case, opportunity cost was the cost of an LC/IOC that may have otherwise been performed had LCBDE not been performed.

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**Abbreviations:** EO, expert opinion; ERCP, endoscopic retrograde cholangiopancreatography; LCBDE, laparoscopic common bile duct exploration; LC/IOC, laparoscopic cholecystectomy with intraoperative cholangiogram; NA, not available or applicable.

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US dollars using the consumer price index for medical care.12 The NIS Medicare population was used to estimate the inpatient cost of hospitalization for patients with a diagnosis of CDL who underwent either ERCP or common bile duct exploration as inpatients. Identification of procedures and diagnoses was accomplished using codes from the International Classification of Diseases, Ninth Revision, Clinical Modification, with appropriate accounting for the complex database structure of the NIS. Because the NIS includes total hospital charges, costs were estimated using Medicare cost-charge ratios (capital cost-charge ratio + operating cost-charge ratio) as described by Radensky et al.13 For 2002, the total cost-charge ratio for Medicare patients was 0.58.14 Because costs were approached from the institutional perspective, the study accounted for the opportunity cost of performing LCBDE. This cost represented the dollar amount equal to the best alternative use of operative time.15 In this case, the opportunity cost was the cost of an LC/IOC that may have otherwise been performed had LCBDE not been performed. The cost of mild pancreatitis was estimated to be one third the cost of severe pancreatitis. The cost of hospitalization of additional procedures performed beyond the initial LC/IOC and either ERCP or LCBDE was estimated at 50% of the stand-alone procedure cost.

EFFECTIVENESS

Effectiveness was measured in terms of quality-adjusted life years (QALYs), which provide a composite value of both time and quality of life. Calculation of QALYs are based on health utilities determined by standard methodology assigning diagnoses and procedures a value ranging from 0 (utility of death) to 1 (utility of perfect health). Health utilities serve as a simplified metric for quality of life; the values used for this study are summarized in Table 1. Quality-adjusted life years incorporate both time (years) and quality of life (health utility) and are calculated by multiplying the health utility by the total time spent in a given health state. In this study, all patients were assumed to survive for an entire year after undergoing the initial LC/IOC. Because only a 1-year time horizon was considered, discounting was not performed.

ANALYSIS

Base case analysis consisted of expected value calculation of cost, effectiveness, cost-effectiveness ratios, and incremental values. One-way and 2-way sensitivity analyses were performed to identify variables that impacted cost-effectiveness of a given treatment strategy. In addition, sensitivity analyses were used to evaluate the influence of variable values with increased uncertainty (eg, those derived by expert opinion). To integrate higher levels of uncertainty often encountered in clinical practice, multiway probabilistic sensitivity analysis using Monte Carlo methods was used. Twenty-one discrete values used in the original base case analysis were replaced with triangular distributions with peak values equal to the base case values and ranges equal to 1-way sensitivity analysis ranges. In this way, multiple ranges of costs, effectiveness, and probabilities could be analyzed simultaneously. One thousand samples of each distribution were taken and expected values were calculated.

RESULTS

BASE CASE ANALYSIS AND MODEL CONFIRMATION

For the base case scenario, ERCP with drainage procedure was both less costly and more effective than LCBDE (Table 2), making ERCP the dominant strategy of choice. Laparoscopic common bile duct exploration cost an additional $4100 compared with ERCP while ERCP gained an additional 0.02 QALY. Extreme values were entered into the model to assess the predictability of the results. When the probability of ERCP-induced pancreatitis was 95% and the subsequent probability of having severe pancreatitis was also 95%, an appropriate rise in ERCP costs and decline in QALYs were observed. Conversely, when the cost of LCBDE was raised to $13 000, the overall cost of LCBDE management rose accordingly.

ONE-WAY AND 2-WAY SENSITIVITY ANALYSES

The model results were robust to changes in all cost and probabilities of events within plausible range 1-way sensitivity analyses. Health utilities of both diagnostic and therapeutic ERCP did impact incremental cost-effectiveness between ERCP and LCBDE, but ERCP remained the optimal strategy in these analyses (Figure 2 and Figure 3).

Two-way sensitivity analyses were performed for 2 variables that could change simultaneously. The model predicted 1 situation in which the optimal strategy for CDL management would be LCBDE instead of ERCP: if the opportunity cost of LCBDE was $3100 or less and the cost of ERCP hospitalization was $18 000 or more (Figure 3). In other words, if LCBDE were performed and the cost of a potential operative case lost was $3100 or less (because of the increased operating room time of LCBDE) and the cost of ERCP hospitalization was $18 000 or more, then LCBDE would be the treatment of choice for CDL.

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MULTIWAY SENSITIVITY ANALYSIS

In multiway sensitivity analyses, 21 discrete cost, utility, and probability values were replaced with triangular distributions to incorporate plausible ranges of these values within the model. In effect, all 21 variables were changed simultaneously in the model to encompass a high level of uncertainty with the decision to choose either ERCP or LCBDE for managing CDL discovered incidentally at LC/IOC. Table 3 summarizes the results of this probabilistic sensitivity analysis. As in the base case analysis, ERCP was less costly and more effective than LCBDE. Notably, costs were generally higher and QALYs were lower when compared with the base case results.

In this cost-effectiveness analysis of CDL treatment, ERCP was found to be less costly and more effective than LCBDE. These results were robust to the known levels of uncertainty in the decision model. Factors important to choosing the best strategy for CDL management included the cost of a potential case lost because of LCBDE performance and the cost of ERCP hospitalization.

The current cost and cost-effectiveness literature regarding CDL management presents conflicting results. In an informal cost analysis, Liberman et al\textsuperscript{10} showed that LCBDE ($14,700) was less costly than ERCP ($21,100) at a single institution. Urbach et al\textsuperscript{7} demonstrated the improved cost-effectiveness of LCBDE over ERCP for CDL from a payer perspective with ERCP reserved for situations in which LCBDE expertise was unavailable. Interestingly, this study found ERCP to be more costly and less effective than LCBDE. In contrast, Sahai et al\textsuperscript{16} evaluated diagnostic modalities of intraoperative cholangiogram, endoscopic ultrasound, and ERCP and determined that patients at “high risk” of having CDL should undergo ERCP. In a subanalysis of a prospective randomized trial, Stain et al\textsuperscript{4} found that, in the prelaparoscopic era, costs were equal for patients undergoing ERCP and sphincterotomy for CDL compared with surgery alone. Our initial national analysis of ERCP and LCBDE found that LCBDE was associated with decreased estimated costs and reduced length of stay compared with ERCP.\textsuperscript{17} These studies provided important insight into evaluating the cost-effectiveness of ERCP and operative management of CDL, but none approached costs from the institutional perspective and accounted for the

<table>
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<th>Figure 1. One-way sensitivity analysis of the health utility of diagnostic endoscopic retrograde cholangiopancreatography (ERCP) with cost in thousands of US dollars. As the health utility of ERCP diminishes, the incremental cost-effectiveness ratio between ERCP and laparoscopic common bile duct exploration (LCBDE) becomes smaller. QALY indicates quality-adjusted life year.</th>
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<tr>
<th>Figure 2. One-way sensitivity analysis of the health utility of therapeutic endoscopic retrograde cholangiopancreatography (ERCP) with cost in thousands of US dollars. As the health utility of ERCP diminishes, the incremental cost-effectiveness ratio between ERCP and laparoscopic common bile duct exploration (LCBDE) becomes smaller. QALY indicates quality-adjusted life year.</th>
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<th>Figure 3. Two-way sensitivity analysis on laparoscopic common bile duct exploration (LCBDE) opportunity cost and endoscopic retrograde cholangiopancreatography (ERCP) hospitalization cost with costs in thousands of US dollars. At low LCBDE opportunity costs and higher ERCP hospitalization costs, LCBDE becomes the preferred choice for choledocholithiasis.</th>
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</table>
In a large randomized trial, Suc et al \(^{18}\) compared endoscopic retrograde cholangiopancreatography (ERCP) with sphincterotomy and laparoscopic common bile duct exploration (LCBDE) for the treatment of choledocholithiasis (CDL). Their study randomizes 80 patients to ERCP with sphincterotomy or LCBDE, with the goal of evaluating the cost-effectiveness of these procedures from an institutional perspective. The results after randomizing 80 patients to ERCP with sphincterotomy or LCBDE became the most cost-effective choice for CDL. If the cost of ERCP hospitalization were important factors that impacted the optimal strategy choice. If the cost of a potential operative case not performed because of LCBDE were low and the cost of ERCP hospitalization high, then LCBDE became the most cost-effective choice for CDL. These data can be used by individual institutions to optimize the treatment strategy for CDL while considering their own available expertise in ERCP and LCBDE and the opportunity cost of LCBDE. In addition, no study incorporated higher levels of uncertainty through probabilistic sensitivity analysis. We aimed to advance our previous work by incorporating these elements and by defining variables that have significant impact on the choice between ERCP and LCBDE using cost-effectiveness analysis techniques.

Several randomized controlled trials have demonstrated similar efficacy between ERCP with sphincterotomy and LCBDE for the treatment of CDL. Cuschieri et al \(^{1}\) randomized 300 patients to receive either operative ERCP with subsequent LC or single-stage laparoscopic management (most with transcytic ductal clearance). This study showed 95% to 99% success with these procedures and reduced length of stay for the single-stage management group. Rhodes et al \(^{2}\) reported similar results after randomizing 80 patients to ERCP with sphincterotomy or LCBDE. In a large randomized trial, Suc et al \(^{18}\) showed a lower probability of additional procedures in CDL managed by surgery than by endoscopy. Minor complications occurred more often in the surgical group compared with endoscopy, but major complications were less with operations. In the present analysis, we sought to build on this knowledge by evaluating the cost-effectiveness of ERCP vs LCBDE from an institutional perspective. Although these 2 treatments are considered to have similar efficacy and effectiveness, these randomized trials did not have the power to detect sufficient numbers of adverse events to assess their impact on outcomes. For this reason, we deemed it necessary to incorporate effectiveness measures in this analysis instead of performing a cost minimization analysis.

This study has 2 important findings. First, ERCP (as opposed to LCBDE) was the optimal choice for incidentally discovered CDL from an institutional perspective at the time of elective LC/IOC—even in the face of high levels of uncertainty with the factors important to this decision. Second, the opportunity cost of LCBDE and the cost of ERCP hospitalization were important factors that impacted the optimal strategy choice. If the cost of a potential operative case not performed because of LCBDE were low and the cost of ERCP hospitalization high, then LCBDE became the most cost-effective choice for CDL. These data can be used by individual institutions to optimize the treatment strategy for CDL while considering their own available expertise in ERCP and LCBDE and the hospital resources. With 700,000 cholecystectomies performed each year in the United States, individualization of the treatment choice of incidental CDL based on these data may enhance hospital resource allocation in hopes of ultimately improving patient care.

The results of this study need to be interpreted within the context of its limitations. First, modeling an extremely complex process such as an individual patient’s operative and postoperative experience requires several assumptions to be practicable. We felt that the assumptions made in this cost-effectiveness analysis were reasonable, and we attempted to incorporate wide variations in these assumptions through our extensive sensitivity analyses. Also, costs were not obtained from a single source. Because of this, cost integration in the model was difficult. Nevertheless, we attempted to use data from published cost-effectiveness analyses to make our results comparable with results found in the literature. In addition, hospitalization costs were estimated from the NIS using cost-charge ratios. Although others have done this successfully, more precise hospitalization cost data would be ideal. We used a limited time horizon of 1 year in which all patients survived. This assumption affected our calculation of QALYs as each individual health utility was multiplied by this survival time. A longer time horizon may have more accurately incorporated the impact on mortality from complications. Another limitation concerns our modeling of the “rescue” ERCP. Should either ERCP or LCBDE fail initially, ERCP was performed as a second procedure for both treatment modalities and was assumed to have 100% success. We felt this was a reasonable assumption given that most patients’ common bile ducts would be cleared with 2 procedures. A small proportion would require common bile duct exploration, but this cost would be borne in both arms, essentially nullifying its overall effect on incremental cost-effectiveness. Finally, although our probabilistic sensitivity analysis did incorporate a high level of uncertainty, all distributions were modeled as triangular in shape. In reality, the individual patterns of a given variable may conform to other distributions (eg, normal, binomial, etc), but we deemed our approximation as acceptable to operationalize the probabilistic sensitivity analysis given the lack of information about most of the variables.

### Table 3. Multiway Sensitivity Analysis of Cost-effectiveness Between ERCP and LCBDE for Incidentally Discovered Choledocholithiasis*

<table>
<thead>
<tr>
<th>Operative Strategy</th>
<th>Cost, Mean (SD), $†</th>
<th>Incremental Cost, $</th>
<th>Effectiveness, Mean (SD), QALYs</th>
<th>Incremental Effectiveness, QALYs</th>
<th>Cost-effectiveness, $/QALY</th>
<th>Incremental Cost-effectiveness, $/QALY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERCP</td>
<td>24 900 (1600)</td>
<td>. . .</td>
<td>0.84 (0.05)</td>
<td>. . .</td>
<td>29 600</td>
<td>. . .</td>
</tr>
<tr>
<td>LCBDE</td>
<td>29 800 (2400)</td>
<td>4900</td>
<td>0.82 (0.05)</td>
<td>−0.02</td>
<td>36 300</td>
<td>Dominated‡</td>
</tr>
</tbody>
</table>

Abbreviations: ERCP, endoscopic retrograde cholangiopancreatography with drainage procedure; LCBDE, laparoscopic common bile duct exploration; QALYs, quality-adjusted life years.

*Multiway sensitivity analysis replaced 21 discrete cost, utility, and probability values with probability distributions based on plausible ranges; these probability distributions were sampled 1000 times with expected value calculations for each sampling of the 21 distributions using Monte Carlo methods.

†Costs are reported in 2004 US dollars.

‡Incremental cost-effectiveness was not calculated because LCBDE was dominated by ERCP, which was less costly and more effective than LCBDE.
an institutional perspective. These results were consistent even while incorporating known levels of uncertainty in the decision process. Important factors in choosing the best strategy for CDL management included the cost of a potential case lost because of LCBDE performance and the strategy for CDL management included the cost of a possible ERCP hospitalization. Individualization of the treatment choice of incidental CDL based on these data may enable institutions to optimize available resources.

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Author Contributions: Study concept and design: Poulose, Speroff, and Holzman. Acquisition of data: Poulose. Analysis and interpretation of data: Poulose, Speroff, and Holzman. Drafting of the manuscript: Poulose, Speroff, and Holzman. Critical revision of the manuscript for important intellectual content: Poulose, Speroff, and Holzman. Statistical analysis: Poulose and Speroff. Obtained funding: Poulose and Holzman. Administrative, technical, and material support: Poulose. Study supervision: Speroff and Holzman.

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REFERENCES