Pulmonary Embolism and Lung Scanning: Cost-Effectiveness and Benefit:Risk

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The cost-effectiveness of pulmonary imaging (lung scan) on the management of 2,023 patients was studied. Prior and postscan probabilities of pulmonary embolism (PE) were obtained from referring physicians. After the scan, anticoagulant therapy (ACT) was appropriately changed in 20% of the patients and confirmed in 67%. The incremental cost of scanning was $124 per patient when the prior probability was 0.01–9.99%, dropping to $38 when the probability was 10–25%. Hospitalization and ACT cost was reduced when the prior probability was 25.01–99.99%. The greatest benefit in lives saved was when the prior probability was 25–74.99%; 1.5% of this probability group would survive as a result of the change in management attributable to the scan, at a cost of $117 per life saved. The benefit:risk ratio, as measured by lives saved compared to estimates of lives lost due to radiation exposure, was of the order of 6,000:1.

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The purpose of this analysis was to determine the cost-effectiveness of lung scans in the management of patients with pulmonary embolism (PE) as defined by the signout diagnosis. The term "lung scan" in this report refers to the nuclear medicine procedure of pulmonary imaging (perfusion/ventilation) (*1*). Cost-effectiveness of the lung scan, in terms of incremental cost and cost per life saved, was determined for groups of patients with varying prior probabilities of PE. For purposes of this analysis, management of PE was considered appropriate if anticoagulant therapy (ACT) was administered, and inappropriate if ACT was not administered; management of patients without a signout diagnosis of PE was considered appropriate if ACT was not given. This paper reports the action of physicians in usual clinical practice.

MATERIALS AND METHODS

Population

The data analyzed in this report are taken from a study by The Society of Nuclear Medicine that was designed to determine the efficacy or usefulness to referring physicians of ventilation-perfusion lung scanning in the diagnosis of PE (*1*). Two different methods for evaluating efficacy, logistic regression, and entropy minimax pattern detection techniques were compared. Logistic regression analyses showed that the lung scan findings had a significant influence on the referring physician's diagnostic thinking and affected the therapeutic management of the patients in a beneficial direction (*1*). Entropy minimax pattern detection analyses showed similar results (*2*).

There are many recent papers dealing with interpretation of lung scans that discuss the appearances of images under various conditions but do not describe the effects on patient management. The papers of Wellman (*3*), Rosen et al. (*4*), and Spies et al. (*5*) review the interpretation of lung scanning comprehensively. Particularly attention is directed to the reports of Patton (*6*), Vea et al. (*7*), and Hull et al. (*8*).

Twenty-two hospitals throughout the United States participated in this study and contributed information on 2,023 cases. Prior to the lung scan the referring physician was asked to supply information pertaining to the patient's most important and most likely diagnoses, the estimates (odds or probability) of these diagnoses being correct, and the management plan for the patient based on present information. The most important (MI) diagnosis was defined as the diagnosis of immediate concern in regard to a patient undergoing an acute episode or sudden change, i.e., the diagnosis the clinician would not want to miss. The diagnosis with the highest probability estimate out of all possible diagnoses being considered was defined as the most likely diagnosis (ML). The probability estimate of the ML diagnosis was further restricted to be greater than or the same as the MI diagnosis. After the results of the lung scan were known, a reassessment of the above estimates was obtained from the same physician. Information was also collected regarding the cost of the lung scan

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and the status of the patient at time of discharge. For the analyses presented here the number of days hospitalized was calculated from the date of the lung scan until the date of discharge.

Costs of Treatment and Scan

The cost of the nuclear medicine test was reported by each institution. The costs of other laboratory tests during the period of data collection, 1978 to 1980, have been estimated from the literature (*9*) and inquiries at participating hospitals. From this pooled information a typical ACT protocol was assembled for purposes of these calculations as follows: heparin ($1.00/dose) given five times per day for 5 days, followed by a daily dose of coumadin ($1.00/dose) for 4 mo; prothrombin times ($8.00/test) done daily while the patient is hospitalized and weekly thereafter for 4 mo; monthly visits to a physician ($25.00/visit) for 6 mo with a final 12-mo checkup. The mean (geometric) hospital stay from date of lung scan in this study for patients given ACT was 13 days ($220/day), and 8 days for patients not receiving ACT. The geometric mean was used due to the log-distribution of the data. The average cost for a ventilation-perfusion scan in the participating hospitals was $188.00. Using these figures, the combined cost for lung scan and ACT was ~$3,608 per patient and for lung scan but no ACT the cost was $1,948 (Table 1). Most patients not given ACT (all 2,023 patients had a lung scan done) had diseases such as congestive heart failure or chronic obstructive pulmonary disease.

Calculations

Total cost of hospitalization, ACT, and lung scan was calculated for various groups of patients, and the cost per patient both before and after the lung scan was obtained. The incremental cost is the difference between the per person cost before and after the scan.

Mortality was estimated using observed rates, and the difference between the estimated mortality before the scan and observed deaths after the scan was expressed as lives saved. The cost per life saved is calculated by dividing the net cost (Table 2) by the number of lives saved (Table 3). The purpose of calculating cost per life saved is for comparison purposes only and is not meant to assign a value to a human life.

RESULTS

Overall Cost

Table 1 shows the costs of the two management regimens. Table 2 shows the total number of patients in each of the management and signout groups. For purposes of this analysis, anticoagulant therapy was considered appropriate if patients with a signout diagnosis of PE were given ACT, and inappropriate if ACT was given when the signout diagnosis was OTHER. The prescription of ACT was appropriately changed after the scan results were known in 20% [(302 + 108)/2,023] of the patients. In 67% [(217 + 1,143)/2,023] of the patients the scan confirmed the appropriateness of management. Therapy in 13% [(119 + 25 + 45 + 2,023] of the patients was considered inappropriate based on the criteria used in this analysis. However, if the scan had not been performed, 29% [(119 + 302 + 108 + 64)/2,023] of the patients would have had inappropriate therapy (Table 2).

There were 217 patients with a signout diagnosis of PE who received ACT before and after the scan. Since the management plan did not change after the scan results were known, there was no difference in the cost of ACT and hospitalization due to scan findings. The cost for scanning these patients was $40,796 (217 × $188). There were 119 patients without a signout diagnosis of PE but who were given ACT before and after scan results were known at a cost to scan of $22,372 (119 × $188). Twenty-five patients with a signout diagnosis of PE had ACT discontinued after the scan outcome was known resulting in a net savings of $36,800 in ACT and hospitalization costs. ACT was discontinued after scan results were known in 302 patients whose signout diagnosis was OTHER, resulting in a net savings of $444,544. ACT was started after the scan results were known in 108 and 45 patients without

TABLE 1
Estimates of Average Cost of Anticoagulant Therapy (ACT), Hospitalization and Lung Scan in 1978–79

	Patients receiving ACT	Patients not receiving ACT
ACT protocol:	$ 25	—
Heparin ($1/dose) 5× daily for 5 days		
Coumadin ($1/dose) daily for 4 mo	120	—
Prothrombin times ($8/test) daily during hospitalization (13 days) and weekly thereafter for 4 mo	240	—
Physician visits ($25/visit) monthly for 6 mo and a 12-mo checkup	175	—
ACT cost	$ 560	0
Hospitalization ($220/day)	2,860 (13 days)	1,760 (8 days)
ACT and hospitalization cost	3,420	1,760
Ventilation/perfusion lung scan	188	188
Total cost	$3,608	$1,948

TABLE 2
Estimated Costs for the Number of Patients in Each Treatment and Signout Group (n = 2,023)

Management			Estimated cost of hospitalization and ACT ($)			
Before scan	After scan	Signout diagnosis	If *no scan* were done[*] (a)	Cost of scan[†] (b)	After scan (c)	Net change (b+c) − a
ACT	ACT	PE n = 217	$ 742,140	$ 40,796	$ 742,140	$ 40,796
		OTHER n = 119	406,980	22,372	406,980	22,372
	NO ACT	PE n = 25	85,500	4,700	44,000	−36,800 (savings)
		OTHER n = 302	1,032,840	56,776	531,520	−444,544 (savings)
NO ACT	ACT	PE n = 108	190,080	20,304	369,360	199,584
		OTHER n = 45	79,200	8,460	153,900	83,160
	NO ACT	PE n = 64	112,640	12,032	112,640	12,032
		OTHER n = 1143	2,011,680	214,884	2,011,680	214,884
Totals		2,023:	$4,661,060	$380,324	$4,372,220	$ 91,484

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[*] Cost calculations based on following patient categories (see Table 1): ACT, no scan: $3,420 per patient; No ACT, no scan: $1,760 per patient.

[†] Cost per scan per patient is $188.

signout diagnoses of PE and OTHER, respectively. The cost was a total of $282,744 ($199,584 + 83,160) in ACT, hospitalization and scanning. No ACT was given before or after scan results were known in 64 and 1,143 patients who had signout diagnoses of PE and OTHER, respectively, at a cost of $226,916 for lung scans. The estimated cost per patient before the scan in the study population was $2,304 ($4,661,060/$2,023), while the estimated cost per patient after the scan was $2,349 ([$4,372,220 + 380,324]/2,023). This results in an incremental cost of $45 per patient for the lung scan ($2,349 − 2,304) (Table 2).

The cost of scanning all 2,023 patients was $380,324 ($188 × 2,023), resulting in a decrease of $288,840 in hospitalization and ACT costs, and a net increase of $91,484 in costs attributable to scanning all 2,023 patients. However, as explained in the succeeding section (mortality), 19 expected deaths were avoided (Table 3).

TABLE 3
Mortality Resulting from Anticoagulant Therapy and PE

Signout diagnosis	Observed[*] mortality rate (a)	Before scan (estimated[†]) No. patients (b)	No. deaths (c)	After scan (observed) No. patients (d)	No. deaths (e)
PE, ACT	0.068	242	16	325	22
PE, NO ACT	0.146	172	25	89	13
NO PE, ACT	0.092	421	39	164	15
NO PE, NO ACT	0.043	1,188	51	1,445	62
Totals		2,023	131	2,023	112

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[*] The observed mortality rates were calculated by dividing observed deaths in each signout category by the number of patients in the corresponding group (e/d = a).

[†] Estimated deaths were derived using the observed mortality rates on the number of patients in each before scan group (b a = c).

TABLE 4
Distribution of Patients by Anticoagulant Therapy Before and After Scan, Signout-Diagnosis and Subgroups Based on Prior Most Important and Most Likely (MI/ML) Diagnoses (n = 2,023)

Management			Subgroups of patients (MI/ML prior to scan)			
Before scan	After scan	Signout	PE/PE	PE/OTHER	OTHER/PE	OTHER/OTHER
ACT	ACT	PE	162	49	5	1
		OTHER	44	66	3	6
	no ACT	PE	17	7	1	0
		OTHER	115	173	4	10
no ACT	ACT	PE	35	67	1	5
		OTHER	11	27	0	7
	no ACT	PE	19	42	0	3
		OTHER	117	723	8	295
	Totals		520	1,154	22	327 = 2,023

Mortality

In this study, the observed mortality rates prior to discharge for treated and untreated PE, based on the signout diagnosis, were 6.8% and 14.6%, respectively (Table 3). Based on these rates, 16 [(217 + 25) × 0.068] and 25 [(64 + 108) × 0.146] deaths would be expected had the lung scan not been done. The mortality of patients who were treated with ACT but did not have PE was 9.2%, whereas the mortality of patients who were not treated with ACT and did not have PE was 4.3%. This results in expected numbers of deaths, if the lung scan had not been done, of 39 [(119 + 302) × 0.092] and 51 [1,143 + 45) × 0.043]. (See Table 2 for number of patients in each group.) Based on these figures (16 + 25 + 39 + 51), 131 deaths would be expected if the scan were not done. Observed deaths totaled 112, a saving of 19 lives at a net cost of $4,815 per life saved ($91,484/19).

Prior Probability of PE

The data were divided into four subgroups of patients based on the referring physician's most important and most likely diagnoses before the scan was done.

1. PE was the most important diagnosis and most likely diagnosis (PE/PE); n = 520.
2. PE was the most important diagnosis but not most likely (PE/OTHER); n = 1154.
3. PE was *not* the most important diagnosis, but was the most likely (OTHER/PE); n = 22.
4. PE was neither the most important nor the most likely diagnosis (OTHER/OTHER); n = 327.

The distribution of patients by ACT before and after the lung scan and signout diagnosis for each of these subgroups is shown in Table 4. Cost-effectiveness analysis, as described above, was performed on each of these groups (Table 5) (see Appendix I). In the two groups in which PE was considered the most likely diagnosis (PE/

TABLE 5
Summary of Cost-Effectiveness of Ventilation-Perfusion Lung Scan on the Management of Patients Grouped Based on Most Important/Most Likely Diagnoses (MI/ML) (n = 2,023)

	Estimated cost/patient ($)					
Before scan group (MI/ML)	Before scan (a)	After scan (b)	Incremental cost ($) (b-a)	Change in total cost* ($) (c)	Number of lives saved† (d)	Cost/life (c/d)
PE/PE n = 520	$2,839	$2,752	$ −87	$−45,000	6.5 (1.2)	$ −6,923‡
PE/OTHER n = 1154	2,184	2,248	64	74,192	11.8 (1.0)	6,287
OTHER/PE n = 22	2,741	2,627	−114	−2,504	0.2 (0.9)	−12,520‡
OTHER/OTHER n = 327	1,846	2,044	198	64,796	0.5 (0.2)	129,592

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* Calculated as shown in Tables 1 and 2 and Appendix I.

† Values in parentheses are the percent of the subgroup whose lives were saved. Number of lives saved corresponds to the 19 lives saved shown in Table 3.

‡ Savings per life saved.

TABLE 6
Distribution of Patients by Anticoagulant Therapy Before and After Scan, Signout-Diagnosis and Prior Probability Group[*] (n = 1,696)

Management			Prior probability groups of PE (%)				
Before scan	After scan	Signout	0.01–9.99	10.00–25.00	25.01–74.99	75.00–90.00	90.01–99.99
ACT	ACT	PE	2	23	57	95	39
		NO PE	8	35	33	32	5
	no ACT	PE	0	2	6	14	3
		NO PE	17	99	120	49	7
no ACT	ACT	PE	7	33	47	14	2
		NO PE	2	11	20	5	0
	no ACT	PE	7	25	17	8	4
		NO PE	165	402	226	50	5
	Totals:		208	630	526	267	65

[*] OTHER/OTHER subgroup was excluded since there was no prior probability of PE (n = 327).

PE and OTHER/PE) there were incremental reductions ($ − 87 and $ − 114, respectively) in costs for ACT and hospitalization as a result of performing the scan.

In order to determine the cost of the lung scan per life saved, the observed mortality rates (Table 3) were used for each MI/ML group and the difference between the estimated number of deaths before and after the lung scan was calculated (Table 5). Estimated mortality in the PE/PE and OTHER/PE groups was lower after the scan, thus a "cost saving/life saved" of $6,923 and $12,520 for the two groups respectively. Of the two groups in which PE was not the most likely diagnosis (PE/OTHER and OTHER/OTHER), the latter group of 327 patients was the most expensive to scan with an incremental cost per patient of $198 and a cost/life saved of $129,592.

The specific prior probabilities for both the most important and most likely diagnoses were obtained from the referring physician. In order to determine the effect of the prior probability of PE on the cost-effectiveness of the scan, these probability estimates were categorized into five groups (Table 6), and the cost-effectiveness of the scan was determined for each group. The distribution of the patients by ACT before and after the lung scan and signout diagnosis is shown in Table 6 for each prior probability group. There were 327 patients in the OTHER/OTHER category for whom a probability of PE was not ascertained. Since PE was not considered either the most important or the most likely diagnosis, these patients are not included in the following analyses.

Costs for the probability groups were calculated using the method as shown in Tables 1 and 2 (see Appendix I), and are summarized in Table 7. The incremental

TABLE 7
Summary of Cost-Effectiveness of Ventilation-Perfusion Lung Scan on the Management of Patients Based on the Prior Probability of Pulmonary Embolism (n = 1,696)[*]

Prior probability of PE (%)	Cost/patient Before scan/after scan		Incremental cost	Total cost[†]	Lives saved[‡]	Cost/life saved
	(a)	(b)	(b-a)	(c)	(d)	(c/d)
0.01–9.99 n = 208	$1,975	$2,099	$124	$25,824	1.3 (0.6)	$19,865
10.00–25.00 n = 630	2,179	2,217	38	23,820	6.7 (1.1)	3,555
25.01–74.99 n = 526	2,442	2,444	2	948	8.1 (1.5)	117
75.00–90.00 n = 267	2,941	2,856	−85	−22,844	2.1 (0.8)	−10,878[§]
90.01–99.99 n = 65	3,139	3,123	−16	−1,060	0.3 (0.5)	−3,533[§]

[*] There are 327 patients in the OTHER/OTHER subgroup for whom a prior probability of PE was not available. They are not included in this table.

[†] Calculated as shown in Tables 1 and 2 and Appendix I.

[‡] Values in parentheses are the percent of the subgroup whose lives were saved.

[§] Savings per life saved.

cost of doing a lung scan is the highest ($124 per person) in patients with a prior probability of PE of 0.01–9.99%. The incremental cost drops to $38 for the prior probability group of 10.00–25.00%. When the prior probability of PE is between 25.01–99.99% doing the lung scan saves money in management and hospitalization costs. The greatest saving is in the prior probability group of 75–90% where the incremental "savings" per person is $85.

The greatest benefit, in terms of lives saved, is in the prior probability group of 25.00–74.99% where 1.5% (8.1/526) of this group would survive as a result of the change in treatment attributable to the scan findings. In this group the cost to save a life was estimated to be $117. In the 75.00–90.00% group there is a negligible reduction in mortality (0.8%). However, the savings are $10,878 per life saved because the scan affects the management of these patients, thereby reducing the cost of ACT and hospitalization.

DISCUSSION

With regard to performing lung scans, this population of 2,023 patients studied is thought to represent typical clinical practice in U.S. hospitals that are approved by the Joint Commission on Accreditation of Hospitals and qualified to receive Medicare payments (*1*). In addition to studying the efficacy of these medical diagnostic procedures, we had sufficient data available to perform a cost-effectiveness analysis on the lung scan relative to the management of PE.

We utilized two major simplifying assumptions in the current analysis. First, the management of PE was considered appropriate only when ACT was administered and inappropriate when ACT was not administered. The management of patients without PE was regarded as appropriate only if ACT was not given. There are circumstances when patients with PE may not be given ACT, for example, patients with peptic ulcer, gastrointestinal bleeding, thrombocytopenia or hematuria, or allergy to heparin. Also, patients with diseases other than PE may be treated with ACT, e.g., myocardial infarction, deep vein thrombosis, or cardiac valve prosthesis.

Second, the analysis deals only with the cost-effectiveness of the lung scan with respect to PE, and does not consider scans used for the diagnosis of other conditions such as chronic obstructive pulmonary disease. There were 1,143 patients without a signout diagnosis of PE who did not receive ACT before or after the scan (Table 4). Among them are 295 patients for whom PE was not considered either the most important or the most likely diagnosis.

The costs used in the present analysis were obtained from either national averages during the period of data collection (1978–1980) or from charges reported by the participating hospitals on the original study questionnaire. The greatest cost difference between patients receiving ACT and those not receiving ACT was in the length of hospitalization. This difference was $1,000 (Table 1). The number of days of hospitalization post-lung scan of patients not receiving ACT was calculated from present data to be 8; patients receiving ACT were hospitalized for 13 days.

Observed mortality rates were used in calculating the cost per life saved. The high observed mortality among patients who did not have a signout diagnosis that included PE but were treated with ACT may indicate an overall poor health status of the patients being scanned. The 4.29% mortality of patients without PE and who did not receive ACT is similar to the Professional Activities Survey mortality figure of patients hospitalized with multiple diagnoses (*10*).

The incremental cost for performing the lung scan as compared to not doing it is $45 per patient ($91,484/2,023) (Table 2). When incremental costs are calculated for each of the four categories based on whether PE was the most important or most likely diagnosis (Table 5), the most expensive group to scan was the OTHER/OTHER group. This group consisted of 327 patients for whom PE was not considered either the most important or the most likely diagnosis. These patients may have been scanned for reasons other than the diagnosis of PE although PE could not be entirely excluded; chronic obstructive pulmonary disease was the signout diagnosis in 36% of this group of patients.

When the cost-effectiveness analyses were completed for the prior probability groups, savings attributable to the lung scan were observed when the probability of PE was 25% or greater (Table 7). The largest monetary savings were realized when the prior probability of PE was between 75% and 90%. The greatest number of lives saved, however, was in the 25.01–74.99% prior probability group where an estimated 1.5% of the patients were saved as a result of a change in management due to the lung scan. The most expensive group to scan was the 0.01–9.99% probability group with an incremental cost to scan of $124 per patient and a cost of $19,925 per life saved. Since many diagnostic tests, especially lung scanning for PE, are performed to reassure both patients and clinicians of the absence of disease (*4*), this incremental cost needs to be weighed against the benefit of ruling out a diagnosis of PE.

The prevalence of a signout diagnosis of PE in this study population is 20%. If one assumes that an individual in a similar population has a prior probability of disease equal to the prevalence of the disease, then it is the probability group of 10–25% that is of interest. The incremental cost for scanning a patient in this group is $38, with a cost per life saved of $3,555.

The cost per life saved for the entire study population was calculated to be $4,815 (Table 2). This cost is low

TABLE 8

Risk of Developing Cancer* from the Averge Administered Dose of 141 MBq of ^{99m}Tc Macroaggregates

Organ	mSv/MBq Administered (Ref. 14)	Age weighted average excess incidence rates per 10^{-6} yr^{-1} mSv^{-1} (Table V-14, *Ref. 12*)		Risk per average dose, cases 10^{-6} yr^{-1}	
		M	F	M	F
Kidney	0.04	0.08	0.09	0.5	0.5
Liver	0.005	0.07		0.05	
Lungs	0.05	0.4	0.4	2.8	2.8
Marrow†	0.004	0.08		0.05	
Thyroid	0.002	0.2	0.6	0.06	0.2
Bladder	0.1	0.08	0.09	1.1	1.3
Testis*	0.002	0.08		0.02	
Ovary*	0.002		0.08		0.02
Total body‡	0.004	1.3	2.3	0.7	1.3

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* Genetically significant risk calculated from risk of $4 \cdot 10^{-6} \cdot \text{mSv}^{-1}$ as a lifetime mortality risk over the first two generations. For yearly risk and in mSv = $4 \cdot 10^{-6} \cdot \text{mSv}^{-1} \cdot 1/50 = 8 \cdot 10^{-8}$ yr^{-1} mSv^{-1} (¶60, *Ref. 13*).

† Leukemia rate calculated from mortality rate of $2 \cdot 10^{-6} \cdot \text{mSv}^{-1}$ lifetime. For 25-year risk period per 10 mSv per year $2 \cdot 10^{-6}$ mSv $\cdot\, 1/25 = 0.8 \cdot 10^{-8}$ yr^{-1} mSv^{-1} (¶44, *Ref. 13*).

‡ The total for "all sites" is one possible measure of the effect (excluding leukemia and bone cancer) of whole-body radiation with all tissues receiving 10 mSv.

compared to other diagnostic procedures. For example, CT scanning of patients with headaches to search for subarachnoid hemorrhage has been reported to cost $43,975 per life saved (*11*).

Risk from Radiation

A frequent question asked of any procedure involving ionizing radiation is whether the radiation will have a deleterious effect either immediately or over a period of several decades. The data collected in this study do not include information on quality of life, activities of daily living or days of work lost. Thus the only risks that can be calculated are those of morbidity and mortality using rates from the published literature. In addition, the number of patients in this study who were less than 40 yr old, and therefore at genetic risk, was 424, or 21% of this population (*1*).

Dose equivalents of technetium-99m (^{99m}Tc) macroaggregates and xenon-133 (^{133}Xe) are given in Tables 8 and 9. Risk rates for late stochastic effects are given using values both from BEIR III (*12*) and ICRP-26 (*13*).

The total somatic risk for this population of 2,023 patients, based on the whole-body dose, is 2.01×10^{-3} yr^{-1} for [^{99m}Tc]MAA and 0.8×10^{-3} cases yr^{-1} for ^{133}Xe representing the increase in tumor incidence over a 20- to 30-year period (see Appendix II). Summing these values yields 2.9×10^{-3} cases yr^{-1} possible deaths due to radiation in the lifetime of the study population undergoing lung scan. No correction has been made for the age distribution of the population even though 993 persons, (49%), are 60 years of age and older. Thus their life expectancies for the development of late radiation effects would probably be much shorter than those of the U.S. population at large. For this reason the above estimate would appear to be conservative.

The total genetic risk for the population of patients under the age of 40 years is 11.0×10^{-6} cases yr^{-1} for ^{99m}Tc and 8.5×10^{-6} cases yr^{-1} for ^{133}Xe (spirometer volume of 5 liters), representing an increase in genetic risk (mortality) (*13*) of 19.5×10^{-6} cases yr^{-1} (see Appendix II).

Benefit:Risk Analysis

This analysis is difficult since the parameters for making such a judgment are not always clearly defined. In this study the comparison used is based on differences in deaths. As shown in Table 3 there was a net survival of 19 patients, the difference between estimated deaths using observed mortality rates and the actual deaths. This value can be compared with the estimated number of 2.9×10^{-3} somatic deaths and 8.5×10^{-6} genetic deaths for a total of 2.9×10^{-3} deaths from radiation. The ratio then is 19 lives saved/2.9×10^{-3} lives lost for a benefit greater than 6,000-fold.

CONCLUSIONS

In summary, this study reports the use of lung scans by physicians in usual clinical practice and the cost-effectiveness of the management of patients with pulmonary embolism. In 20% of the 2,023 patients the prescription of ACT was appropriately changed after

TABLE 9
Risk of Developing Cancer[*] from the Averaged Administered Dose of 570 MBq of ^{133}Xe

Organ	Spirometer volume in liters (Ref. 15)	mSv/MBq (Ref. 15)	mSv per group[†]	Age weighted average excess incidence rates per 10^{-6} y^{-1} mSv^{-1} (Table V-14, Ref. *12*)		Risk per average dose, cases 10^{-6} y^{-1}	
				M	F	M	F
Lung	5	0.003	1.7	0.4		0.7	0.7
	7.5	0.002	1.1	0.4		0.4	0.4
	10	0.002	1.1	0.4		0.4	0.4
Red marrow[‡]	5	0.0004	0.2	0.08		0.02	
	7.5	0.0003	0.2	0.08		0.02	
	10	0.0002	0.1	0.08		0.008	
Ovary[*]	5	0.0004	0.2		0.08		0.02
	7.5	0.0003	0.2		0.08		0.02
	10	0.002	1.1		0.08		0.09
Testis[*]	5	0.0003	0.2	0.08		0.02	
	7.5	0.0002	0.1	0.08		0.008	
	10	0.0002	0.1	0.08		0.008	
Total body	5	0.0004	0.2	1.3	2.3	0.3	0.5
	7.5	0.0003	0.2	1.3	2.3	0.3	0.5
	10	0.0002	0.1	1.3	2.3	0.1	0.2

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[*] Genetically significant risk calculated from risk of $4 \cdot 10^{-6} \cdot mSv^{-1}$ as a lifetime mortality risk over the first two generations. For yearly risk and in mSv = $4 \cdot 10^{-6}$ per $mSv^{-1} \cdot 1/50 = 0.8 \cdot 10^{-8}$ yr^{-1} mSv^{-1} (¶*60, Ref. 13*).

[†] mSv per group mean about the same for ages <18 and >18 (*Ref.* 14).

[‡] Leukemia rate calculated from mortality rate of $2 \cdot 10^{-6} \cdot mSv^{-1}$ lifetime. For 25-year risk period per mSv per year $2 \cdot 10^{-6}$ per $mSv^{-1} \cdot 1/25 = 0.8 \cdot 10^{-8}$ yr^{-1} mSv^{-1} (¶*44, Ref. 13*).

the scan results were known; in 67% of the patients the appropriateness of ACT was confirmed. ACT was inappropriate in 13% of the patients as defined for purposes of this analysis. In these patients ACT may have been given for conditions other than PE, such as myocardial infarction; where ACT was not given, despite a diagnosis of PE, it may have been withheld because the patient had some contraindication, such as allergy to heparin (*1*).

Mortality was estimated to have decreased as a result of performing lung scans, and performing the lung scan often resulted in savings in hospitalization and ACT costs.

Regarding radiation exposure, the benefit:risk ratio, as measured by lives saved compared with estimates of lives lost due to radiation exposure, was of the order of 6,000:1, a value that can be considered medically acceptable.

APPENDIX I

Calculation of values in Tables 5 and 7 is as follows:

The costs of patient care before and after lung scans are given in the footnote of Tables 1 and 2.

The distribution of patients by ACT before and after the lung scan is given in Table 4; distribution by probability groups is in Table 6.

Numbering the row values as $n_1, n_2, \cdots n_8$ for each category (PE/PE, PE/OTHER, etc.) separately, the costs before scan (CBS) and costs after scan (CAS) are calculated for each group as:

$$CBS = 3420(n_1+n_2+n_3+n_4) + 1760(n_5+n_6+n_7+n_8)$$

$$CAS = 3608(n_1+n_2+n_5+n_6) + 1948(n_3+n_4+n_7+n_8).$$

The change in total cost per group is calculated as the difference between CAS and CBS. The incremental cost per patient is calculated by dividing this difference by the number of patients in the group.

Example (Table 5)

Subgroup PE/PE, before scan (a)

$$\text{ACT } \$3420 \times (162 + 44 + 17 + 115) = \$1,155,960$$

$$\text{NO ACT } \$1760 \times (35 + 11 + 19 + 117) = \frac{320,320}{\$1,476,280} = \text{Cost before scan (CBS)}$$

Subgroup PE/PE, after scan (b)

$$\begin{aligned} \text{ACT } \$3608 \times (162 + 44 + 35 + 11) &= \$909{,}216 \\ \text{NO ACT } \$1948 \times (17 + 115 + 19 + 117) &= \frac{522{,}064}{\$1{,}431{,}280} = \text{Cost after scan (CAS)} \end{aligned}$$

$\Sigma(n_1, n_2, \ldots n_8) = 520$

Change in total cost = \$1,431,280 (CAS) − \$1,476,280 (CBS) = −\$45,000 per group.
Incremental cost = −\$45,000/520 = −\$87 per patient.
Example (Table 7)
Prior probability group .01 − 9.99%, before scan (a)

$$\begin{aligned} \text{ACT } \$3420 \times (2 + 8 + 0 + 17) &= \$\ 92{,}340 \\ \text{NO ACT } \$1760 \times (7 + 2 + 7 + 165) &= \frac{318{,}560}{\$410{,}900} = \text{CBS} \end{aligned}$$

Prior probability group .01 − 9.99%, after scan (b)

$$\begin{aligned} \text{ACT } \$3608 \times (8 + 2 + 7 + 2) &= \$\ 68{,}552 \\ \text{NO ACT } \$1948 \times (0 + 17 + 7 + 65) &= \frac{368{,}172}{\$436{,}724} = \text{CAS} \end{aligned}$$

$\Sigma(n_1, n_2, \ldots n_8) = 208$

Change in total cost = \$436,724 (CAS) − \$410,900 (CBS) = \$25,824 per group. Incremental cost = \$25,824/208 = \$124 per patient.

APPENDIX II

Calculations of Somatic and Genetic Risks

Somatic risk is calculated based on risk from whole-body dose as given in Tables 8 and 9.
^{99m}Tc:
0.73 10^{-6} cases yr^{-1} × 962 males = 702 × 10^{-6} male cases yr^{-1} 1.30 10^{-6} cases yr^{-1} × 1,061 females = 1,379 × 10^{-6} female cases yr^{-1}

Total risk from ^{99m}Tc: 2.1 × 10^{-3} cases yr^{-1}

^{133}Xe (5 l):
0.28 10^{-6} cases yr^{-1} × 962 males = 269 × 10^{-6} male cases yr^{-1} 0.51 10^{-6} cases yr^{-1} × 1,061 females = 541 × 10^{-6} female cases yr^{-1}

Total risk from ^{133}Xe (5 liters): 0.8 × 10^{-3} cases yr^{-1}

Genetic risk is based on genetic risks given in Tables 8 and 9.
^{99m}Tc:
0.02 10^{-6} cases yr^{-1} × 171 males <40 yr of age = 3.4 10^{-6} cases in males <40 yr yr^{-1}
0.03 10^{-6} cases yr^{-1} × 253 females <40 yr of age = 7.6 10^{-6} cases in females <40 yr yr^{-1}

Total risk from ^{99m}Tc: 11.0 10^{-6} cases yr^{-1}

^{133}Xe (5 l):
0.02 10^{-6} cases yr^{-1} × 171 males <40 yr of age = 3.4 10^{-6} cases in males <40 yr yr^{-1}
0.02 10^{-6} cases yr^{-1} × 253 females <40 yr of age = 5.1 10^{-6} cases in females <40 yr yr^{-1}

Total risk from ^{133}Xe (5 l): 8.5 × 10^{-6} cases yr^{-1}.

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