

---

---

# Interdepartmental Audit with an Anatomically Realistic Lung Phantom

Jari O. Heikkinen, PhD<sup>1</sup>; Jyrki T. Kuikka, PhD<sup>2</sup>; and Pentti J. Rautio, MD<sup>3</sup>

<sup>1</sup>Department of Nuclear Medicine, Etelä-Savo Hospital District, Mikkeli Central Hospital, Mikkeli, Finland; <sup>2</sup>Department of Clinical Physiology, Kuopio University Hospital and Niuvanniemi Hospital, Kuopio, Finland; and <sup>3</sup>Department of Clinical Physiology, North Karelia Central Hospital, Joensuu, Finland

---

The diagnostic proficiency of nuclear medicine professionals and the accuracy of equipment may be tested with phantoms. All phases of the imaging chain should be included in the external quality assurance of imaging. **Methods:** The aim of this study was to evaluate and compare the quality of nuclear imaging of the lung in Finland. For this purpose, we developed a new anatomically realistic lung phantom. The phantom consisted of plastic containers filled with plastic pellets to imitate the 3-dimensional shape of the lungs. These containers were filled with radioactive liquid and placed inside an anatomically accurate phantom of the chest cavity. The attenuation properties of the phantom were close to those of a real human thorax. Perfusion and ventilation defects were positioned inside the phantom to mimic 2 clinical cases. The phantom was imaged and interpreted as a patient simulation study in 18 Finnish hospitals. Reconstruction, printout, and reporting were according to the clinical routine of each hospital. The quality of the image sets and reports was evaluated and scored from 0 to 10. Additionally, technical performance was evaluated by a nuclear medicine specialist and hospital physicians. **Results:** The average score ( $\pm$ SD) for overall quality was  $7.1 \pm 1.1$  (range, 5.2–8.5). Reports received a score of  $7.2 \pm 1.7$  (4.7–10.0); image sets,  $7.2 \pm 1.3$  (4.8–9.7), technical evaluation by hospital readers,  $6.5 \pm 2.3$  (1.6–9.5); and technical evaluation by a specialist,  $7.8 \pm 1.2$  (5.7–10.0). **Conclusion:** Lung imaging routines and the results of this survey were diverse. None of the participating hospitals routinely used tomography. In planar imaging, the most valuable projections were oblique (left anterior oblique, right anterior oblique, left posterior oblique, and right posterior oblique) and straight sides (right and left). The phantom mimicks variable clinical situations well and is suitable for testing of imaging protocols and for proficiency testing of nuclear medicine professionals and equipment. Clinical phantom studies are an effective way of assessing an imaging program.

**Key Words:** phantom; pulmonary embolism; quality assurance; ventilation–perfusion

**J Nucl Med Technol 2006; 34:34–42**

---

Received Dec. 28, 2004; revision accepted Nov. 21, 2005.  
For correspondence or reprints contact: Jari Heikkinen, PhD, Department of Nuclear Medicine, Mikkeli Central Hospital, Etelä-Savo Hospital District, FIN-50100 Mikkeli, Finland.  
E-mail: jari.heikkinen@esshp.fi

**A**cute pulmonary embolism is a prevalent disease with a high mortality. Conventional diagnostic strategies have relied on ventilation–perfusion imaging complemented by venous imaging (1). Diagnostic strategies and new techniques in nuclear medicine will probably be able to improve the management of patients with clinically suspected pulmonary embolism (2). Standardization of procedures according to published guidelines (3) is a step toward that aim. The diagnostic proficiency of nuclear medicine professionals and the accuracy of equipment may be tested with phantoms. All phases of the imaging chain should be included in the external quality assurance of imaging. With artificially created phantoms, one can test the majority of the chain and know the true values of the parameters being measured.

Since 1993, 6 external quality assurance surveys have been performed in Finland (4–7). The last one, described in this paper, dealt with lung ventilation–perfusion imaging. No sufficient phantom was commercially available at the time of the survey. A new ventilation–perfusion phantom was constructed. The results of the survey on this new phantom are evaluated in this paper.

## MATERIALS AND METHODS

Eighteen Finnish nuclear medicine departments participated in the survey. An experienced physicist visited all the hospitals. The staff of each department performed its routine  $\gamma$ -camera acquisitions, analysis, and printing. The acquisition parameters used in the various departments are given in Table 1. Commercially available clinical radiopharmaceutical delivery systems were used for ventilation imaging. The pharmaceuticals included <sup>99m</sup>Tc-labeled aerosols and Technegas (Vita Medical Ltd.), an ultrafine suspension of <sup>99m</sup>Tc-labeled particles that closely resemble a true gas.

## The Phantom

Two pairs of wooden models of lungs were made. Plastic plates were melted and vacuum-sucked over the lateral and medial sides of the models. Shells were filled with plastic pellets (diameter, 1–4 mm) and glued together. Two filling tubes were situated in the containers, one at the top and one at the bottom of the phantom. Molding wax and plastic pellets were mixed and shaped to produce defects inside the containers, which were then filled with a solution of <sup>99m</sup>Tc and water. CT-based density values

**TABLE 1**  
Acquisition Parameters for Standard Lung Perfusion and Ventilation Imaging in 18 Participating Hospitals

Hospital	Camera age (y)	Collimator	Matrix	Patient position	Perfusion dose (MBq)	No. of projections	Frame (kcts or time)	Ventilation method	Dose (MBq)	Frame (kcts or time)	No. of projections
TU	8	HR	512	Supine	111	6	300 s	Venticol	740	600 s	6
IJ	10	AP	256	Supine	50	4	300 s	Venticol	1,100	300 s	4
B	6	HR	256	Supine	185	6	600	Venticol	111–1,110	100	4
H	10	HS	256	Supine	130	6	600	Solcovent	2,000	300	6
E	10	GP	256	Supine	148	6	700	Technegas	22–33	300 s	4
PQ1	3	HR	128	Supine	185	8	130 s	Solcovent	2,220	180 s	8
PQ2	10	AP	128	Supine	15	6	600+t	Solcovent	2,220	600+t	6
V1	15	GP	256	Supine	110	6	600	Technegas	20–40	200	6
V2	10	AP	128	Supine	110	6	600	Technegas	20–40	200	6
FG	16	AP	128	Supine	111–158	6	600	Technegas	370	400	6
R	8	HR	128	Supine	110	6	1,000+t	Venticol	900	400+t	6
N	12	HR	128	Supine	185	6	90 s	Venticol	740	150+t	6
Z	16	AP	128	Supine	148	4	600	Technegas	37	400	4
S	12	AP	256	Supine	100	6	400	Technegas	400	200	6
XY	4	GP	128	Supine	100	6	120 s	Technegas	300	120 s	6
M	12	HS	128	Supine	74	6	400	Venticol	1,300	400	6
K	21	GP	256	Supine	110	4	1,000	Aerosol	740	300 s	4
O	1	AP	256	Supine	150–185	8	90 s	Technegas	150–400	120 s	8
CD	11	GP	256	Supine	111	4	400	Venticol	740	150–300	4
L	15	GP	256	Sitting	74	4	600/500	Ultravent	1,480	300	4

HR = high resolution; AP = all purpose; HS = high sensitivity; GP = general purpose; 600+t = first frame is images at 600 kcts and rest are with same time.

Hospitals are coded to maintain anonymity.

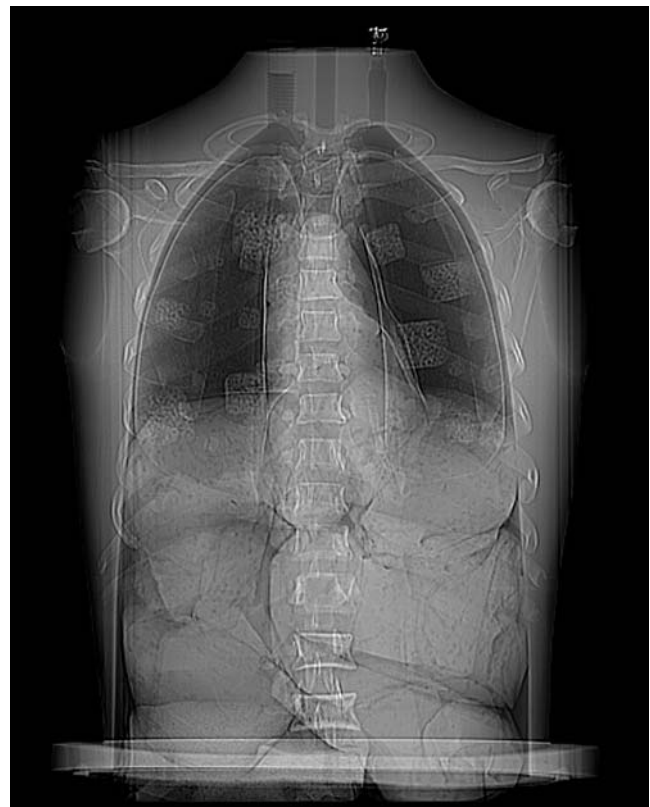
(Hounsfield units) were –616 for the pellet and water combination and –488 for the pellet and molding wax combination. As a comparison, the number of Hounsfield units was determined for an inspiring human lung and found to be –818 without contrast medium and –650 with contrast medium.

The radioactivity concentration of the solution was adjusted to achieve the usual counting rate for patients in that hospital. For example, in the phantom, a 137 kBq/mL solution of <sup>99m</sup>Tc in water corresponds to a 110-MBq dose of <sup>99m</sup>Tc-labeled macroaggregated albumin in a patient. The radioactivity concentration was adjusted separately for the ventilation simulation. Clinical counting rates were measured from 5 perfusion and 5 ventilation patients in corresponding hospitals. The average counting rate determined the activity concentration for lung containers.

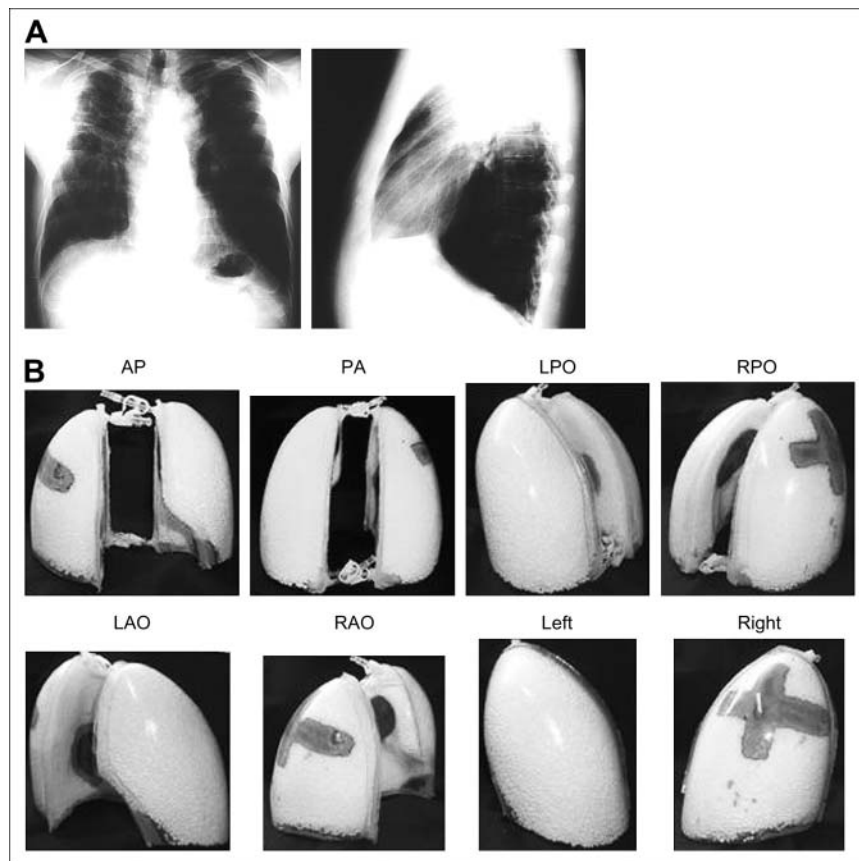
Five different pairs of lung containers were constructed. Each lung container was filled with defects of varying positions and sizes to simulate a given clinical ventilation–perfusion situation. Filled containers were situated inside a physical chest cavity phantom simulating the thorax (model RS-801, thoracic cavity with bottom plate; Radiology Support Devices, Inc.) (Fig. 1). The rest of the cavity was filled with water bags (9 bags containing 1,300 mL each). The shoulders of the thorax phantom were cut because they produced too distinct an attenuation defect on the lateral  $\gamma$ -camera images.

### Simulated Case 1 (Fibrosis)

Case 1 was a 50-y-old man with increasing shortness of breath. His sarcoidosis had been treated with corticosteroids since 1997. Chest radiographs (Fig. 2A) showed parenchymal fibrosis in the right upper lobe. Molding wax was placed in the same position of the lung container to simulate fibrosis (Fig. 2B). The same container pair was used to simulate perfusion and ventilation.



**FIGURE 1.** Radiograph of plastic lung models inside thorax phantom.



**FIGURE 2.** Case 1: chosen patient radiographs (A) and defects inside lung containers (B). Same containers were used for both perfusion simulation and ventilation simulation. AP = anterior; LAO = left anterior oblique; LPO = left posterior oblique; PA = posterior; RAO = right anterior oblique; RPO = right posterior oblique.

The radioactivity concentration was adjusted separately for perfusion and ventilation simulations to reach the clinical counting rate in the corresponding hospital.

### Simulated Case 2 (Lung Embolus)

Case 2 was a 55-y-old woman with asthma and acute shortening of breath. Chest radiography findings were normal (Fig. 3A). Separate container pairs were used to simulate perfusion and ventilation. Inside the containers were 5 defects simulating emboli, 1 fixed defect simulating asthma or a small scar, and 1 ventilation defect simulating asthma (Fig. 3B).

All image series were numbered and sent to 2 experts (physicist and physician, both having more than 20 y of experience in nuclear medicine) who were familiar with the structure of the phantom. They evaluated all image sets in a masked test. Visual scores were given according to consensus criteria (Table 2). The reports were evaluated by the nuclear medicine physician according to the criteria in Table 3. The readers also wrote a more subjective overall evaluation.

### Simulated Case 3 (Technical)

Inside the physical torso phantom were lung inserts with 22 cubic defects (10 in the left and 12 in the right insert) (Fig. 4). Three were 2.5 cm<sup>3</sup>, 3 were 2.0 cm<sup>3</sup>, 4 were 1.5 cm<sup>3</sup>, 6 were 1.0 cm<sup>3</sup>, and 6 were 0.7 cm<sup>3</sup>. The routine protocol of each hospital was used to scan the phantom in all 8 standard projections. Local interpreters (29 persons) evaluated visible lesions from all projections and recorded their findings on a standardized data sheet. Sensitivity in seeing the lesions was determined for different

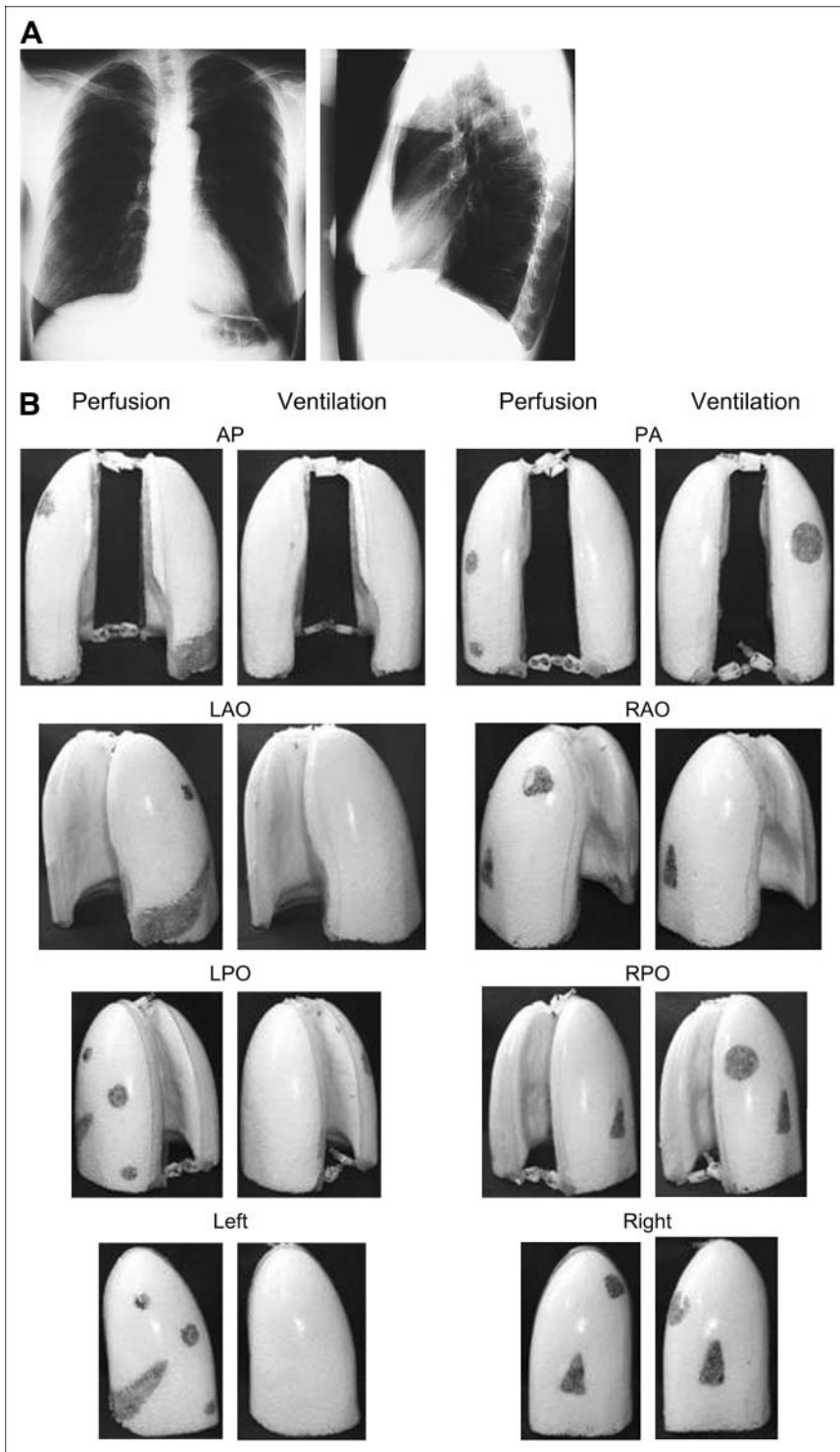
combinations of projections. Variations between combinations were tested with the paired-samples *t* test. Also, a physicist who was familiar with the structure of the phantom evaluated the image sets. Points were given according to how many defects were seen. The final results were normalized to 10 points.

After data analysis and evaluation, every participating hospital received its own numeric results and anonymous distribution plots of the results for the other participating centers. The experts gave each hospital a written summary of the major pitfalls in its imaging systems and protocols and the corrective actions required. The experts also gave general recommendations based on the international literature and national standards.

## RESULTS

The average values of the reports can be seen in Table 3. The most frequent (5/25 reports) comment was that the conclusion of the report should be more assertive. In Table 4 are the individual numeric results for the participating centers. Graphical distribution plots can be seen in Figure 5. Typical sets of  $\gamma$ -camera images are illustrated in Figures 6 and 7.

The percentage visibility of the defects inside the technical phantom according to the hospital readers is presented in Table 5. Almost everybody saw the biggest defects (2.5 and 2.0 cm<sup>3</sup>). Also, the 1.5-cm<sup>3</sup> defects were seen well (92% and 90%) when they were situated laterally in the insert. Medial defects were significantly harder to find, as



**FIGURE 3.** Case 2: chosen patient radiographs (A) and defects inside lung containers (B). AP = anterior; LAO = left anterior oblique; LPO = left posterior oblique; PA = posterior; RAO = right anterior oblique; RPO = right posterior oblique.

expected. One of the lateral 1.0-cm<sup>3</sup> defects was seen by more than half the interpreters (55%). The visibility of the smallest cubes was less than 18%, even though all were situated laterally in the inserts.

The best sensitivity was found when left-right projections were available. Statistically significant variations in sensitivity, compared with the use of all 8 projections,

occurred in combinations from which the anterior-posterior or left-right projections were missing (Table 6).

#### DISCUSSION

The present work was a continuation of previous surveys (4-7) comparing clinical imaging routines and results

**TABLE 2**  
Ranking of Lung Phantom Image Sets

Parameter	Maximum points
Colors, shade, contrast	4
Material (shine/blurred, manageability, etc.)	3
Notes (projections, counts, etc.)	2
Layout	2
Visibility of lesions	8
Number of projections	8
Total	27

Final points were summed and normalized to 10.

among hospitals. These surveys are easy and efficient to perform and provide valuable information to the participating centers. Labquality Ltd. (an internationally operating agency in Helsinki, Finland, for external quality assurance schemes) has gained acceptance among Finnish hospitals. The hospitals have noticed the benefits of these surveys, and almost all hospitals are now participating in every survey we arrange. In addition to receiving the results of other hospitals, the hospitals received national recommendations, which can also be found at the Web site of the Finnish Society of Nuclear Medicine ([www.fsnm.org](http://www.fsnm.org)).

As in previous surveys, we found varying acquisition protocols and poor image quality in some hospitals. Some details in acquisition protocols could be changed to improve image quality. If a  $256 \times 256$  matrix is used, one should acquire at least 600,000 counts (national consensus of nuclear medicine experts). None of the participating hospitals that used a  $256 \times 256$  matrix was able to acquire sufficient counts to provide acceptable image quality. We think that a  $128 \times 128$  matrix ( $\sim 4$ -mm pixel size) is enough for the imaging of moving objects such as lungs. Of course, a change in patient dose or collimator can influence the counting rate. In printing the images, the use of the whole range of a suitable color table is advisable. In some

**TABLE 3**  
Ranking of Lung Reports

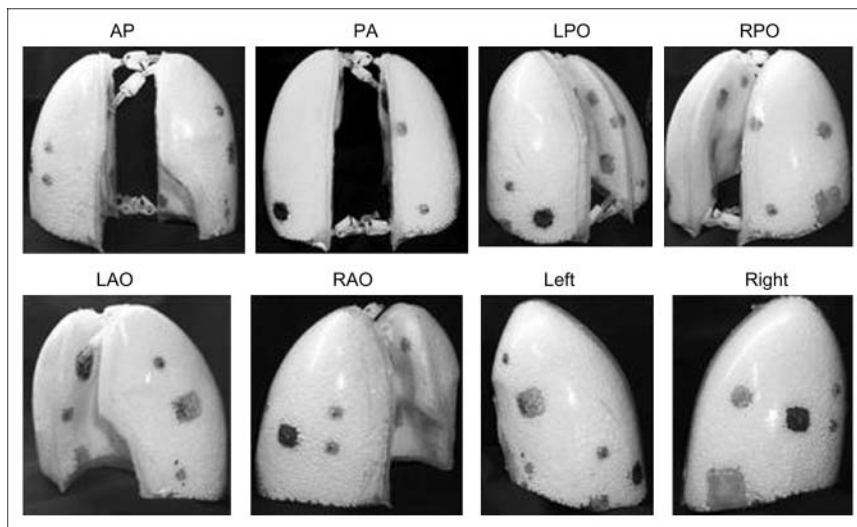
Parameter	Maximum points	Average	SD
Structure	2	1.31	0.62
Length	1	0.82	0.33
Comparison between perfusion and ventilation	2	1.58	0.53
Acquired projections mentioned	1	0.75	0.52
Comparison to radiologic findings	1	0.95	0.11
Conclusions	3	1.87	0.62
Findings	1	0.78	0.35
Extent	3	2.25	0.64
Additional findings	3	1.01	0.71
Total	17		

Final points were summed and normalized to 10.

hospitals, the printer was of inferior quality. According to our specialists, radiograph printers and high-quality sublimation printers produced the best images.

At least 6 projections should be used, and the best combination is left posterior oblique, right posterior oblique, left anterior oblique, right anterior oblique, and left-right. However, sensitivity was better for the combination of left posterior oblique, right posterior oblique, left anterior oblique, and right anterior oblique than for all 8 projections. If well chosen, even 4 projections can be enough. Still, some defects could be seen only if all projections were used. The specialist found that the lack of straight, lateral projections usually led to underestimation of the defects. Also, the best sensitivity was found when straight, lateral left-right projections were available.

The participating hospitals can use the results of this survey in several ways. A poor score for the technical portion and a better score for reporting might indicate too sensitive an interpretation. A technical score for the local



**FIGURE 4.** Case 3: defects inside technical containers. AP = anterior; LAO = left anterior oblique; LPO = left posterior oblique; PA = posterior; RAO = right anterior oblique; RPO = right posterior oblique.

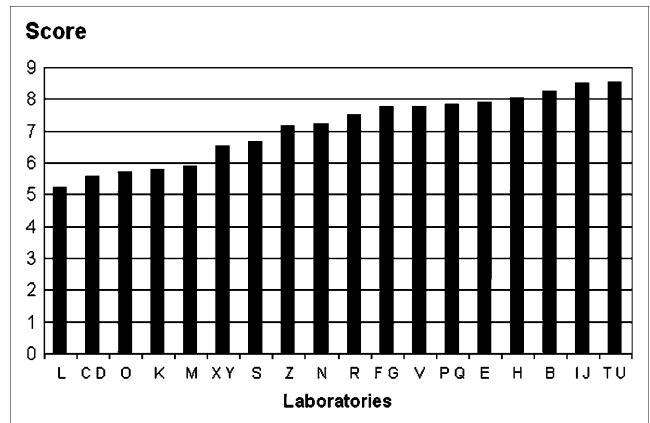
**TABLE 4**  
Results of Lung Survey

Hospital	Overall	Report	Image set	Technical 1	Technical 2
TU	8.5	10.0	7.2	8.2	8.4
IJ	8.5	9.9	7.4	8.0	8.2
B	8.3	8.8	7.1	9.2	8.9
H	8.1	8.7	7.0	9.4	6.8
E	7.9	9.0	8.3	5.4	6.6
PQ	7.8	5.9	9.0	8.6	10.0
V	7.8	7.9	6.7	9.5	8.3
FG	7.8	8.1	9.7	4.2	5.7
R	7.5	7.2	8.5	5.5	9.1
N	7.2	6.8	7.6	6.6	9.1
Z	7.2	8.5	5.9	6.8	7.8
S	6.7	6.8	5.8	8.0	7.1
XY	6.5	6.9	8.5	1.6	7.1
M	5.9	4.8	6.1	7.1	7.5
K	5.8	5.7	5.7	5.8	6.8
O	5.7	5.1	7.1	3.0	8.9
CD	5.6	4.7	6.9	4.6	5.9
L	5.2	5.3	4.8	5.2	7.3
Average	7.1	7.2	7.2	6.5	7.8
SD	1.1	1.7	1.3	2.3	1.2

Technical 1 = local interpreters; technical 2 = expert.  
Hospitals are coded to maintain anonymity.

interpreter (Table 4, technical 1) that is better than that for the report might indicate too specific an evaluation (small defects that could be seen were not reported). If the technical scores are clearly better than the score of the image set, then the printer, printing method, or protocol may require modification. If the score of the report is low, then the interpreter should receive some extra training.

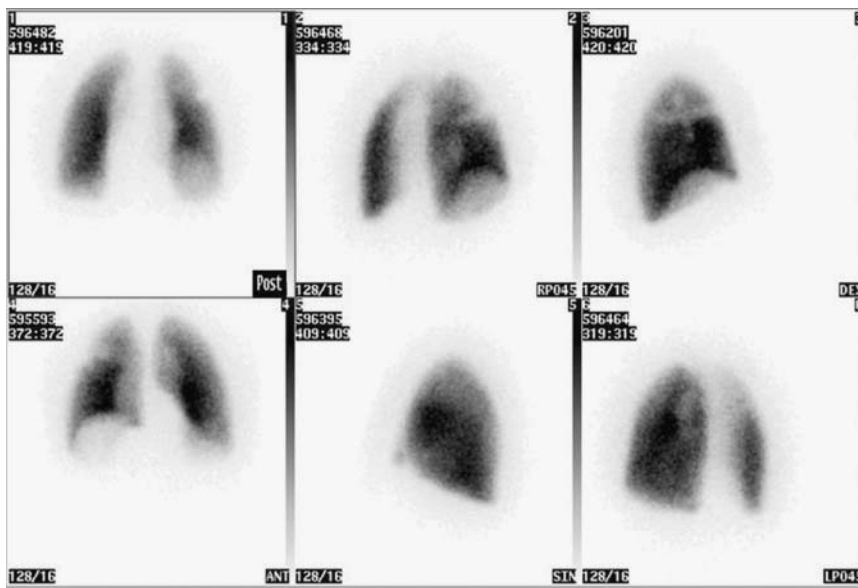
We made a few general observations about the reports. The comparison between ventilation and perfusion was frequently used and usually separated good reports from



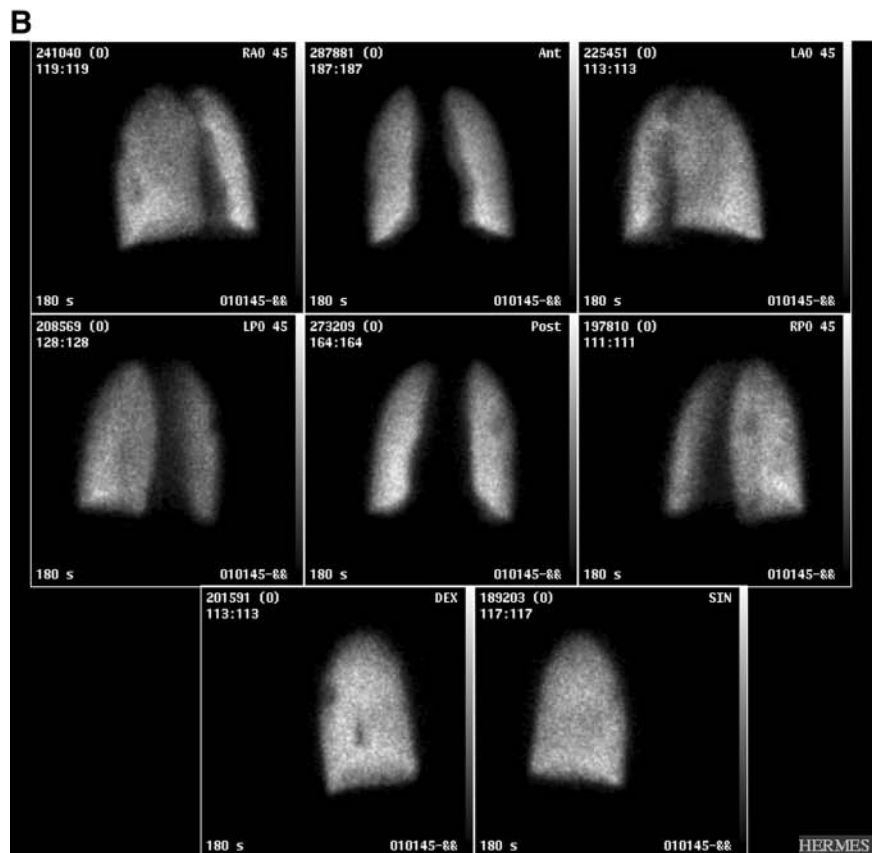
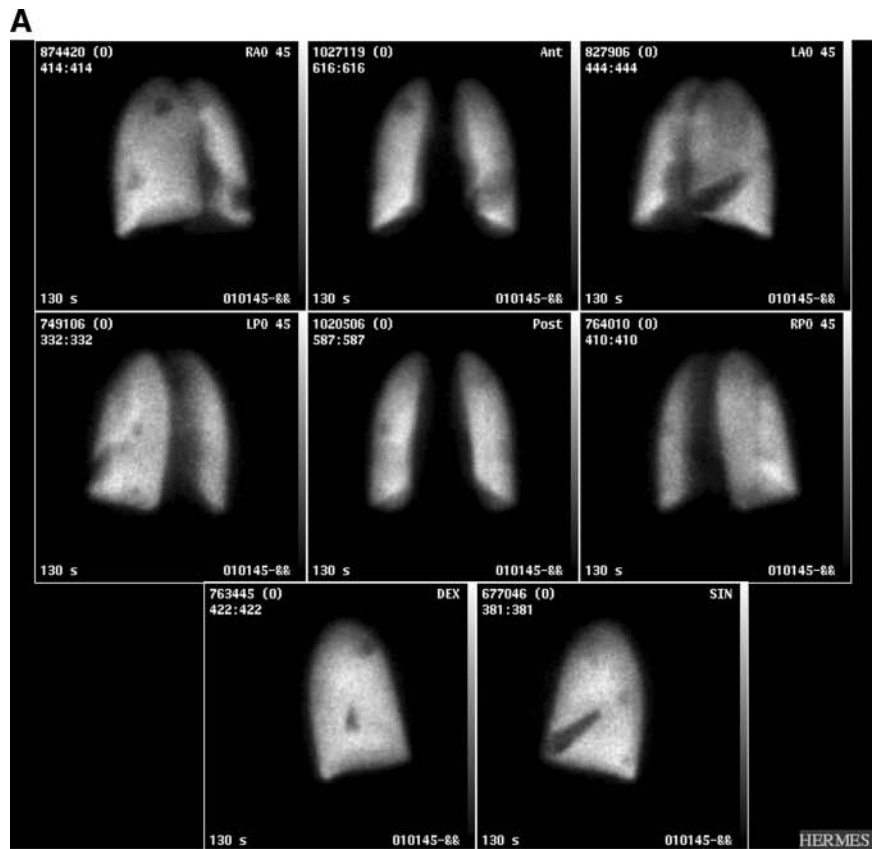
**FIGURE 5.** Histogram of individual results sent to all participating hospitals. Numbers of image sets in different hospitals are shown on x-axis and scores on y-axis. Mean values of scores, together with their own results, were sent to each hospital. Hospitals are coded to maintain anonymity.

poor ones. The conclusion needed to be more assertive. Additional findings were usually missing. Also, few interpreters mentioned normal findings (case 1, left lung). The reports should be structured on internationally accepted recommendations (e.g., procedure guidelines of the Society of Nuclear Medicine [www.snm.org] or of the British Nuclear Medicine Society [www.bnms.org.uk]).

The attenuation properties of the phantom presented in this paper closely resemble those of actual clinical cases. The thorax is fully tissue equivalent, and the cavity is filled with tissue-equivalent lung models. Also, the perfusion defects have almost the same attenuation properties as does human lung. Mandell (8) demonstrated the appearance of segmental perfusion defects with a phantom made of anatomic latex molds, plaster of Paris, and <sup>57</sup>Co. Individual segments were created separately and appeared nicely on



**FIGURE 6.** Example of static perfusion images for case 1 from hospital B.



**FIGURE 7.** Example of static images for case 2 from hospital PQ: perfusion (A) and ventilation (B). Ant = anterior; DEX = right; LAO = left anterior oblique; LPO = left posterior oblique; Post = posterior; RAO = right anterior oblique; RPO = right posterior oblique; SIN = left.

**TABLE 5**

Percentage Visibility of Defects Inside Technical Containers (Case 3) in All 8 Planar Views According to Participating Hospitals' Readers

Defect		Visibility (%)							
Size (cm <sup>3</sup> )	Side	AP	PA	LPO	RPO	LAO	RAO	Left	Right
2.5	Right	39	51		82		100 <sup>†</sup>		100 <sup>†</sup>
2.5	Right*	90	65				82		96 <sup>†</sup>
2.5	Left*	16	75	100 <sup>†</sup>	100 <sup>†</sup>	59		100 <sup>†</sup>	
2.0	Left	92	47	69		92		92	
2.0	Left*	8	69	100 <sup>†</sup>		63		96	
2.0	Right*		29		96 <sup>†</sup>				61
1.5	Right	90 <sup>†</sup>			27		75		78
1.5	Left		49	90				92 <sup>†</sup>	
1.5	Right*				27		37		53 <sup>†</sup>
1.5	Right*	10					33 <sup>†</sup>		14
1.0	Right		16		29 <sup>†</sup>				16
1.0	Right		29		16		41		43 <sup>†</sup>
1.0	Left		4	45		53		55 <sup>†</sup>	
1.0	Left*	10		16		20		41 <sup>†</sup>	
1.0	Left*		12	14 <sup>†</sup>				2	
1.0	Right*	12					10		20 <sup>†</sup>
0.7	Left	14 <sup>†</sup>		4		8		6	
0.7	Right	6 <sup>†</sup>							
0.7	Left	18 <sup>†</sup>				18 <sup>†</sup>		14	
0.7	Right								4
0.7	Right		8		12 <sup>†</sup>				
0.7	Left		12 <sup>†</sup>	12 <sup>†</sup>		12 <sup>†</sup>		2	8

\*Defect was in medial side of lung insert.

<sup>†</sup>Maximal percentage visibility for each defect.

AP = anterior; LAO = left anterior oblique; LPO = left posterior oblique; PA = posterior; RAO = right anterior oblique; RPO = right posterior oblique.

γ-camera images. The author did not discuss the attenuation properties of the phantom. If the cobalt is mixed with water, the density is too high compared with real lung

tissue. The Society of Nuclear Medicine provides a similar proficiency-testing program for lung perfusion.

The phantom can be imaged in the same manner as a real patient: Both planar and SPECT (Fig. 8) images can be acquired, and all kinds of clinical situations can be simulated. Filling is easy and quick because the filling tubes are compatible with syringes. The limitation of the phantom is the lack of respiratory movement. Defects appear slightly sharper than in a real patient. However, instead of adding movement to the phantom, one can blur the physical borders of the defects.

**TABLE 6**

Comparison of Sensitivity for Detecting Lesions vs. Number of Views

View	Sensitivity (%)	P	
AP-PA LPO-RPO LAO-RAO	Left-right	37.7	
AP-PA LPO-RPO LAO-RAO		35.1	0.006*
AP-PA LPO-RPO		32.4	0.001*
AP-PA		27.0	0.002*
AP-PA LAO-RAO		32.1	0.014*
AP-PA	Left-right	35.9	0.140
AP-PA LPO-RPO	Left-right	36.7	0.057
AP-PA LAO-RAO	Left-right	36.6	0.199
LPO-RPO LAO-RAO		42.2	0.040*
LPO-RPO LAO-RAO	Left-right	42.8	0.006*
	Left-right	44.9	0.006*

\*Statistically significant ( $P < 0.05$ ) variation compared with all 8 views.

AP = anterior; LAO = left anterior oblique; LPO = left posterior oblique; PA = posterior; RAO = right anterior oblique; RPO = right posterior oblique.

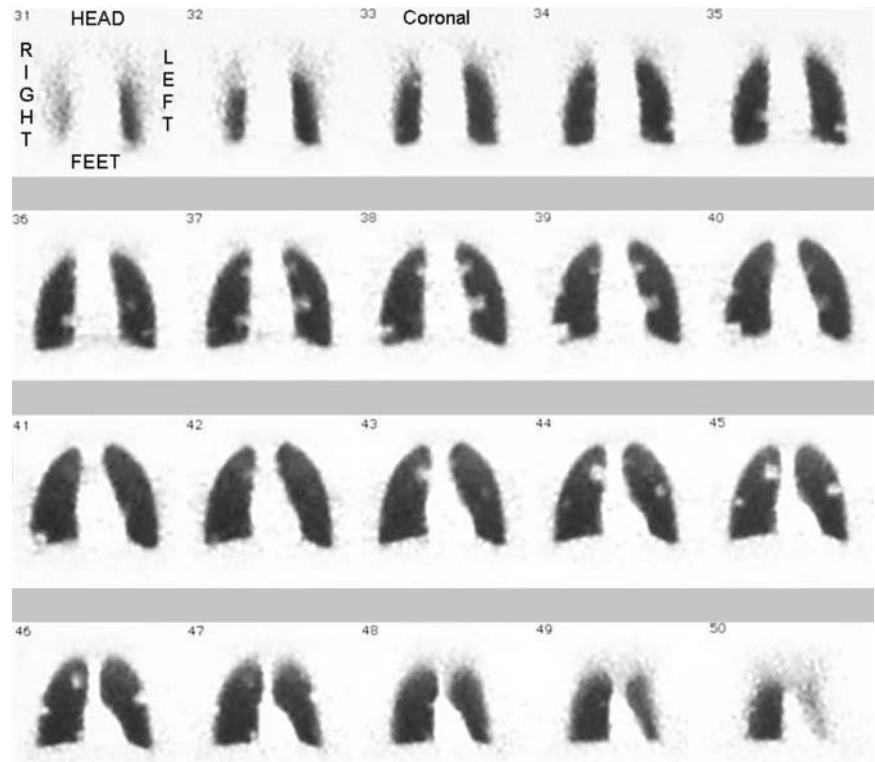
**CONCLUSION**

The phantom mimics scintigraphic studies of the lungs and is suitable for testing the performance of equipment and the proficiency of nuclear medicine professionals in reading lung scans. The use of anatomically realistic phantoms can be an effective way of evaluating nuclear medicine clinics. In some of the participating hospitals, this survey raised serious questions about the overall quality of lung imaging.

**ACKNOWLEDGMENTS**

We thank the participating hospitals for their contribution: Hämeenlinna, Joensuu, Jorvi, Kajaani, Kemi, Kokkola,





**FIGURE 8.** SPECT images of phantom with technical lung containers.

Kotka, Kuopio, Laakso, Lahti, Lappeenranta, Maria, Mikkeli, Oulu, Pori, Seinäjoki, Tampere, and Vaasa. We thank Mika Teräs and the PET Centre of Turku University Hospital for the thorax phantom; Mauri Keinänen and Minna Loikkanen of Labquality Ltd. for financial and organizational help; Jarkko Antikainen of Malliakopio Ltd. for valuable work with the plastic models; Kyösti Hakkarainen of Pipelife M-Plast Ltd. for the plastic pellets; Voitto Heikkinen for excellent suggestions and help with planning the phantom; Timo Karas and the Kouvola Institute of Modeling for machinery for producing the plastic models; the Departments of Technics and Dialysis of Mikkeli Central Hospital for material and technical help with construction of the phantom; and the laboratory and radiology staff of Mikkeli Central Hospital, especially Sinikka Valanta and Matti Airaksinen of the Department of Nuclear Medicine, for helping with tests of the phantom.

## REFERENCES

1. Kauczor HU, Heussel CP, Thelen M. Update on diagnostic strategies of pulmonary embolism. *Eur Radiol.* 1999;9:262–275.
2. Weiss K. Pulmonary thromboembolism: epidemiology and techniques of nuclear medicine. *Semin Thromb Hemost.* 1996;22:27–32.
3. Parker JA, Coleman RE, Siegel BA, et al. Procedure guideline for lung scintigraphy: 1.0. *J Nucl Med.* 1996;37:1906–1910.
4. Heikkinen J, Kuikka JT, Ahonen A, et al. A Finnish multicentre quality assurance project in bone scintigraphy and brain SPET: a phantom study. *Nucl Med Commun.* 1994;15:795–805.
5. Heikkinen J, Kuikka JT, Ahonen A, Rautio P. Quality of brain perfusion single-photon emission tomography images: multicentre evaluation using an anatomically accurate three-dimensional phantom. *Eur J Nucl Med.* 1998;25:1415–1422.
6. Heikkinen JO. A dynamic phantom for radionuclide renography. *Phys Med Biol.* 1999;44:N39–N53.
7. Heikkinen J, Ahonen A, Kuikka JT, Rautio P. Quality of myocardial perfusion single-photon emission tomography imaging: multicentre evaluation with a cardiac phantom. *Eur J Nucl Med.* 1999;26:1289–1297.
8. Mandell CH. *Scintillation Camera Lung Imaging: An Anatomic Atlas and Guide.* New York, NY: Grune and Stratton, Inc.; 1976.