The economic impact of using single-operator cholangioscopy for the treatment of difficult bile duct stones and diagnosis of indeterminate bile duct strictures

Authors
Pierre H. Deprez[1], Rodrigo Garces Duran[1], Tom Moreels[1], Gianluca Furneri[2], Federica Demma[2], Len Verbeke[3], Schalk W. Van der Merwe[3], Wim Laleman[3]

Institutions
1 Department of Hepatogastroenterology, Cliniques universitaires Saint-Luc, Université Catholique de Louvain, Brussels, Belgium
2 Health Economics and Outcome Research Department, EBMA Consulting, Milan, Italy
3 Department of Gastroenterology and Hepatology, University Hospital Gasthuisberg, Leuven, Belgium

Submitted: 24.4.2017
Accepted after revision: 14.9.2017

Bibliography
DOI https://doi.org/10.1055/s-0043-121268
Published online: 24.11.2017 | Endoscopy 2018; 50: 109–118

ISSN 0013-726X

Corresponding author
Pierre H. Deprez, MD, PhD, Department of Hepatogastroenterology, Cliniques universitaires Saint-Luc, Université Catholique de Louvain, Av Hippocrate 10, 1200 Brussels, Belgium
Fax: +32-2-7648927
pdeprez@uclouvain.be

ABSTRACT

Background and study aim Conventional endoscopic retrograde cholangiopancreatography (ERCP) combines endoscopy and radiography to diagnose and treat pathological conditions of the bile duct. The aim of the present analysis was to evaluate the clinical and economic impact of the use of single-operator intraductal cholangioscopy (IDC), which allows for direct visualization of the bile duct, as an alternative to ERCP for the treatment of difficult bile duct stones and the diagnosis of bile duct strictures.

Patients and methods The clinical and economic consequences of single-operator IDC use were evaluated using two decision-tree models, one for management of difficult-to-remove stones and one for stricture diagnosis. A hospital perspective was adopted. Data to populate the models were derived from two Belgian hospitals that specialize in endoscopic procedures of the bile duct. Overall, the examined population consisted of 62 patients with difficult stones and 49 patients with indeterminate strictures.

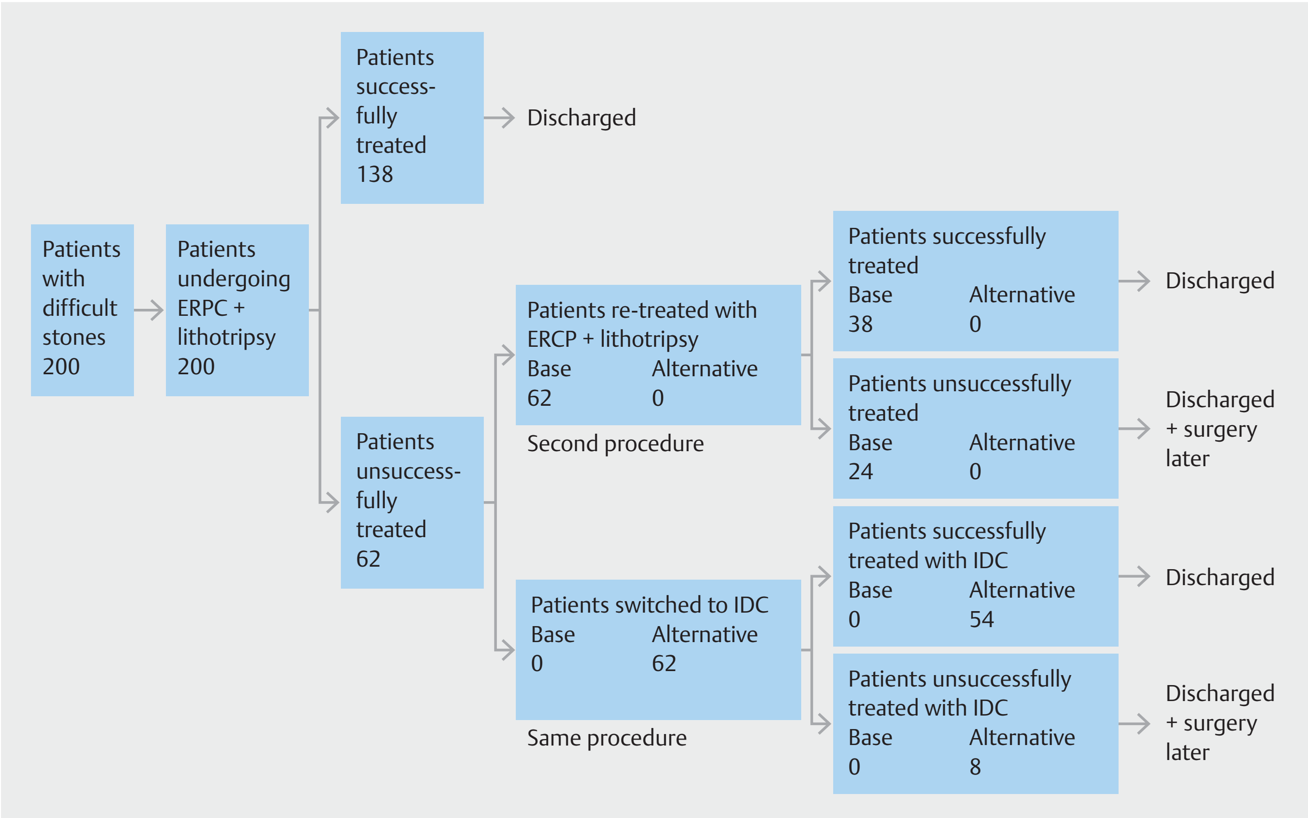
Results In the model for difficult stone management, the use of IDC determined a decrease in the number of procedures (−27 % relative reduction) and costs (−€73 000; −11 % relative reduction) when compared with ERCP. In the model for stricture diagnosis, the use of IDC determined a decrease in the number of procedures (−31 % relative reduction) and costs (−€13 000; −5 % relative variation) when compared with ERCP.

Conclusions The single-operator IDC system performed better than ERCP for the treatment of difficult bile duct stones and the diagnosis of bile duct strictures, and reduced the overall expenditure in hospitals in Belgium.

Introduction

The endoscopic retrograde cholangiopancreatography procedure (ERCP) technique combines upper gastrointestinal endoscopy and radiography to diagnose and treat pathological conditions of the bile and pancreatic ducts [1]. In some cases, however, ERCP may not be successful, owing to failed cannulation of the papilla, untraversable strictures, large or difficult-to-remove bile duct stones, or diagnosis of indeterminate or unexplained biliary strictures [2].

The SpyGlass DS (Boston Scientific, Marlborough, Massachusetts, USA) is a new single-operator intraductal cholangioscopy (IDC) system developed for investigation of the biliary ducts. Unlike standard ERCP-associated procedures, this new IDC system allows the scope to be inserted directly into the common bile duct, thus allowing direct visualization. This technology allows the endoscopist to fragment stones under direct visualization or to obtain a targeted biopsy with an increased level of diagnostic accuracy [3]. Recent studies have demonstrated the clinical value of single-operator IDC in these two indications.



▶ **Fig. 1** Decision-tree for difficult stone management model. ERCP, endoscopic retrograde cholangiopancreatography; IDC, intraductal cholangioscopy.

For stone management, procedural success of IDC with lithotripsy was 87 % at first intervention [4] vs. 69 % at first mechanical lithotripsy with ERCP, and 62 % at second ERCP intervention [5]. For the diagnosis of stricture, IDC correctly diagnosed approximately 86 % of malignancies [4, 12] vs. 45 % with conventional brushing [6].

The aim of the current study was to evaluate the clinical and economic impact of the use of single-operator IDC as an alternative to conventional ERCP techniques, for the treatment of difficult bile duct stones and the diagnosis of biliary strictures.

Patients and methods

Study aim

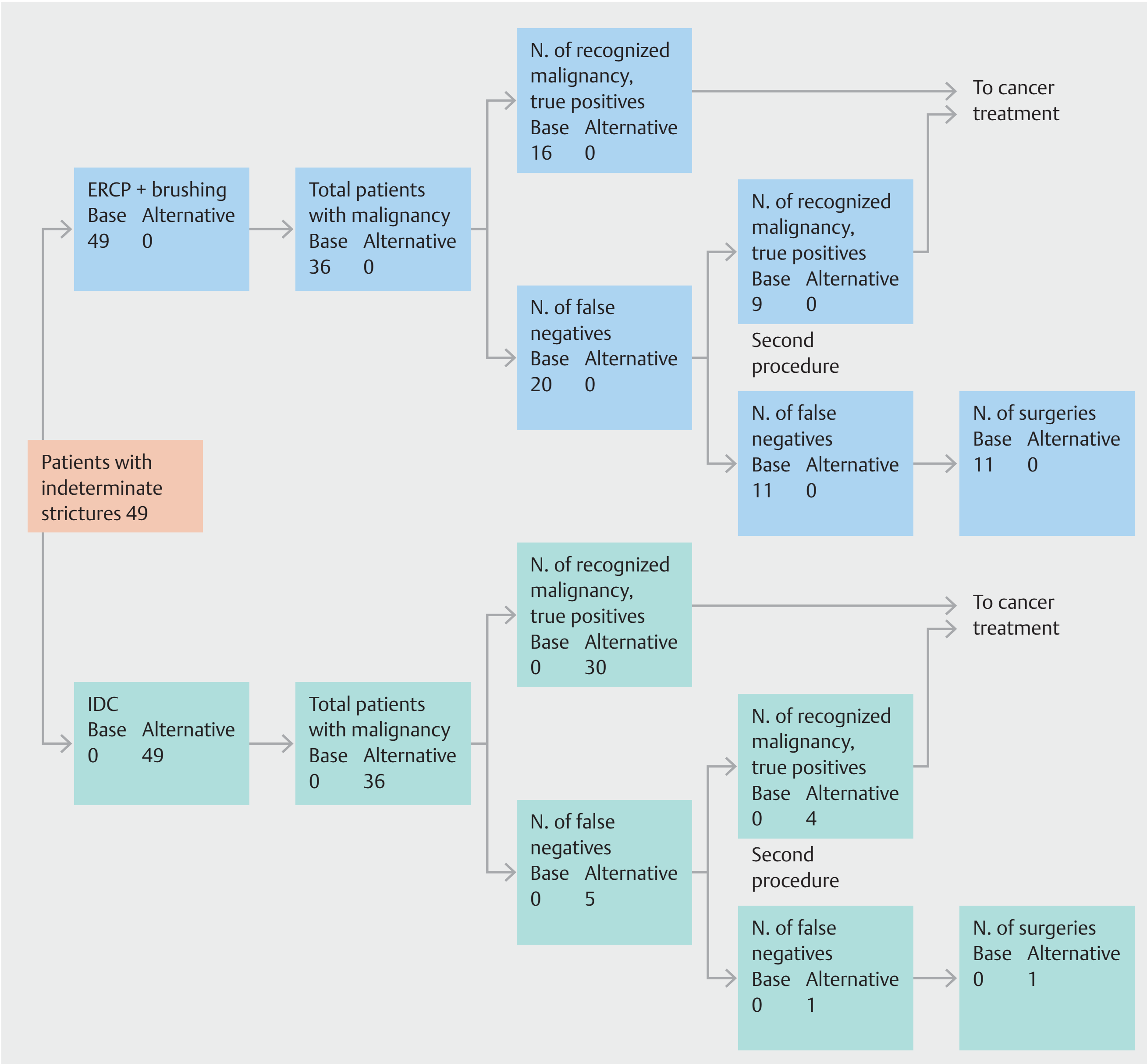
The aim of the present analysis was to evaluate whether the introduction of IDC would improve the treatment of difficult stones and the diagnosis of patients with strictures, by reducing the number of procedures and related costs. The economic and clinical value of IDC was evaluated through two decision-tree models, one for the management of difficult-to-remove stones and one for the diagnosis of strictures. The two models estimated the annual budget impact of IDC use, from the hospital perspective in Belgium. The economic impact of IDC was determined, in both models, by comparing a scenario in which IDC is not used in clinical practice (Base Scenario) with a scenario in which all patients are treated (stones)/diagnosed (strictures) with IDC (Alternative Scenario).

The models were developed in compliance with the principles of good practice for pharmacoeconomic analyses, from the International Society for Pharmacoeconomics and Outcomes Research [7]. The analyses were run using Microsoft Excel 2016.

Model overview

Difficult stone management model

Difficult bile duct stones were defined as stones that could not be removed via conventional methods (ERCP with standard extraction balloons, baskets or lithotriptors; large endoscopic papillary balloon dilation). In the model, patients with bile duct stones are treated with ERCP + lithotripsy as the first option (▶ **Fig. 1**). If the first treatment with ERCP + lithotripsy allows the complete removal of the stones (success rate: 69 % of cases [5]), patients are discharged and exit the model. If the first treatment with ERCP + lithotripsy is unsuccessfully performed (failure rate: 1 – 0.69 = 31 % of cases [5]), patients can be either: i) re-treated with a second ERCP + lithotripsy (during a second hospitalization; Base Scenario); or ii) switched to IDC + holmium laser fiber or electrohydraulic lithotripsy (during the same procedure as the first ERCP + lithotripsy, as IDC can be easily performed as an extension of any ERCP procedure; Alterna-



▶ **Fig. 2** Decision-tree for stricture diagnosis model. ERCP, endoscopic retrograde cholangiopancreatography; IDC, intraductal cholangioscopy.

tive Scenario). In the Base Scenario, patients undergoing a second procedure have a 62 % probability of being successfully treated, and then discharged [5]. In the remaining 38 % of patients, the second intervention fails and patients are assumed to undergo a surgical intervention later in time [5]. In the Alternative Scenario, patients undergoing a second procedure have an 87 % probability of being successfully treated, and then discharged [4].

This 87 % success rate may be somewhat optimistic. Using the first-generation SpyGlass device, both Chen et al. and Patel et al. found index stone clearance rates of approximately 70 % [8]. The study by Patel et al. only recruited patients in whom conventional ERCP had failed (so most applicable to the current model), and their index stone clearance rate was only 74 % [9]. More recently, using the single-operator Spyglass DS, Wong et al. found an index stone clearance rate of 63 % in a group of patients with difficult bile duct stones, defined as impacted stones or stones that failed to be removed by prior conventional ERCP) [10]. However, a recent review of the aggregated literature in this context (cumulating eight series and our own experience) showed an overall success rate of 87 %, with 79 % being cleared during one procedure [4]. As this review included a total of 244 patients and was peer reviewed, we considered this to be a validated figure. In the remaining 13 % of patients, the second intervention fails and patients are assumed to undergo a surgical intervention later in time. The current model was designed to consider a maximum of three procedures: two interventions (two ERCPs + lithotripsy or one ERCP + one lithotripsy followed by IDC) plus one surgical intervention.

Stricture diagnosis model

Overall, 73 % of patients who are annually screened for strictures are assumed to have malignancies [11]. Indeterminate biliary strictures are defined as strictures that could not be definitively diagnosed with conventional ERCP sampling techniques (brushings, intraductal biopsy). Based on our experience, we considered that all strictures, even type III and type IV, were studied with ERCP rather than with percutaneous cholangiography. In the model, patients with indeterminate strictures (▶ **Fig. 2**) can undergo either: i) ERCP + brushing (and biopsy) (Base Scenario); or ii) IDC + optically guided biopsy (Alternative Scenario). In the Base Scenario, according to the published sensitivity for ERCP + brushing procedure [6], 45 % of patients receive a confirmed diagnosis of malignancy and are subsequently treated for their malignancy (patients exit the model as malignancy treatment phase is not considered in this analysis).

The 45 % diagnostic rate may seem too optimistic but refers to a recent systematic review and meta-analysis [6] that compared the effectiveness of biliary brush cytology with that of intraductal biopsy for the detection of malignant biliary strictures. The Base Scenario did not consider endoscopic ultrasound with or without fine-needle aspiration (FNA) as an alternative to a second ERCP for stricture evaluation, because the model aims to evaluate undetermined strictures rather than those associated with a significant mass detected by conventional imaging and endoscopic ultrasound (EUS). Moreover EUS-FNA is not advised for resectable cholangiocarcinomas. The remaining 55 % of patients, who are assumed in our model to be false negatives, are re-evaluated with a second ERCP + brushing (and biopsy). By iterating sensitivity outcomes of ERCP + brushing, an additional 45 % of these patients receive a diagnosis of malignancy and are subsequently treated for their malignancy; as the model stops after two ERCPs + brushing (and biopsy), the remaining 55 % of these patients, who are still false negatives, remain undiagnosed and are expected to receive a diagnosis later in time, with a more invasive surgical procedure. In the Alternative Scenario, according to the sensitivity in the published literature on IDC + optically guided biopsy procedures [4, 12], 86 % of patients receive a confirmed diagnosis of malignancy and are subsequently treated for their malignancy (patients exit the model as malignancy treatment phase is not considered in this analysis). The remaining 14 % of patients, who are false negatives, are re-evaluated with a second IDC + optically guided biopsy. By iterating sensitivity outcomes of ERCP + IDC + optically guided biopsy, an additional 86 % of these patients receive a diagnosis of malignancy and are subsequently treated for their malignancy; as the models stops after two IDC + optically guided biopsy procedures, the remaining 14 % of these patients, who are still false negatives, remain undiagnosed and are expected to receive a diagnosis later in time, with a more invasive surgical procedure.

Economic data

The economic analysis evaluated the economic impact of endoscopic procedures and hospital admissions required to manage difficult stones and to diagnose strictures, from a hospital perspective. The cost of each procedure was calculated, adopting a micro-costing approach, i. e. multiplying the number of resources used during the procedure by unit costs (and by the procedure duration, if the unit cost was on a time basis, e. g. physician time to conduct the intervention). Hospitalization costs for each endoscopic procedure were calculated by taking the mean length of stay of the procedure (in days) and multiplying it by the unit cost per day in a general medical ward. Unit costs, procedure durations, length of hospital stay, and resource consumption were derived from two Belgian hospitals: Gasthuisberg Leuven and Cliniques Universitaires St.-Luc. Weighted means (for the number of procedures registered in the two hospitals) were calculated for all inputs. In the absence of micro-costing data, the cost of open surgery interventions was estimated using the All Patient Refined-Diagnosis Related Group (APR-DRG) tariffs [13]. The capital invested for IDC equipment acquisition was included in the analysis, and a 5-year amortization schedule was considered. All costs were VAT excluded and expressed in € 2016. Discounting was not applied, as costs and consequences of the cohorts treated in a year in the two hospital were analyzed.

Difficult stone management model

As shown in ▶ **Table 1**, the following costs were evaluated: treatment with ERCP + lithotripsy; treatment with IDC + laser or electrohydraulic lithotripsy; surgery to remove stones in case of failure of the previous approaches. For stone removal surgery, the APR-DRG code used was 284, corresponding to the procedure "Trouble of gallbladder and of the biliary ducts," with a cost of about €4628. For IDC equipment acquisition, a list price of €84000 was used (€42000 for each one of the two hospitals considered) [14]. ▶ **Table 1** shows unit costs and resources used to determine the procedure costs. These data were obtained as means of the values provided by the two hospitals considered in the analysis.

Stricture diagnosis model

As shown in ▶ **Table 2**, the following costs were evaluated: brushing procedure; IDC + optically guided biopsy procedure; exploratory surgery in case of missed diagnosis with the two previous brushing/IDC + optically guided biopsy procedures. For exploratory surgery, the APR-DRG code used was 261, corresponding to the procedure "Major procedure on the biliary duct," with a cost of about €11 714. For IDC equipment acquisition, a list price of €84000 was used (€42000 for each one of the two hospitals considered) [14].

▶ **Table 2** shows unit costs and resources assumed to determine the procedure costs. These data were obtained as means of the values provided by the two hospitals considered in the analysis.

Sensitivity analysis

One-way deterministic sensitivity analysis was performed, changing some parameters of the two models by ± 10 %.

► **Table 1** Unit costs and resource consumption used for micro-costing approach in the difficult stone management model.

Item of expenditure and resource	Unit cost, €	Resource consumption	
		ERCP + lithotripsy	IDC + laser
Procedures			
▪ Physician[1]	1.9 (per minute)	1.0	1.0
▪ Nurse[1]	0.7 (per minute)	1.0	1.0
▪ Other personnel[1]	0.4 (per minute)	0.6	0.6
▪ Operating room	8.4 (per minute)	49.5 minutes	75.5
Diagnostic			
▪ MRI	175.9	1.0	1.0
▪ CT	208.3	0.3	0.3
▪ External ultrasound	34.7	1.0	1.0
▪ Blood exams	29.2	1.0	1.0
▪ Check visit	36.6	1.0	1.0
Hospital stay			
▪ Normal ward per day	220.0	2.4	2.4
Single-use consumables other than those for IDC			
▪ Sphincterotome	104.2	0.6	0.0
▪ Guidewire	82.7	1.1	1.0
▪ Dilation balloon	183.3	0.2	0.0
▪ Retrieval balloon	73.4	1.0	1.0
▪ Retrieval basket	167.8	1.4	0.7
▪ Lithotripter	267.7	0.6	0.0
▪ Plastic stent	100.9	0.6	0.3
▪ Laser probe	344.3	0.0	1.0
IDC system acquisition			
▪ Cholangioscope[2]	1760.0	0.0	1.0
Total, €[3]	–	2138	4121

MRI, magnetic resonance imaging; CT, computed tomography; ERCP, endoscopic retrograde cholangiopancreatography; IDC, intraductal cholangioscopy.
[1] Cost multiplied by procedure duration (minutes reported for "Operating room").
[2] List price [14]
[3] Considering approximation.

► **Table 2** Unit costs and resource consumption used for micro-costing approach in the stricture diagnosis model.

Item of expenditure and resource	Unit cost, €	Resource consumption	
		ERCP + brushing	IDC + optically guided biopsy
Procedures			
▪ Physician[1]	1.8 (per minute)	1.0	1.0
▪ Nurse[1]	0.6 (per minute)	1.0	1.0
▪ Other personnel[1]	0.4 (per minute)	0.5	1.0
▪ Operating room	7.6 (per minute)	49.9 minutes	63.1
Diagnostic			
▪ MRI	185.2	1.0	1.0
▪ CT	202.7	0.3	0.3
▪ External ultrasound	37.4	1.0	1.0
▪ Blood exams	29.2	1.0	1.0
▪ Check visit	36.5	1.0	1.0
Hospital stay			
▪ Normal ward per day	211.5	2.2	2.5
Single-use consumables other than those for IDC			
▪ Sphincterotome	102.9	0.5	0.5
▪ Guidewire	82.5	1.0	0.5
▪ Dilation balloon	191.2	0.7	0.7
▪ Retrieval balloon	74.2	0.1	0.1
▪ Biopsy	12.3	1.0	0.0
▪ Plastic stent	92.5	1.0	1.0
IDC system acquisition			
▪ Cholangioscope[2]	1760.0	0.0	1.0
▪ Biopsy forceps	340.2	0.0	1.0
Total, €[3]	–	1699	3946

MRI, magnetic resonance imaging; CT, computed tomography; ICU, intensive care unit; ERCP, endoscopic retrograde cholangiopancreatography; IDC, intraductal cholangioscopy.
[1] Cost multiplied by procedure duration (minutes reported for "Operating room").
[2] List price [14].
[3] Considering approximation.

▶ **Table 3** Difficult stone management model: results of the economic analysis.

Item of expenditure	Expenditure in the Base Scenario, € (%)	Expenditure in the Alternative Scenario, € (%)	Absolute difference (Alternative–Base)	Percentage difference (Alternative–Base)
Equipment	0 (0)	9384 (2)	9384	Not applicable
Single-use consumables other than those for IDC	187 589 (28)	138 996 (23)	– 48 593	– 26 %
IDC system acquisition	0 (0)	109 120 (18)	109 120	Not applicable
Procedures[1]	145 353 (22)	129 023 (22)	– 16 330	– 11 %
Diagnostics	88 777 (13)	67 769 (11)	– 21 008	– 24 %
Hospital stay[2]	247 368 (37)	142 040 (24)	– 105 328	– 43 %
Total	669 087 (100)	596 332 (100)	– 72 755	– 11 %

IDC, intraductal cholangioscopy; ERCP, endoscopic retrograde cholangiopancreatography.
[1] Includes personnel and operating room.
[2] Includes the stay in a normal ward after ERCP/IDC procedure and after open surgery.

▶ **Table 4** Difficult stone management model: number of procedures by approach.

Scenario	Endoscopic procedures	Surgical procedures	Total procedures
Treatment pathway without IDC (Base Scenario)	262	24	286
Treatment pathway with IDC (Alternative Scenario)	200[1]	8	208
Percentage difference (Alternative – Base)	– 24 %	– 67 %	– 27 %

IDC, intraductal cholangioscopy.
[1] Includes IDC procedure.

Difficult stone management model

The parameters used for sensitivity analysis were: percentage of mechanical lithotripsy success at first procedure; percentage of mechanical lithotripsy success at second procedure; percentage of IDC success at first procedure; cost of ERCP + lithotripsy; cost of IDC + laser; IDC equipment capital.

Stricture diagnosis model

The parameters used for sensitivity analysis were: total percentage of malignancies; brushing sensitivity; IDC sensitivity; cost of ERCP + brushing; cost of IDC + optically guided biopsy.

Results

Difficult stone management model

To run the model, an estimated annual number of 200 patients with difficult stones was considered, of whom 62 (1 – 69 % = 31 % over the total) were unsuccessfully treated with a first ERCP + lithotripsy and then re-treated. The associated costs were € 669 087 in the Base Scenario and € 596 332 in the Alternative Scenario (▶ **Table 3**). Thus, the net saving associated with the adoption of IDC was approximately € 72 755. In the Base Scenario, the cost of ERCP + lithotripsy was € 3345 per treated patient. In the Alternative Scenario, the cost of IDC + holmium laser fiber was € 2982 per treated patient. As shown in ▶ **Table 3**, expenditure for hospitalizations was the cost driver in both the Base Scenario (37 % of total costs) and in the Alternative Scenario (24 % of total costs). The IDC strategy performed better than ERCP + lithotripsy, allowing an mean saving of € 363 per patient and avoiding 27 % of procedures (▶ **Table 4**, derived from ▶ **Fig. 1**). The savings obtained with the adoption of IDC could be reallocated and used to treat 25 additional patients with difficult stones.

A tornado diagram of the one-way sensitivity analysis (▶ **Fig. 3**) confirmed the base-scenario model trend, showing how, for all tested scenarios, IDC was superior to ERCP + lithotripsy. Moreover, the sensitivity analysis indicated that the results of the base scenario model are least sensitive to variation in the investment required for the acquisition of the IDC equipment. In terms of number of procedures avoided with IDC vs. ERCP + lithotripsy, results of the base scenario model are most sensitive to the variation in the ERCP + lithotripsy success rate at first procedure: a variation of + 10 % produced a percentage reduction of 23 %; a variation of – 10 % produced a percentage reduction of 31 %.

Stricture diagnosis model

To run the model, an estimated annual number of 49 patients per year with indeterminate strictures was used, of whom 36 (73 %) were assumed to have malignancies. Using the hospital perspective, the associated costs were € 242 316 in the Base

▶ **Table 5** Stricture diagnosis model: results of the economic analysis.

Item of expenditure	Expenditure in the Base Scenario, € (%)	Expenditure in the Alternative Scenario, € (%)	Absolute difference (Alternative – Base)	Percentage difference (Alternative – Base)
Equipment	0 (0)	7416 (3)	7416	Not applicable
Single-use consumables other than those for IDC	25 718 (11)	17 400 (8)	– 8318	– 32 %
IDC system acquisition	0 (0)	113 577 (50)	113 577	Not applicable
Procedures[1]	35 022 (14)	35 561 (16)	539	2 %
Diagnostics	23 303 (10)	18 387 (8)	– 4916	– 21 %
Hospital stay[2]	158 273 (65)	36 984 (16)	– 121 288	– 77 %
Total	242 316 (100)	229 325 (100)	– 12 990	– 5 %

IDC, intraductal cholangioscopy; ERCP, endoscopic retrograde cholangiopancreatography.
[1] Includes personnel and operating room.
[2] Includes the stay in a normal ward after ERCP/IDC procedure and after open surgery.

▶ **Table 6** Stricture diagnosis model: number of procedures by approach.

Scenario	Diagnostic procedures	Surgical procedures	Total procedures
Treatment pathway without IDC (Base Scenario)	69	11	80
Treatment pathway with IDC (Alternative Scenario)	54	1	55
Percentage difference (Alternative – Base)	– 22 %	– 91 %	– 31 %

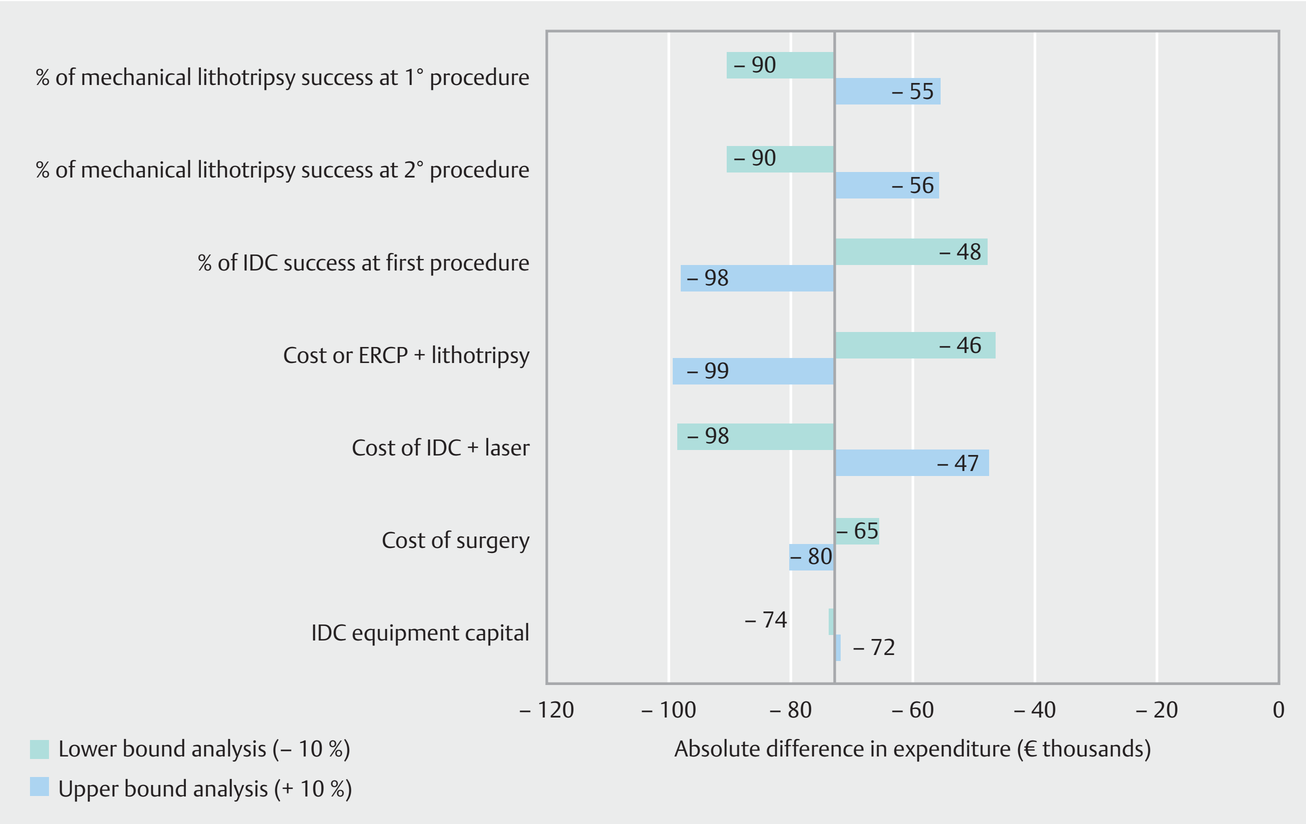
IDC, intraductal cholangioscopy.

Scenario and € 229 325 in the Alternative Scenario (▶ **Table 5**). Thus, the net saving associated with the adoption of IDC was about € 12 990. In the Base Scenario, the cost of ERCP + brushing was € 4945 per treated patient. In the Alternative Scenario, the cost of IDC + optically guided biopsy was € 4680 per treated patient. As shown in ▶ **Table 5**, expenditure for hospitalizations was the cost driver in the Base Scenario (65 % of total costs), whereas the expenditure for IDC acquisition was the cost driver in the Alternative Scenario (50 % of total costs). The IDC strategy performed better than ERCP + brushing, allowing an mean saving of about € 265 per patient and avoiding 31 % of procedures (▶ **Table 6**, derived from ▶ **Fig. 2**). The savings obtained from the adoption of IDC could be reallocated and used to diagnose three additional patients with strictures.

A tornado diagram of the one-way sensitivity analysis (▶ **Fig. 4**) shows how increasing the brushing sensitivity or reducing the IDC sensitivity brings the costs associated with the two therapeutic approaches closer together. To adopt IDC in place of ERCP + brushing resulted in a reduced number of procedures and an additional investment per patient of about € 220. Moreover, the sensitivity analysis indicated that the results of the base-case model are least sensitive to variation in the investment required for the acquisition of the IDC equipment. In terms of efficacy, results of the base scenario model are most sensitive to the variation in the IDC sensitivity: a variation of + 10 % produced a percentage reduction of 35 % in the number of total procedures avoided with IDC vs. ERCP + brushing; a variation of – 10 % produced a percentage reduction of 26 % in the number of total procedures avoided with IDC vs. ERCP + brushing.

Discussion

Each year more than one million people throughout the world undergo ERCP for conditions related to the liver, gallbladder, pancreas, and bile ducts [1]. The benefits of direct visualization cholangioscopy are well known and documented [15 – 17]; however, traditional approaches have limited its adoption because of the need for two operators and continual, costly, capital scope repairs. The IDC system (SpyGlass DS) addresses both of these limitations with a single-operator, single-use device that is redefining cholangioscopy. The economic analysis in the current study was conducted using data from two of the largest Belgian hospitals performing cholangioscopy. The results of the analysis relate to Belgium but the approach used is applicable across countries. The analysis showed that the use of IDC was effective in reducing the number of procedures performed and saved hospital costs for both stone treatment and stricture detection. According to the models, the adoption of IDC for the management of difficult bile duct stones allows a



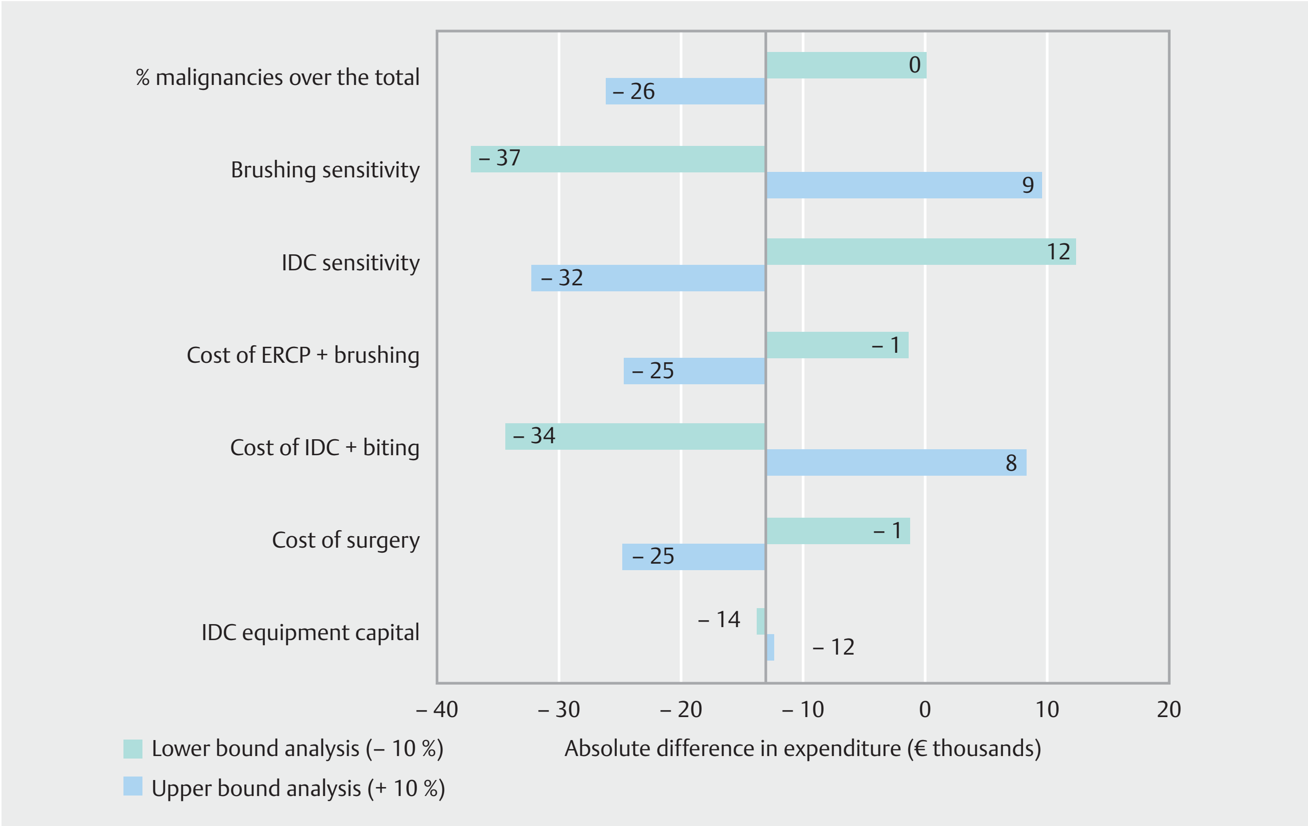
► **Fig. 3** Difficult stone management model: results of the sensitivity analysis. IDC, intraductal cholangioscopy.

27 % reduction in the number of procedures and saves about 11 % of the allocated budget. Similarly, the adoption of IDC for stricture diagnosis allows a 31 % reduction in the number of procedures and saves about 5 % of the allocated budget. A simulation conducted with our model showed that increasing the use of IDC in this case study may potentially save up to one patient over a cohort of 36 patients with malignancies, increasing the overall survival to 17 %.

At present there is only one paper addressing the economic impact of the adoption of single-operator cholangioscopy for the diagnosis of cholangiocarcinoma in primary sclerosing cholangitis [18]. Single-operator cholangioscopy with biopsy sampling was found to be cost-effective in this particular context. To our knowledge, for difficult bile stones and indeterminate strictures in a broader perspective, there are currently no data estimating the number of procedures avoided or, in case of malignancies, the survival gained.

We acknowledge that there are some limitations to the study. The first set of limitations relate to the patient pathways used for the two analyses. In real practice, patients treated for difficult-to-manage stones who are unsuccessfully treated with IDC can undergo a second treatment with IDC. In order to remain consistent with the pathway drawn for patients treated with ERCP + lithotripsy and to be conservative, only one procedure with IDC was considered in the model. In real practice, not all false-negative patients undergo surgery, and there is a highly selected subgroup of patients unsuitable for surgery. Other options could be endoscopic drainage, percutaneous approach, extracorporeal shock wave lithotripsy, or palliative treatments such as stenting. As the cost of listed alternatives is quite similar to that for surgery, only surgery procedures were considered in order to simplify the model structure. Similarly, for indeterminate strictures, we assumed that all were malignant, but if some of the strictures were truly fibrotic or of benign origin, then this could not be considered "false negative." Our model also considered that pre-operative diagnosis of malignancy was a pre-requisite for surgery. In other parts of the world such as Asia, were the incidence of cholangiocarcinoma is much higher than in Europe, a significant number of patients go directly to surgery and no previous histological diagnosis (i. e. ERCP or percutaneous transhepatic biliary drainage with cytology or biopsy) is done.

The second limitation relates to the data and sources used. The analysis does not take into account the fact that stone recurrence occurs in 25 % of mechanical lithotripsy-treated patients. Therefore the advantages of IDC could be even greater than our analysis determined because direct visualization may allow more comprehensive stone clearance. In the absence of randomized studies or studies reporting a direct comparison between IDC and ERCP + lithotripsy, the success rate of IDC was derived from an observational study with no control group [4]. Even for IDC + brushing, there are no available published randomized studies that directly compare IDC with ERCP + brushing. With regard to costs, we used some proxies when



▶ **Fig. 4** Stricture diagnosis model: results of the sensitivity analysis. IDC, intraductal cholangioscopy.

unit costs were not available and the micro-costing approach was not feasible. For hospitalization costs, the APR-DRG data were, in our opinion, the best proxies we could use. In terms of IDC cost, the net price could be used in place of the list price. The sensitivity analyses we conducted to evaluate the variability in results should have overcome all of the limitations listed above.

In conclusion, our model suggests that single-operator IDC offers a better performance than ERCP for the treatment of difficult stones and the diagnosis of bile duct strictures, and reduces the overall expenditure in hospitals in Belgium. Prospective randomized studies may be needed to prove these findings.

Competing interests

Pierre Deprez has a consultant agreement with Boston Scientific

References

[1] Endoscopic retrograde cholangiopancreatography (ERCP). PubMed health glossary; Available from https://www.ncbi.nlm.nih.gov/pubmedhealth/PMHT0022879/ Accessed 25 September 2017

[2] Ramchandani M, Reddy DN, Lakhtakia S et al. Per oral cholangiopancreatoscopy in pancreatic biliary diseases – expert consensus statements. World J Gastroenterol 2015; 21: 4722–4734

[3] Draganov P. The SpyGlass® direct visualization system for cholangioscopy. Gastroenterol Hepatol (N Y) 2008; 4: 469–470

[4] Laleman W, Verraes K, Van Steenbergen W et al. Usefulness of the single-operator cholangioscopy system SpyGlass in biliary disease: a single-center prospective cohort study and aggregated review. Surg Endosc 2017; 31: 2223–2232

[5] Chang WH, Chu CH, Wang TE et al. Outcome of simple use of mechanical lithotripsy of difficult common bile duct stones. World J Gastroenterol 2005; 11: 593–596

[6] Navaneethan U, Njei B, Lourdusamy V et al. Comparative effectiveness of biliary brush cytology and intraductal biopsy for detection of malignant biliary strictures: a systematic review and meta-analysis. Gastrointest Endosc 2015; 81: 168–176

[7] Mauskopf JA, Sullivan SD, Annemans L et al. Principles of good practice for budget impact analysis: report of the ISPOR Task Force on good research practices – budget impact analysis. Value Health 2007; 10: 336–347

[8] Chen YK, Parsi MA, Binmoeller KF et al. Single-operator cholangioscopy in patients requiring evaluation of bile duct disease or therapy of biliary stones (with videos). Gastrointest Endosc 2011; 74: 805–814

[9] Patel SN, Rosenkranz L, Hooks B et al. Holmium-yttrium aluminum garnet laser lithotripsy in the treatment of biliary calculi using single-operator cholangioscopy: a multicenter experience (with video). Gastrointest Endosc 2014; 79: 344 – 348

[10] Wong JC, Tang RS, Teoh AY et al. Efficacy and safety of novel digital single-operator peroral cholangioscopy-guided laser lithotripsy for complicated biliary stones. Endosc Int Open 2017; 5: E54 – E58

[11] Tummala P, Munigala S, Eloubeidi MA et al. Patients with obstructive jaundice and biliary stricture ± mass lesion on imaging: prevalence of malignancy and potential role of EUS-FNA. J Clin Gastroenterol 2013; 47: 532 – 537

[12] Navaneethan U, Hasan MK, Kommaraju K et al. Digital, single operator cholangiopancreaticoscopy in the diagnosis and management of pancreatobiliary disorders: a multicentre clinical experience (with video). Gastrointest Endosc 2016; 84: 649 – 655

[13] Belgium Government. APR-DRG tariffs. Available from: https://tct.fgov.be/webetct/etct-web/anonymous?lang=fr Accessed 4 November 2016

[14] Boston Scientific Corp. Data on file.

[15] Moon JH, Ko BM, Choi HJ et al. Direct peroral cholangioscopy using an ultra-slim upper endoscope for the treatment of retained bile duct stones. Am J Gastroenterol 2009; 104: 2729 – 2733

[16] Parsi MA, Stevens T, Vargo JJ. Diagnostic and therapeutic direct peroral cholangioscopy using an intraductal anchoring balloon. World J Gastroenterol 2012; 18: 3992 – 3996

[17] Parsi MA. Direct peroral cholangioscopy. World J Gastrointest Endosc 2014; 6: 1 – 5

[18] Njei B, McCarty TR, Varadarajulu S et al. Cost utility of ERCP-based modalities for the diagnosis of cholangiocarcinoma in primary sclerosing cholangitis. Gastrointest Endosc 2017; 85: 773 – 781.e10