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ORIGINAL ARTICLE

Cost-utility advantage of interventional endoscopy

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Abstract

Background Gastroenterologists frequently face the dilemma of how to choose among different management options.

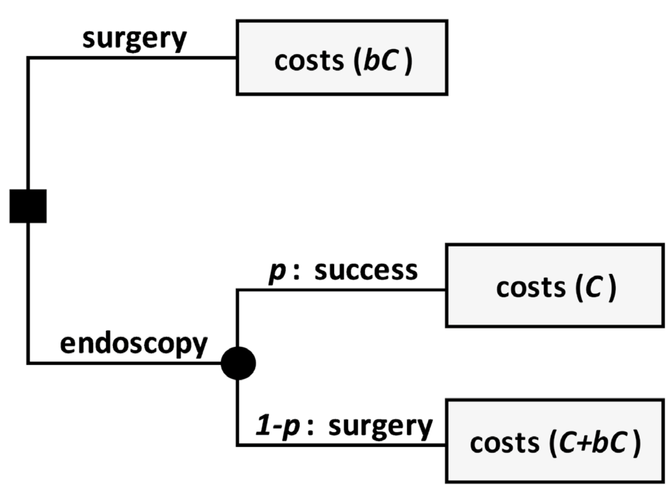
Aim To develop a tool of medical decision analysis that helps choosing between competing management options of interventional endoscopy and surgery.

Methods Carcinoma-in-situ of the esophagus, large colonic polyps, and ampullary adenoma serve as three examples for disorders being managed by both techniques. A threshold analysis using a decision tree was modeled to compare the costs and utility values associated with managing the three examples. If the expected healing or success rate of interventional endoscopy exceeds a threshold calculated as the ratio of endoscopy costs over surgery costs, endoscopy becomes the preferred management option. A low threshold speaks in favor of endoscopic intervention as initial management strategy.

Results If the decision in favor of surgery is focused exclusively on preventing death from a given disease, surgical intervention may seem to provide the best treatment option. However, interventional endoscopy becomes a viable alternative, if the comparison is based on a broader perspective that includes adverse events and long-term disability, as well as the healthcare costs of both procedures. For carcinoma-in-situ of the esophagus, the threshold for the expected success rate is 24% (range in the sensitivity analysis: 7–29%); for large colonic polyps it is 10% (5–12%), and for duodenal papillary adenoma it is 17% (5–21%).

Conclusions Even if a management strategy surpasses its alternative with respect to one important outcome parameter, there is often still room for the lesser alternative to be considered as viable option.

Graphical abstract



- For treatment of premalignant lesions of the GI tract, a clinician can often choose between surgery and endoscopy, with their overall costs of ***bC*** and ***C***, respectively.
- Endoscopy becomes the favored treatment option, if the a-priori probability ***p*** for endoscopic success exceeds the ratio ***1/b*** between the costs of endoscopy and surgery.
- For premalignant lesions of the esophagus, pancreas, and colon the threshold probability for endoscopic success varies between **5%** and **29%**.
- If the a-priori chance for endoscopic success falls below the threshold, surgery becomes the therapy of choice.

Keywords Decision analysis · Esophagectomy · Hemicolectomy · Interventional endoscopy · Pancreatoduodenectomy

Extended author information available on the last page of the article

Gastroenterologists are frequently faced with the dilemma of choosing among different management options in caring for their patients. The same medical condition can be pursued with different diagnostic tools of radiology and gastrointestinal endoscopy. As the armamentarium of interventional endoscopy continues to expand, it offers an ever-increasing number of therapeutic options for managing digestive diseases that in the past were dealt with exclusively by surgical procedures [1]. The competing endoscopic and surgical options may vary with respect to their medical efficacy, cost, invasiveness, frequency, and severity of adverse events. It may be difficult for the clinician to account for all these varying aspects at the same time and make a convincing argument that speaks unequivocally in favor of one or the other management strategy. In the present analysis, carcinoma-in-situ of the esophagus, ampullary adenoma, and large colonic polyps serve as 3 examples that lend themselves to be managed by means of endoscopy, as well as surgery. Although the guidelines may generally support endoscopic approach to deal with any of these conditions [2], in the individual patient, the choice between the two therapeutic alternative still remains difficult to make. The primary objective of our analysis was to compare the outcomes of endoscopic with surgical treatment options. The comparison was carried out using threshold analysis as a tool of medical decision making [3]. Threshold analysis utilizes a decision tree to calculate a probability value for therapeutic success that endoscopy needs to surpass in order to become a viable treatment option when compared with surgery. The lower a threshold, the more viable (or competitive) the endoscopic treatment option becomes.

Methods

No patient records or real patients were included in the present analysis. The article reports the results of a mathematical model using the concept of threshold analysis of medical decision theory. The cost data, on which the analysis was based, were retrieved from the published medical literature. For these reasons, no IRB approval was necessary to conduct the study.

Threshold analysis

The analysis is based on the exemplary case of a 60-year-old asymptomatic patient who would need a surgical or endoscopic intervention to treat a carcinoma-in-situ of the esophagus, ampullary adenoma, or large colonic polyp. The patient's or a surgeon's possible perspective is illustrated by the left decision tree of Fig. 1. This perspective is *exclusively* focused on survival and avoidance of death from cancer, but ignores any mortality or disability associated with the surgical or medical interventions. The small black square on the far left represents a *decision* node between surgery and endoscopy. The small black circle represents a *chance* node. The probabilities associated with the two individual branches emanating from the same chance node add up to 1 or 100%. The chances for successful and unsuccessful endoscopic intervention are p and $1-p$, respectively [3]. From a perspective focused exclusively on preventing premature death from cancer, the decision making in favor of surgery or endoscopy are both associated with the same underlying risk of death from esophageal, ampullary, or colon cancer, as indicated by the capital letter D. However, an unsuccessful endoscopic intervention may delay or even compromise the subsequent surgical procedure and only increase the risk of death by a factor a, that is aD. In calculating the overall

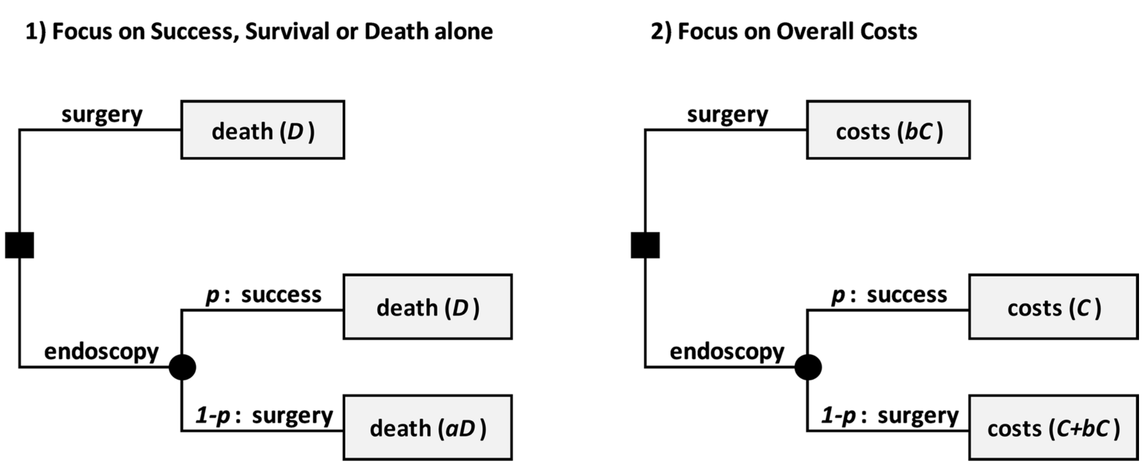


Fig. 1 Decision tree comparing surgery and endoscopy in the management of gastrointestinal disease

outcome of the lower decision branch, the two final outcomes are multiplied by their probability of occurrence, that is *p* or *1−p*, and then added up. In comparing the two primary branches at the decision node, one would choose surgery, if its costs were lower than those of endoscopy, that is,

$$D < pD + (1 - p)aD$$

Few simple algebraic transformations lead to

$$1 < p + (1-p)a$$

$$(1-p) < (1-p)a$$

$$1 < a,$$

which applies under all circumstances for all possible *a*-values because it was initially assumed that compared to surgery an endoscopic intervention would not change the underlying risk of dying from cancer except for possibly increasing it. Therefore, someone focused exclusively on preventing death from cancer might argue that from the onset that a surgical procedure constitutes the best available treatment option.

A different perspective, most likely espoused by endoscopist, is illustrated by the right decision tree of Fig. 1. The endoscopist assumes that the overall costs of surgical intervention would exceed the overall costs of endoscopic intervention *C* by a factor *b*, that is *b C*. The costs *C* include all procedural costs, adverse events, and death associated with either type of management. If endoscopy failed, the resulting costs would include those of endoscopy plus subsequent surgery. In comparing the two primary branches at the decision node, one would choose endoscopy only if its costs were lower than those of surgery, that is,

$$bC > pC + (1-p)(C + bC)$$

$$b > p + (1-p)(1 + b)$$

$$b > p + 1 + b - p - pb$$

$$pb > 1$$

$$p > 1/b,$$

which means, if the probability of success associated with endoscopy exceeds the inverse of the cost factor *b* (comparing surgery to endoscopy), then endoscopy becomes the preferred management option. For instance, if surgery is overall ten-times more expensive than endoscopy, endoscopy needs to be successful in at least $p > 1/b = 1/10 = 10\%$ of cases to become the preferred management option. Phrased slightly differently, this also means that to be considered as treatment option, the *a-priori* chances of success associated with endoscopy should exceed 10%. The lower the threshold, the greater the chances for success. The same model applies to all examples of competing therapeutic approaches using endoscopy or surgery.

Cost analysis

Based on the decision analysis from above, the comparison of two management options primarily depends on a comparison of their relative costs. In general, the healthcare costs of medical procedures comprise professional and facility fees. The costs must include the costs of adverse events and follow-up interventions as the disease progresses after the initial endoscopic or surgical intervention, such as admissions to the intensive care unit, repeat surgeries or endoscopies, and re-admissions to the hospital for the same disease condition. Lastly, the costs should also account for the loss in life-years secondary to premature death and reduced quality of life following the medical intervention [4].

In estimating the overall healthcare costs, we relied on published cost data associated with esophagectomy, pancreatoduodenectomy, and hemicolectomy [5]. This publication (based on the US National Inpatient Survey from 2001 to 2014) also included cost data of the aftercare following the initial intervention. For endoscopic mucosal resection of esophageal adenocarcinoma, we relied on published healthcare costs [6]. The costs for endoscopic ampullectomy and colonoscopy with resection of large colon polyps were based on average reimbursements of the Portland, Oregon area, or hospitals affiliated with Oregon Health & Science University in 2020–2021. All cost data were converted to 2021 US dollars using the Consumer Price Index to adjust for inflation and the different time periods covered by the individual publications [7].

Mortality associated with the three surgical procedures were estimated based on published large case series [8–14]. Following common practice in cost–benefit analysis, the impact of lost life-years from premature death was equated with lost income, using the average annual US income as benchmark, multiplied by the number of lost life-years. For the USA, the latest available individual annual income was $35,805 [15]. Each surgical procedure was also associated with partial disability, reflected by quality adjusted life-years (QALYs) of less than 1 applied to each life-year of the postsurgical time period. The QALYs following each type of surgical intervention were again taken from published reports [11, 16–21].

Sensitivity analysis

All healthcare costs for the three major surgical procedures were provided as mean or median values with a corresponding range of outcomes associated with a minimal or maximal amount of adverse events. The estimates for postsurgical QALYs also varied among different investigators. In the baseline analysis, we used the mean cost values and a time horizon of 5 years to calculate the disutility associated with premature death and reduced postsurgical QALYs. In a sensitivity analysis, a minimal cost value was calculated based on the minimal amount of adverse events and least reduction in QALYs. A maximal cost value was calculated based on the maximal amount of adverse events and most reduction in QALYs. Rather than using a 5-year time horizon, for the maximal cost, we also assumed the reduced QALYs to apply to the entire average life expectancy of a 60-year-old patient, that is, 22.9 years [22].

Results

Table 1 contains the costs and outcomes associated with the three surgical procedures considered in the present analysis. In comparison with esophagectomy and hemicolectomy, the cost for pancreatoduodenectomy appeared relatively low. However, other cost analyses of pancreatoduodenectomy provided supportive data that were of similar order of magnitude [23–25]. Mortality and reduction in QALYs following surgery were most pronounced in esophagectomy, followed by pancreatoduodenectomy. Hemicolectomy was the least invasive procedure with respect to postoperative mortality and loss in QALYs.

Table 2 contains a comparison of the overall surgical and endoscopic cost data for each organ. The minimal threshold value is generated dividing endoscopic costs by the maximal surgical costs, whereas the maximal threshold value is generated dividing the endoscopic costs by the minimal surgical costs. Therefore, large surgical costs are associated with low thresholds and vice versa. For each organ, the data are arranged by the mean threshold values, followed by its minimal and maximal range values. A low threshold speaks in favor of an endoscopic intervention, whereas a high threshold speaks more in favor of a surgical procedure.

Table 1 Outcomes of 3 surgical interventions

Procedure type	Mean	Min	Max
Healthcare costs of surgery			
Esophagectomy	$60,703	$56,974	$100,085
Hemicolectomy	$59,223	$52,350	$66,097
Pancreatoduodenectomy	$50,060	$47,976	$52,033
Mortality			
Esophagectomy	5.00%	3.00%	8.50%
Hemicolectomy	0.75%	0.50%	1.25%
Pancreatoduodenectomy	2.50%	1.00%	4.00%
Quality adjusted life years (QALYs)			
Esophagectomy	0.80	0.68	0.85
Hemicolectomy	0.95	0.91	0.98
Pancreatoduodenectomy	0.81	0.75	0.85

Table 2 Comparison of 3 competing surgical and endoscopic interventions

Procedure type	Cost-utility-based threshold		
	Mean	Min	Max
Esophagus			
Esophagectomy	$105,459	$389,048	$89,199
Endos. mucosal resection	$25,522	$25,522	$25,522
Threshold (b)	24%	7%	29%
Colon			
Hemicolectomy	$69,517	$136,393	$56,825
Endos. mucosal resection	$6,864	$6,864	$6,864
Threshold (b)	10%	5%	12%
Pancreas			
Pancreatoduodenectomy	$88,550.75	$285,756.92	$76,619.91
Endoscopic papillectomy	$14,925	$14,925	$14,925
Threshold (b)	17%	5%	21%

The overall cost data shown in Table 2 include the healthcare costs plus the disutility costs associated with premature death and reduced quality of life. For the baseline value, the inclusion of disutility increases the overall costs only 1.2-fold in hemicolectomy, but 1.7- and 1.8-fold in esophagectomy and pancreatoduodenectomy, respectively. If one extends the time horizon of the disutility analysis from 5 to 22.9 years, the impact of premature death and reduced quality of life becomes even more pronounced. The overall costs increase 2.1-fold in hemicolectomy, but 3.9- and 5.5-fold in esophagectomy and pancreatoduodenectomy, respectively. Considering patients younger than 60 years old would further extend the time horizon and increase the costs of premature death even more.

Discussion

Occasionally, it becomes difficult for a clinician to choose among multiple competing management options in patients presenting with gastrointestinal disease. The present study utilizes a threshold analysis to compare the cost relationships of competing management options. A low threshold is generally indicative of an attractive management strategy. Three exemplary scenarios were studied to illustrate that in multiple instances, the armamentarium of interventional endoscopy contains useful tools for avoiding more invasive and costly surgical alternatives. The three scenarios included a carcinoma-in-situ of the esophagus, a large polyp of the colon, and an adenoma of the duodenal papilla. In all three scenarios, the baseline threshold for trying to first achieve therapeutic success through endoscopy before resorting to more invasive surgical procedures was relatively low, ranging between 10 and 17%. Rather than encouraging endoscopists to embark on their own threshold analysis, the clinical applicability of the present decision analysis relates to emphasizing the general benefit of starting treatment of many complex gastrointestinal diseases by means of advanced endoscopy.

In general, a low threshold associated with any type of medical intervention speaks in its favor. The higher the threshold, the less favorable the medical intervention becomes. A threshold of 30% associated with a given type of intervention means that when choosing such intervention, a success should occur in at least 30% of its applications. As the threshold increases, the *a-priori* demands for a high success rate increase as well. For instance, if the threshold for an intervention rises above 50% or 80%, the physician needs to be exceedingly sure about its expected success rate, or otherwise other procedural alternatives should be considered instead. It also needs to be stressed that even a low threshold for endoscopy never completely rules out the use of its surgical alternative. As already built into the original second decision model, the surgical approach always remains a welcome alternative should the endoscopic approach fail.

Our analysis confirms the validity of a general principle in medical practice that most gastroenterologists may intuitively have already implemented in their clinical routine. If multiple means are available to achieve a therapeutic goal, clinicians should use these means in succession and start with the cheapest and least invasive one first. In speaking to patients, surgeons, and endoscopists about their treatment preferences, we encountered two types of general arguments that we tried capturing by two different types of threshold analysis. The first argument (and threshold analysis) was centered on a single medical issue, such as risk of death from cancer. This argument strongly advocated for the procedure that would provide the best response in terms of reducing death from cancer, but willfully chose to ignore death and costs associated with the medical interventions. Such approach always favors the procedural alternative that most profoundly reduces the risk of death from the disease itself. The focus on preventing death from a life-threatening disease is easy to understand and may appeal to many patients. However, such outlook tends to ignore the impact of a seemingly life-saving procedures on healthcare expenditures and patients' long-term quality of life. The second argument (and threshold analysis) was based on a broader perspective that included the costs of various approaches with respect to their financial expenses, as well as their post-procedural adverse events and associated long-term disability. For its completion, the second approach requires a far more elaborate analysis of various factors associated with healthcare expenditures. The second analysis reveals that although some therapeutic means, which are surpassed in their efficacy by more aggressive and sweeping alternatives, may still retain their clinical relevance, usefulness, and even superiority by providing less expensive, invasive, or debilitating alternatives. As complex decision making is nowadays often done in a multidisciplinary manner, including surgeons and gastroenterologists, the latter points would need to be emphasized by the gastroenterology side in these discussions.

In the analysis, costs of failure or adverse events are reflected by the costs of repeated endoscopic or surgical interventions and lengthy hospitalization during and after the initial intervention as the disease progresses, as well as the resulting diminished quality of life and overall loss in life-years. Lost life-years or quality of life were expressed as loss in income. We deliberately used the average annual income in the USA, unstratified by age or gender group, to capture the impact of reduced wellbeing or life expectancy that occurs even after retirement. Although such usage is generally accepted by health economists, it may grossly underestimate the discomfort, anguish, and loss perceived by individual patients and their family. There are several other aspects, such as oncologic outcomes, disease free survival, and payment by insurance companies for endoscopic procedures, which were not addressed in the present analysis. Yet another potential limitation with respect to endoscopic intervention relates to the sparsity of reliable long-term outcome data. All types of modeling in medical decision analysis assume that physicians act rationally and follow current standards of practice. They model the ideal case and only account for relative common adverse events. In individual patients, the actual costs may vary to an even larger extent than shown here. Such underestimation of costs and their heterogeneous origins most likely affects both comparison groups alike, that is, surgery as well as interventional endoscopy.

Besides the three types of medical conditions discussed in the present analysis, other examples abound for the decision making between a surgical and endoscopic treatment choice. Based on prospective randomized clinical trials, it has been suggested that in patients with pancreatic duct stones, better outcomes are achieved by a surgical rather than endoscopic approach to management [26]. In a fraction of patients with symptoms of gastro-esophageal reflux disease, surgical fundoplication may provide a better symptom relief than chronic intake of antisecretory medication [27]. Autoimmune pancreatitis may mimic pancreatic cancer, where timely surgical excision is crucial for survival [28]. Even if a management strategy surpasses its alternative with respect to one important outcome parameter, there is often still room for the lesser alternative to be considered a viable option. In the analysis, the cost comparison of the two competing strategies eventually boils down to a single factor *b* that easily translates into a threshold value. To apply the present decision tool to other clinical scenarios, one may not always need to engage in an elaborate cost analysis. Frequently, a quick mental assessment of the orders of magnitude associated with the resource utilization by the two management alternatives may already provide the physician with a fairly reliable estimate of the cost ratio and its associated threshold value.

In conclusion, threshold analysis is a useful instrument to study the factors, which influence the choice between competing management options of various gastrointestinal disorders. Such decision analysis reveals that many procedures of interventional endoscopy can serve as relatively inexpensive substitutes for more invasive surgical operations. The threshold for choosing between endoscopic versus surgical management options is influenced by the costs of the available alternatives, as well as characteristics and preferences of the individual patient. Ideally, these issues are being addressed in a multidisciplinary discussion among gastroenterologists and surgeons.

Author contributions Conception and design: AS, GB, PB; decision analysis: AS; writing of manuscript: AS, GB, PB.

Declarations

Disclosures Amnon Sonnenberg, Gennadiy Bakis, and Peter Bauerfeind have no conflict of interest or financial ties to disclose.

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