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Cost-Effective Diagnosis of Ingested Foreign Bodies

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Objectives: **To compare the cost effectiveness of plain film radiography, computed tomography (CT), and endoscopy as initial diagnostic modalities in adult patients complaining of retained ingested foreign bodies. *Design:* A systematic literature review was conducted to determine key statistics for the analysis, such as prevalence of disease, prevalence of complications, and the sensitivity and specificity of each diagnostic modality. Costs were estimated using 2006 Medicare reimbursement for hospital and professional fees. A deterministic cost-effectiveness analysis was then conducted using decision analysis software and a decision tree model to evaluate the various diagnostic strategies. After identifying initial results, we also performed sensitivity and threshold analysis to assess the strength of the recommendations. *Results:* We reviewed 316 abstracts, identified 16 pertinent studies that included a total of 7,088 patients with possible foreign bodies, and extracted key statistics from those papers. Decision analysis showed that CT scanning as an initial diagnostic strategy proved more cost effective than plain film or operative endoscopy. The incremental cost of immediate endoscopy for every additional correctly diagnosed patient was $5,238. Plain radiography was more costly and less effective, even with the addition of confirmatory CT scanning after a negative plain film. Sensitivity and threshold analyses demonstrated that these results are robust. *Conclusions:* Patients presenting with a complaint of a retained ingested foreign body are most cost-effectively managed with CT scan, after history and physical. Immediate endoscopy may be considered if CT is not available, although it adds significant cost. Plain films are dominated by these two diagnostic strategies. *Key Words:* Cost-effectiveness analysis, esophageal foreign bodies, pharyngeal foreign bodies, computed tomography, plain radiography.**

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INTRODUCTION

Retained ingested foreign bodies are a frequent and potentially dangerous presenting complaint, resulting in approximately 1,500 deaths annually.[1,2] The diagnosis of foreign bodies, however, is fraught with difficulty: many patients who present with complaints of a retained foreign body do not actually have one. Clinicians are aware of this and often choose a diagnostic strategy to minimize cost and risk. However, a missed foreign body carries with it a significant potential for morbidity and even mortality. Traditionally, plain radiography (XR) of the neck has been used as the initial diagnostic modality, but it is notoriously unreliable.[2–4] To combat this unreliability, other modalities have been proposed, from immediate endoscopy in the setting of a negative plain film[5] to initial computed tomographic (CT) scanning.[6] Both modalities offer better sensitivity and specificity than plain films, but both are associated with a significant increase in cost.

As a result of the rising cost of health care, there is a commensurate rising interest in cost containment and cost effectiveness. Studies in the cost-effective management of various surgical and nonsurgical entities have been published with increasing frequency in the last two decades.[7,8] These studies compare the costs of diagnostic or therapeutic modalities with their relative effectiveness, determining the modality that relatively costs the least for the most incremental benefit. Finding the most appropriate modality for the diagnosis of esophageal foreign bodies lends itself to such an analysis. This study was therefore performed to compare the costs and benefits of XR, CT, and direct endoscopy in the diagnosis of a retained esophageal foreign body.

MATERIALS AND METHODS

This paper evaluates ingested, retained pharyngoesophageal foreign bodies, referred to throughout the manuscript as "retained foreign bodies."

Literature Review

A PubMed search using the MeSH terms “Foreign Bodies” and “Esophagus” yielded 2,078 papers written between 1966 and 2006. Limiting these citations to those written in English and to those containing adult patients pared the list to 316. Each citation was evaluated and its bibliography searched for citations missed in the initial screen. Studies were included if they contained data on the rate or type of complications, the prevalence of retained foreign body in patients with this presenting complaint, or a comparison of radiologic modalities with each other or with endoscopy. Case reports were excluded. Sixteen studies were identified that fit the above criteria.

Data extracted from each study are summarized in Tables I and II. Many papers included children; when possible, data from adults were considered alone. In some cases, however, this was impossible, and data were combined.

Cost and Prevalence Estimation

Actual cost data in medicine can be difficult to obtain; as a result, in this study, average Medicare reimbursement (standardized for Manhattan, New York, USA, for 2006) was used as a surrogate marker for cost. The ICD-9 code employed for these determinations was 935.1 (esophageal foreign body). The ICD-9 code employed for mediastinitis, which was taken as representative of complications, was 519.2. Costs for radiography include Medicare reimbursement for physician interpretation. Costs for operative procedures include the surgeon’s reimbursement, the anesthesia reimbursement, and the hospital charge. It should be noted that there is a slight increase in reimbursement for endoscopy in the presence of a foreign body compared with simple endoscopy. The following CPT codes were employed: plain film, 70360; CT without contrast, 70490; endoscopy with foreign body removal, 43215; endoscopy without foreign body removal, 43205.

To complete the analysis, it was necessary to assign a cost for death. This estimation can be problematic and varies across industries. The National Safety Council estimates death from unintentional injuries to be worth $1,130,000.[9] This was adopted in our study. The prevalence of foreign body, complications, and the true-positive and true-negative rates of radiological studies were calculated using a weighted average of the compilation of the literature. All variables were subjected to a sensitivity analysis (see below).

Design of Decision Trees

A deterministic decision-making tree was constructed first using each diagnostic modality singly (Fig. 1). Endoscopy was employed as the gold-standard diagnostic modality for this comparison. For each radiological modality, branches were constructed for each of the true-positive, true-negative, false-positive, and false-negative possibilities. False-negative patients were assumed to be sent home with their foreign body. A sub-tree was constructed for these patients with branches for the passage of the foreign body, a return visit with an uncomplicated endoscopy, complications, or death.

At this point, a second tree was constructed. This tree merits explanation: in an attempt to obviate the high chance of false negatives with XR, the practitioner may choose to follow a negative study with a second radiological study or to take the patient directly to endoscopy. The latter option negates the value of the radiological studies and simply adds their cost to patients who were destined for endoscopy regardless of radiological results. As a result, only the former was modeled. In the case of a negative XR, it made sense for CT to be considered. However, the contrapositive did not. The resultant tree is given in Figure 2.

Cost-Effectiveness Analysis

In cost-effectiveness studies, effectiveness can comprise any number of variables; examples include quality-adjusted life years, changes in life expectancy, or effectiveness of diagnosis. In this study, effectiveness was defined as a correct diagnosis of the presence or absence of a retained foreign body prior to direct

TABLE IA.
Literature Review of Prevalence of Foreign Bodies and Sensitivity and Specificity of Diagnostic Modality: Plain Radiography.

Author	Year	Prospective?	Number of Patients	Number of FB	Percent of Symptomatic Patients With FB*	FP	FN	TP	TN	Sens (%)	Spec (%)
Akazawa[3]	2004	Y	76	31	40.79	0	14	17	45	54.84	100.00
Athanassiadi[10]	2002	N	400								
Braverman[6]	1993	Y	12	9	75.00	0	6	3	2	33.33	100.00
Chaikhouni[11]	1985	N	88	88		0	12	67	0	84.81	
Ciriza[12]	2000	Y	122	64	52.46	0	54	10	58	15.63	100.00
de Lucas[23]	2004	Y	36	14	38.89						
Eliashar[21]	1999	Y	45	29	64.44	1	14	15	15	51.72	93.75
Gonzalez[13]	1991	Y	100	72	72.00	10	17				
Hsu[14]	2000	N	1,943								
Khan[15]	2004	Y	103								
Lai[1]	2003	N	1,028	401	39.01	58	294	114	562	27.94	90.65
Lam[16]	2001	N	5,240	198	3.78						
Lim[17]	1994	Y	397	197	49.62		123	48		28.07	
Loh[18]	2000	N	273	273							
Singh[19]	1997	N	119	119		0	37	55	0	59.78	
Watanabe[20]	1998	Y	32	24	75.00	1	8	2	0	20.00	0.00
Weighted average			7,088	1,039	14.66	70	579	331	682	36.37	90.69

*Studies looking only at patients with documented foreign bodies were not included in this column.

FB = foreign body; FP = number of patients with false-positive plain films; FN = number of patients with false-negative plain films; TP = number of patients with true-positive plain films; TN = number of patients with true-negative plain films; Sens = sensitivity; Spec = specificity.

TABLE IB.
Literature Review of Prevalence of Foreign Bodies and Sensitivity and Specificity of Diagnostic Modality: Computed Tomography.

Author	FP	FN	TP	TN	Sens (%)	Spec (%)
Akazawa[3]						
Athanassiadi[10]						
Braverman[6]	0	0	9	3	100	100
Chaikhouni[11]						
Ciriza[12]						
de Lucas[23]	2	0	14	20	100	90.91
Eliashar[21]	1	0	29	15	100	93.75
Gonzalez[13]						
Hsu[14]						
Khan[15]						
Lai[1]						
Lam[16]						
Lim[17]						
Loh[18]						
Singh[19]						
Watanabe[20]	1	0	10	0	100	0
Weighted average	4	0	62	38	100	90.48

FN = number of patients with false-negative computed tomography (CT); TP = number of patients with true-positive CT; TN = number of patients with true-negative CT; Sens = sensitivity; Spec = specificity.

endoscopy. Modalities which were able to diagnose the presence or absence of the foreign body correctly were assigned an effectiveness of 1; those which were not were assigned an effectiveness of 0. By definition, the branches of the decision tree which used endoscopy as the initial diagnostic modality were both assigned an effectiveness of 1.

Cost-effectiveness analyses attempt to determine whether one intervention provides enough of an incremental increase in effectiveness to justify its cost. This incremental increase in effectiveness versus cost is determined by the calculation of an incremental cost-effectiveness ratio (ICER) between two strategies by dividing the difference in the cost (c) of two strategies by the difference in the effectiveness (e) of the same two strategies. As an example, the ICER comparing a new diagnostic strategy with one already accepted would be $(c_{\text{new}} - c_{\text{old}})/(e_{\text{new}} - e_{\text{old}})$. This ICER, therefore, represents the cost of every incremental increase in effectiveness in the new strategy.

A modality can be defined as *dominant* if it is both less costly *and* more effective than another modality. In the above equation, this would be represented by a negative numerator and

TABLE II.
Prevalence of Complications From Esophageal Foreign Bodies.

Author	Number of Foreign Bodies	Complications (%)	Mean LOS With Complications (days)	Mortality of Complications (%)	Overall Mortality (%)
Athanassiadi[10]	400	0.50	6–12	50	0.25
Chaikhouni[11]	88	11.36			
Ciriza[12]	64	0			0
de Lucas[23]	36	0.50			
Gonzalez[13]	72	1.39			0
Hsu[14]	1943	0.41			
Khan[15]	35	5.71			
Lai[1]	401	7.23	10.3		
Lam[16]	198	5.56		0	0
Loh[18]	273	7.33		10	0.73
Singh[19]	119	12.61			
Watanabe[20]	34	4.17			
Weighted Average	3663	2.72			0.32

Only major complications (mediastinitis, perforation, abscess formation, and the need for thoracotomy) are included.
LOS = length of stay.

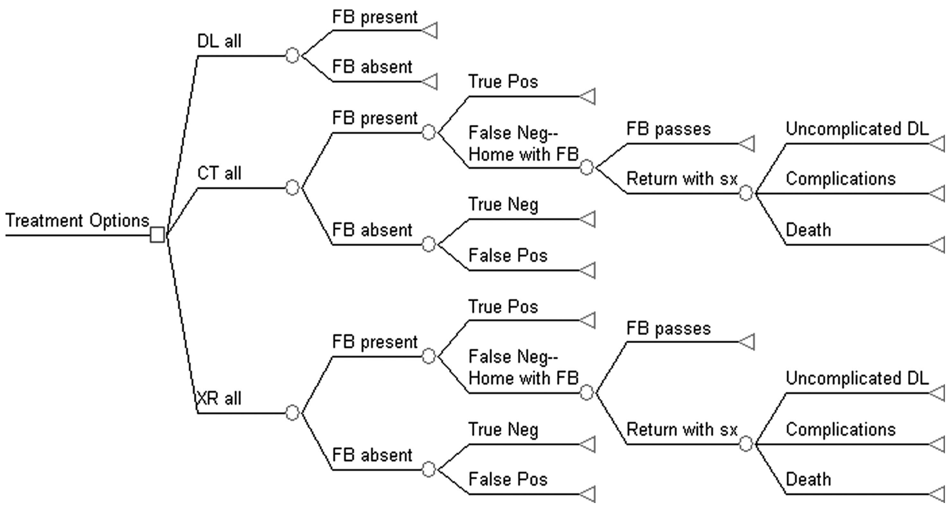

Fig. 1. Single-modality decision tree. DL = endoscopy; XR = plain radiography; CT = computed tomography; FB = foreign body; □ = decision node; ○ = probability node; ◁ = terminal node. Numerical value of all variables is defined in Table III.

a positive denominator, making the ICER a negative number. In this situation, the new strategy is said to dominate the old. If, however, the ICER is positive (meaning the new strategy is more costly than the old but also more effective), the value of the ICER represents the cost associated with this increased effectiveness. The acceptability of this increased cost depends on the willingness of payers (insurance agencies, patients, or the health care system itself) to pay that incremental cost.

Cost-effectiveness analysis was performed using TreeAge Pro Healthcare Module 2006 decision analysis software (DATA Version 4.0; TreeAge Software, Inc., Williamstown, MA). Sensitivity analysis was performed on every cost and prevalence variable in this study. If changing the value of the variable changed the result of the cost-benefit analysis significantly, then the analysis was said to be sensitive to that particular variable.

Assumptions

We assumed that every patient had undergone a complete history and physical, including flexible laryngoscopy, and that no ingested foreign body was seen. In addition, we assumed that the patients entering this decision tree had findings on history and/or physical that were concerning enough for the diagnosing physician to entertain the possibility of a retained ingested foreign body.

There is a small, but present, risk of complications from routine direct laryngoscopy, either with or without the presence of a foreign body. This includes the risks of general anesthesia as well as minor (e.g., chipped tooth) and major surgical risks and their attendant costs. Because the probability of this risk is small, all initial direct laryngoscopies were assumed to proceed without complication.

In addition, we had to estimate the cost of "complications" in general, not including death. Because esophageal perforation with its attendant sequelae is the most feared complication, we assigned this event as the cost of complications, and included a stay in the intensive care unit, intravenous antibiotics, possible mechanical ventilation, and possible thoracotomy. This assumption is discussed in more detail below. Finally, the personal and societal costs associated with this condition, including those of missed work and missed pay, were not factored into this calculation.

RESULTS

Literature Review

Overall, 316 studies were screened, of which 16[1–3,6,10–21] were included in this analysis. The combined studies evaluated 10,014 patients. The studies by Khan,[15] Singh,[19] Chaikhouni,[11] Hsu,[14] Loh,[18] and Athanassiadi[10] evaluated only patients with known esophageal foreign bodies. With these excluded, 7,088 presenting with a possible foreign body were used to calculate a prevalence of disease. Of these, 1,039 patients (14.66%) had foreign bodies in the upper aerodigestive tract.

XR of the neck was performed on 1,662 patients. Calculated sensitivity and specificity for this modality were 36.37% and 90.69%, respectively. CT was performed

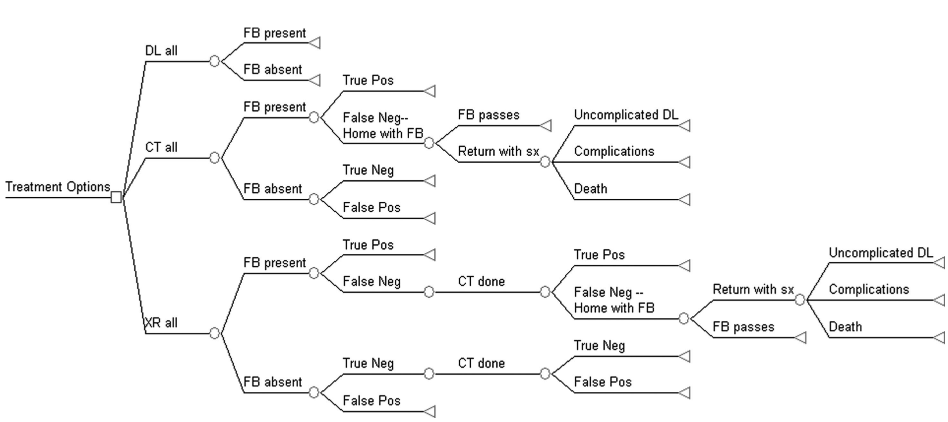

Fig. 2. Sequential decision tree. DL = endoscopy; XR = plain radiography; CT = computed tomography; FB = foreign body; □ = decision node; ○ = probability node; ◁ = terminal node. Numerical value of all variables is defined in Table III.

TABLE III.
Estimation of Costs With Ranges Used in Sensitivity and Threshold Analyses.

Variable	Value	Range
Costs (US$)		
Plain radiography	30.72	10–100
CT	308.01	200–500
Endoscopy		
+FB	999.95	500–1,500
−FB	950.04	500–1,500
Complications	90,797.00	10,000–500,000
Death	1,130,000	100,000–3,000,000
Probabilities (%)		
Presence of FB*	14.66	5–25
XR sensitivity	36.37	10–80
XR specificity	90.69	75–100
CT sensitivity	100	75–100
CT specificity	90.48	75–100
Self-resolution	10	0–50
Complications	2.72	0–5
Death	0.32	0–5

*Expressed as a percentage of patients presenting with complaint of foreign body ingestion.
FB = foreign body; XR = plain radiography; CT = computed tomography.

on 104 patients. Calculated sensitivity and specificity were 100% and 90.48%, respectively. These results are summarized in Table I. Complications occurred in 2.72% of cases (range: 0% to 12.6%), and overall mortality was less than 0.73%, as summarized in Table II. The mortality of complications ranged from 0% to 50%.[10,12,16,18]

Cost Estimation

Costs were estimated based on Medicare reimbursement, standardized for Manhattan, NY, for 2006. The cost of a plain film was estimated at $9.91, with interpretation adding $20.81. A CT of the neck without contrast was estimated to cost $72.30 (or $308.01 with interpretation). Hospital and anesthesia reimbursement for endoscopy were $804.02; the surgeon's reimbursement varied with the presence of a foreign body ($195.93 with removal of foreign body and $146.02 without).

The costs of complications and of death were problematic. Depending on the treatment required, the cost of major complications was found to run between $90,797 and $487,908. In an attempt to minimize the impact of this variable on the result, the lower number was assigned to the cost of complications, and a sensitivity analysis was performed on this variable. Finally, death was estimated at $1,130,000.[9] Estimated costs are summarized in Table III.

Design of Decision Trees

A deterministic decision-making tree was constructed first using each diagnostic modality singly (Fig. 1) then using the diagnostic modalities in sequence (Fig. 2). As stated above, endoscopy was used as the gold-standard diagnostic modality.

Cost-Effectiveness Analysis

Using the single-modality tree (Fig. 1), cost-effectiveness calculations were carried out. Baseline values for cost, effectiveness, and ICERs are summarized in Table IV. CT as the initial diagnostic modality had an expected cost of $531.80 per patient and could be expected to diagnose the presence or absence of a foreign body correctly (i.e., its effectiveness) in 91.9% of patients. XR as the initial diagnostic modality had an expected cost of $751.80 per patient and an effectiveness of 82.7%. Because this modality is both more costly and less effective than CT alone, it is said to be dominated by CT. Taking patients directly to endoscopy as their diagnostic modality increased effectiveness to 100%, by definition. However, the cost of this strategy is $957.40, leading to an ICER of $5,238. Adding CT scans to a negative XR, as represented in Figure 2, increased the effectiveness of the XR arm, as expected, to 84.7% and decreased its expected cost to $589.90 (Table V), but initial CT scanning continued to dominate, remaining both more effective and less costly.

Sensitivity Analyses

To assess how dependent our results were on the value chosen for each variable, sensitivity and threshold analyses were performed on all variables in both decision trees, within the limits shown in Table III. The results are given in Tables VI and VII. Our recommendation for CT as the most cost-effective initial diagnostic modality is dependent on few variables. If the cost of death drops below $310,971, the risk of death from an undiagnosed foreign body below 8 in 10,000, or the prevalence of foreign bodies overall below 8.8%, then XR becomes the

TABLE IV.
Expected Costs, Effectiveness, and Incremental Cost-Effectiveness Ratios (ICERs) for Single-Modality Decision Tree*.

Strategy	Expected Cost (US$)	Incremental Cost (US$)	Expected Effect	Incremental Effect	Cost/Effect (US$)	ICER (US$)
CT alone	531.80	NA	0.919	NA	579	NA
XR alone	751.80	220.00	0.827	−0.091	−909	Dominated†
Endoscopy alone	957.40	425.60	1.000	0.081	957	5,238

*Calculated from the single-modality decision tree modeled in Figure 1.
†See text for details.
CT = computed tomography; XR = plain radiography.

TABLE V.
Expected Costs, Effectiveness, and Incremental Cost-Effectiveness Ratios (ICERs) for Sequential Decision Tree.

Strategy	Expected Cost (US$)	Incremental Cost (US$)	Expected Effect	Incremental Effect	Cost/Effect (US$)	ICER (US$)
CT alone	$531.80	NA	0.919	NA	$579	NA
XR, then CT if negative	589.90	58.10	0.847	−0.072	−697	Dominated†
Endoscopy alone	957.40	425.60	1.000	0.081	957	5,238

*Calculated from sequential decision tree modeled in Figure 2.
†See text for details.
CT = computed tomography; XR = plain radiography.

preferred modality. In addition, if the sensitivity of plain films rises to 64.4% or the chance of self-resolution of the retained foreign body to 43.4%, then XR again becomes more cost effective.

Because we chose to model only the more feared complications, we varied the cost of complications between $1,000 and $500,000 to take less severe complications into account. At no point along that range did CT lose its dominance (Fig. 3). A two-way sensitivity analysis was also performed, varying the sensitivity of CT along with the cost of complications. These results are represented in Figure 4; over the vast majority of values, CT remains most cost effective.

When the possibility of proceeding to a CT scan in the presence of a negative plain film is added to the decision tree, the results become significantly more robust. In this case, the above variables no longer impact on the recommendation for CT, which becomes dependent only on the sensitivity of CT itself. If this sensitivity drops to 78.1% (rather than 100% as implied in the literature), then XR becomes the most cost-effective diagnostic modality. A similar two-way sensitivity analysis plotting cost of complications against sensitivity of CT was performed using this tree. Again, throughout the believable range of values, CT remains most cost effective. These results are represented in Figure 5.

DISCUSSION

That a retained ingested foreign body is a common and potentially life-threatening complaint is known.[1,2]

TABLE VI.
Sensitivity and Threshold Analysis Results for Single Diagnostic Modalities*.

Variable	Sensitive?	Value	Threshold Value†	Preferred Modality
Costs (US$)				
Plain radiography	N	30.72		
CT	N	308.01		
Endoscopy				
+FB	N	999.95		
−FB	N	950.04		
Complications	N	90,797.00		
Death	Y	1,130,000	310,971	XR
Probabilities (%)				
Presence of FB‡	Y	14.66	8.2	XR
XR sensitivity	Y	36.37	64.4	XR
XR specificity	N	90.69		
CT sensitivity	N	100		
CT specificity	N	90.48		
Self-resolution	Y	10	43.4	XR
Complications	N	2.72		
Death	Y	0.32	0.08	XR

*This analysis is carried out using the single-modality decision tree delineated in Figure 1.
†The threshold value is the value below which the recommended modality switches from CT to the preferred modality indicated.
‡Expressed as a percentage of patients presenting with a complaint of foreign body ingestion.
FB = foreign body; XR = plain radiography; CT = computed tomography.

TABLE VII.
Sensitivity and Threshold Analysis Results for Sequential Diagnostic Strategy*.

Variable	Sensitive?	Value	Threshold Value†	Preferred Modality
Costs (US$)				
Plain radiography	N	30.72		
CT	N	308.01		
Endoscopy				
+FB	N	999.95		
−FB	N	950.04		
Complications	N	90,797.00		
Death	N	1,130,000		
Probabilities (%)				
Presence of FB‡	N	14.66		
XR sensitivity	N	36.37		
XR specificity	N	90.69		
CT sensitivity	Y	100	78.1	XR
CT specificity	N	90.48		
Self-resolution	N	10		
Complications	N	2.72		
Death	N	0.32		

*This analysis is carried out using sequential decision tree delineated in Figure 2.
†Threshold value is value below which modality switches from CT to preferred modality indicated.
‡Expressed as percentage of patients presenting with complaint of foreign body ingestion.
FB = foreign body; XR = plain radiography; CT = computed tomography.

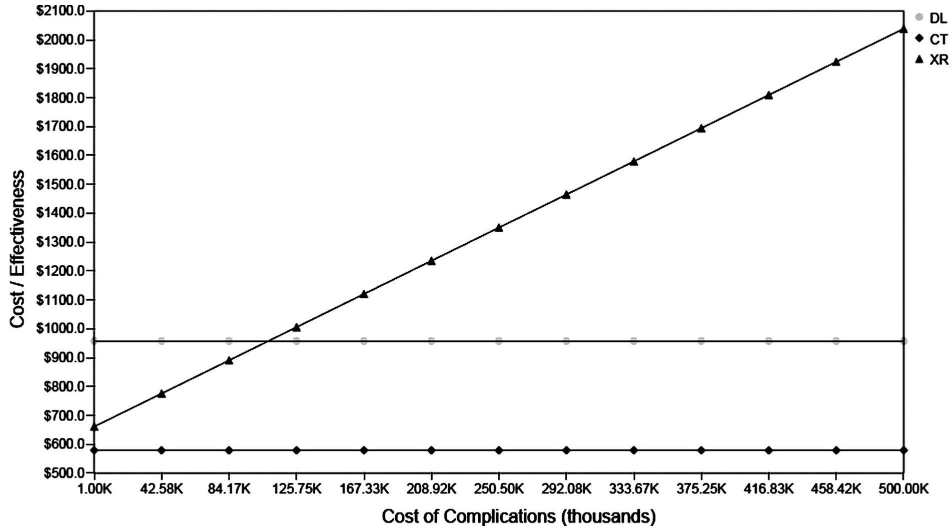

Fig. 3. One-way sensitivity analysis on cost of complications. At all values, computed tomography remains most cost effective.

Unfortunately, its diagnosis often presents a dilemma. Classically, plain roentgenograms of the neck or chest have been used in an attempt to detect the presence of retained foreign bodies.[1,2,6,15,22] These, however, are notoriously unreliable, especially in the presence of small, nonopaque foreign bodies such as fish bones,[6,11] leading to the development of alternate protocols for diagnosis, based on the location of symptoms,[16] or the use of other diagnostic modalities.

Some authors recommend immediate endoscopy,[5] whereas others have proposed barium esophagography,[10,13,22,23] or CT[6,20] for patients presenting with symptoms of a retained foreign body. Contrast esophagography deserves mention. As a technique, it has been largely abandoned because of its significant false-positive and -negative rates and its potential for interference with later endoscopy.[3,13] As a result, it was not included in our cost-effectiveness analysis.

In the current cost-saving milieu in which medicine is now practiced, cost-effectiveness analyses are important. The question of the most appropriate modality for the diagnosis of a retained foreign body lends itself ideally to this sort of analysis: the sensitivities and specificities of each diagnostic modality are available in the literature as are the rates of complications and the prevalence of the condition itself. Cost may easily be estimated from a standardized reimbursement schedule. Therefore, we set out to determine whether plain film, which is currently the de facto study of choice, really represents the most cost-effective diagnostic modality for retained foreign bodies.

Comparisons of the three modalities on their own show that initial CT scan is more cost effective than either direct endoscopy or plain film radiography. Specifically, as an initial strategy, plain films are dominated by CT. However, an argument may be made for a stepwise algorithm, with performance of the easiest and least expensive test (plain film) first, then a CT scan if the plain film is negative. We evaluated this strategy in the decision tree modeled in Figure 2. As expected, adding the improved diagnostic

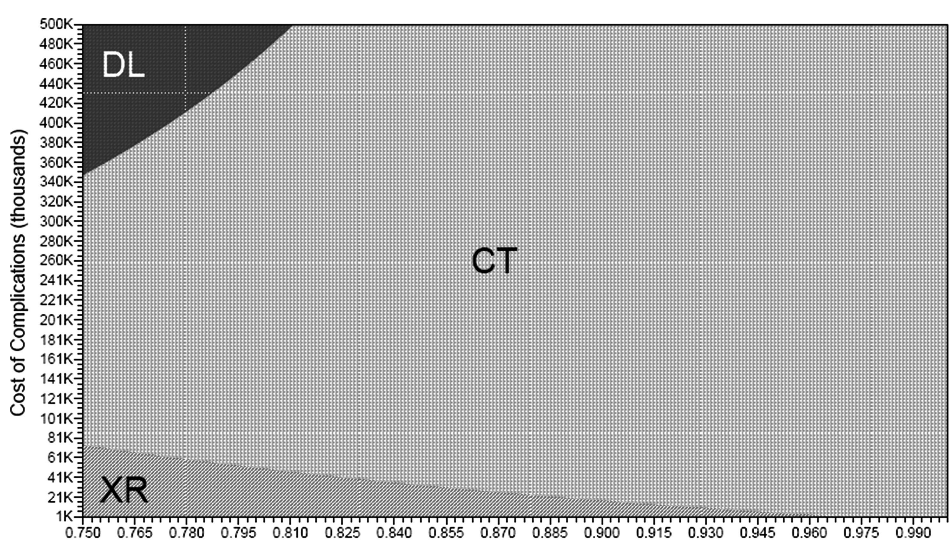

Fig. 4. Two-way sensitivity analysis varying cost of complications against sensitivity of CT scanning. This analysis uses single-modality decision tree (Fig. 1). Most cost-effective strategy is labeled: DL = endoscopy; XR = plain radiography; CT = computed tomography.

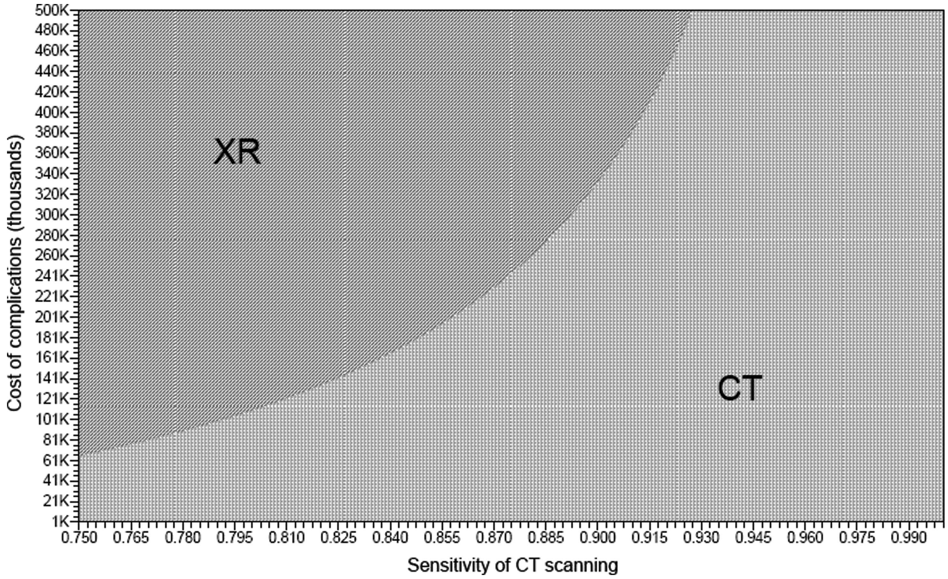

Fig. 5. Two-way sensitivity analysis varying cost of complications against sensitivity of CT scanning. This analysis uses sequential decision tree (Fig. 2). Most cost-effective strategy is labeled: XR = plain radiography; CT = computed tomography.

accuracy of CT to a plain film reduced the expected cost and improved the overall accuracy of that diagnostic strategy; however, it remained more costly and less effective than CT alone. As a result, CT is recommended as the initial diagnostic modality for a suspected retained foreign body.

To perform this study, we were required to estimate costs and probabilities from the best available data in the literature. There are, unfortunately, few prospective studies evaluating these various diagnostic modalities. As a consequence, our results risk strong dependence on these potentially flawed estimations. For this reason, sensitivity and threshold analyses were performed on every variable. Wide ranges were given for each particular variable; the ICERs were recalculated within these ranges; and our conclusions remain robust. Although five variables appear to influence our calculations, this influence occurs only at thresholds drastically different from values quoted in the literature. In addition, when CT is added after a negative plain film, these sensitivities disappear. Variability in this setting only occurs when the sensitivity of CT scanning drops to an unrealistically low number.

Regarding the sensitivity and the specificity of CT scanning, the numbers in the literature from which our values were calculated are significantly smaller than those for plain film, likely because of the recent addition of CT scanning to the diagnostic armamentarium. However, despite what appears to be an inordinately high sensitivity for this modality (100%), our results are resistant to moderate fluctuations in this value; at no point in the literature does the sensitivity for this test drop below 90%, well above the threshold value determined by our sensitivity analyses. In addition, given the theoretical ability of CT to diagnose a retained foreign body, the fact that the specificity of this modality is less than 100% appears surprising. In all the studies reviewed, there were four false-positive results; the authors of one study[20] interpreted their single false-positive (of 11 cases) as passage of the foreign body in the interval between radiographic diagnosis and endoscopy. Although this is conceivable, for the purposes of this study, all theoretical "passages" were interpreted as false-positive CT scans, possibly artificially lowering the specificity of this modality. Regardless of this decision, our results are not affected by variability in the specificity of CT scanning. This, however, forms the basis of our assumption that the chance of passage of the foreign body is approximately 10%.

In our experience, the false-negative rate of plain film radiography is high, and this is borne out in the literature. Despite what may appear to be a low sensitivity for plain films in the body of the literature, doubling this sensitivity does not change our recommendations. Furthermore, even adding CT scanning after a negative plain film does not make that strategy more cost effective than CT scan alone.

Finally, although mediastinitis represents the most feared complication of a foreign body removal, it is definitely not the most common. A one-way sensitivity analysis varying the cost of "complications" from minimally more than the cost of the operation itself to significantly greater showed no threshold at which plain films became more cost effective. We attributed this to the high sensitivity and specificity of CT scanning; as a result, two-way analyses were performed varying costs of complications against the sensitivity of CT. Again, both variables require drastic changes before CT loses its dominance.

Any cost-effectiveness study makes assumptions. Ours is no different. We assumed that all patients had been evaluated by history, physical, and flexible laryngopharyngoscopy, and that, despite a concerning history, no foreign body was visualized on examination. The cost of a visit to the emergency room, with these attendant modalities, was not factored into our calculations. Although a patient with a missed foreign body would be subject to these costs twice, sensitivity analysis does not support variability in our conclusions with additional cost to death, complications, or the price of a positive endoscopy.

In the models shown in Figures 1 and 2, we assumed direct laryngoscopy and esophagoscopy to be the diagnostic gold standard. It could be argued that the fact that we did not include potential additional costs of routine direct laryngoscopy, such as complications, missed work, or additional hospital time, in our analysis might unfairly bias the results *toward* laryngoscopy. This strengthens our actual recommendation that routine laryngoscopy is not a cost-effective strategy. We recognize that there is a small, but present, chance of false-negatives with this modality and a theoretical chance of false-positives. As a result, a sensitivity analysis was performed on a tree in which these theoretical possibilities were modeled (not shown). The data were resistant to variability in the sensitivity and specificity of endoscopy between 50% and 100%.

In addition to these assumptions, there are weaknesses to this study that must be mentioned. Our probabilities are estimated from a review of the literature and a combined analysis of the data contained in 16 studies. These studies are heterogeneous and therefore contribute a significant variability to our numbers. For this reason, sensitivity analyses were performed on each variable in an attempt to dilute this heterogeneity. In addition, as much as possible, children were separated from the calculations. Although children more frequently aspirate foreign bodies, many children ingest foreign bodies as well. Their presentations, however, are different: up to 40% are not witnessed, up to 50% of children with documented foreign body ingestion are not symptomatic, and, considering the nature of the objects children ingest, a significantly increased number of them pass spontaneously.[24] In studies in which children were included, they formed 7% to 66% of the study group.[10-12,15,17,19] A sensitivity analysis (not shown) in which the chance of passage of the foreign body is increased to 90% still shows no change in the recommendation for CT as the most cost-effective diagnostic modality.

Finally, there is an inherent weakness in the design of any cost-effectiveness study because access to actual costs is limited, and costs vary across institutions. Accepted surrogate markers include estimation from either random sampling of patients or from the reimbursement schedules of standardized payers.[8] The latter method was used in this study, specifically estimating costs as Medicare reimbursements standardized to Manhattan, New York. However, the portability of these results to other institutions across the United States or to other countries with other health care systems may be limited.

CONCLUSIONS

For a patient presenting with a complaint of a retained ingested foreign body, initial CT scanning is the most cost-effective diagnostic strategy. In situations in which CT scanning is not readily available, consideration must be given to immediate rigid endoscopy, especially if the cost of obtaining this CT scan rises to greater than $5,200. XR is more costly and less effective than either CT or endoscopy and is therefore not recommended by this analysis. Sensitivity and threshold analyses demonstrate that these recommendations are robust. Prospective clinical studies are warranted to validate these findings.

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