Dynamic Lung Phantom as an Educational Tool

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We constructed a dynamic lung phantom in which various ventilatory abnormalities could be simulated from a piece of soft foam covered with latex rubber. This phantom was then used to illustrate the effects of detector collimation as well as the influence of the physical characteristics of Xe-133 and Kr-81m on image quality.

Phantoms representing various organs are frequently used in nuclear medicine mainly for quality control of instrument performance (*1*). They can, however, also be of considerable value in training programs for both technologists and physicians. Using suitable phantoms, the shortcomings in lesion detection that result from unsuitable collimators or from errors in positioning or instrument settings can be graphically illustrated on simulated organ abnormalities.

Although a lung phantom was used recently by Coates and Nahmias (*2*), a suitable model approximating both lung motion and pulmonary ventilation had not been described. A phantom of this nature, in which the effects of certain pathological conditions on the distribution of ventilation of radioactive gases can be illustrated, would be advantageous in training staff in a nuclear medicine laboratory. Expressions such as regional hypoventilation, air trapping, collateral ventilation, etc., would then become meaningful illustrations instead of vague concepts that are difficult to grasp without a thorough understanding of pulmonary physiology. We have developed a relatively simple lung phantom in which normal and abnormal distribution of ventilation can be simulated using various radioactive tracers. For example, the relative advantages and disadvantages of Xe-133 and Kr-81m can be illustrated.

Materials and Methods

A rectangular piece of soft foam, 200 × 150 × 80 mm in size, was covered with a thin layer of latex rubber. This is best achieved by spreading the latex on a glass pane first and then rolling the foam over the dried film (Fig. 1). Three corrugated polyethylene tubes (the "bronchi") interconnected by means of a four-way connection were inserted approximately 2 cm deep into one side of the foam (the "lung") (Fig. 2). At the site of entry an airtight seal was procured with the aid of additional latex rubber.

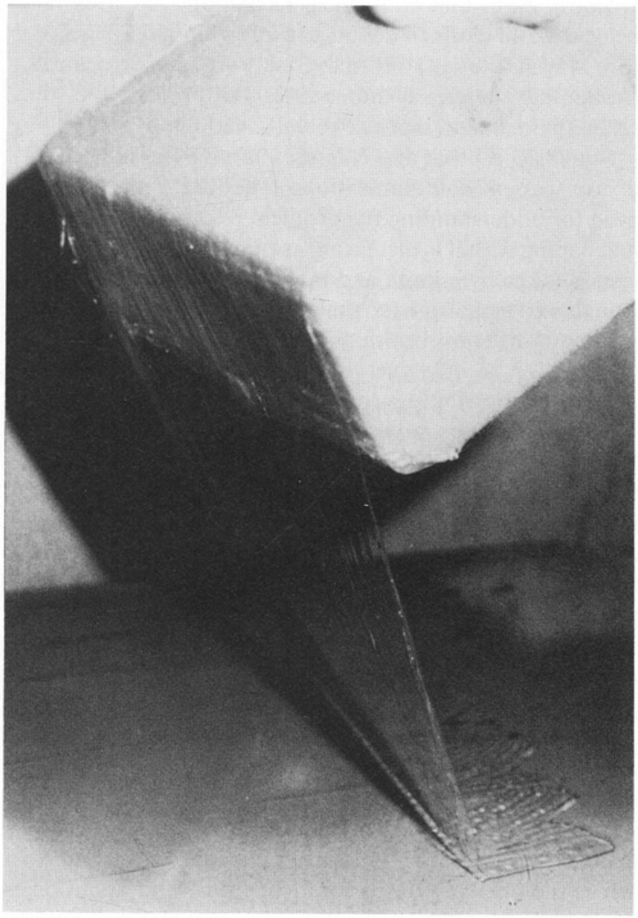

FIG. 1. Covering soft foam with layer of latex rubber spread on glass pane.

The covered foam was then placed within a lucite box with an airtight lid (Fig. 3). The open end of the four-way connection was extended by means of another straight

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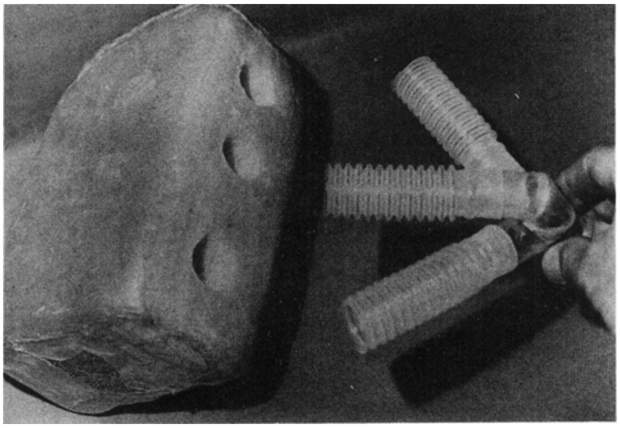

FIG. 2. "Bronchi" are introduced into one side of latex covered foam.

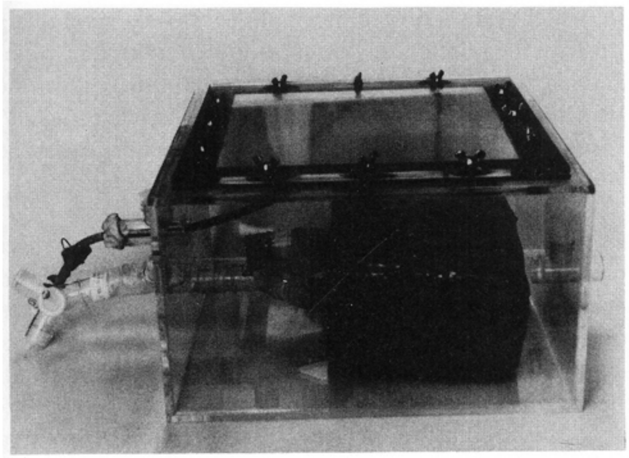

FIG. 3. "Lung" is sealed in air-tight lucite box with portholes for "trachea", balloon catheter, and Bird respirator.

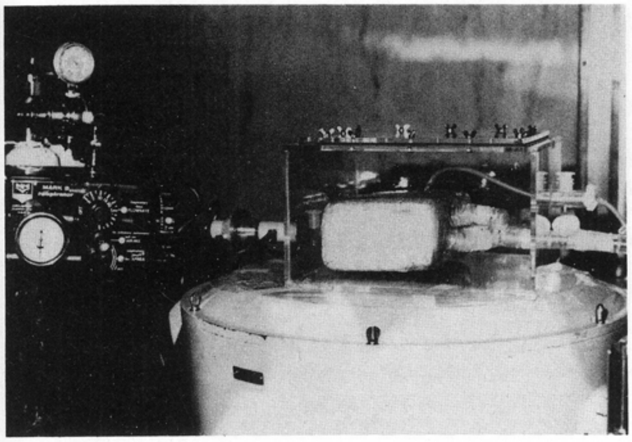

FIG. 4. "Lung" is positioned on detector of gamma camera.

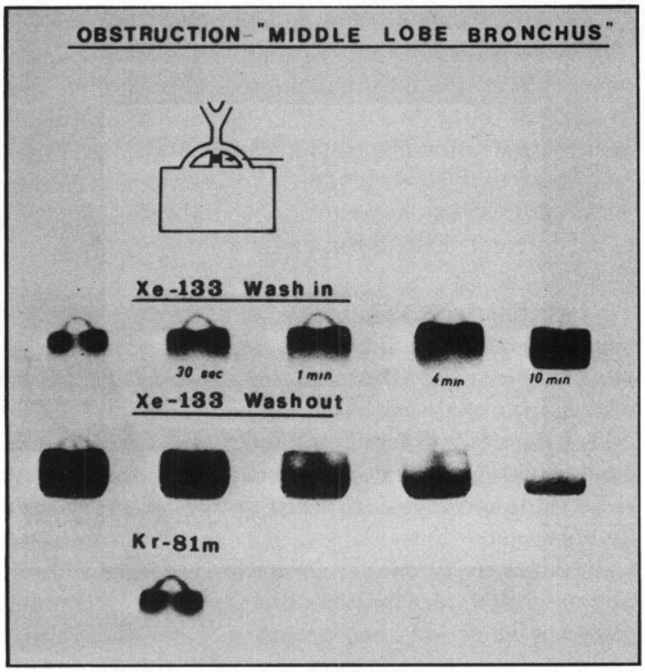

FIG. 5. Wash-in, washout, and equilibrium images of "lung" with the "middle lobe bronchus" occluded. The time intervals of the washout images of the Xe-133 were similar to those of the wash-in images. With the Kr-81m images, 500K counts were collected (approximately 120 sec).

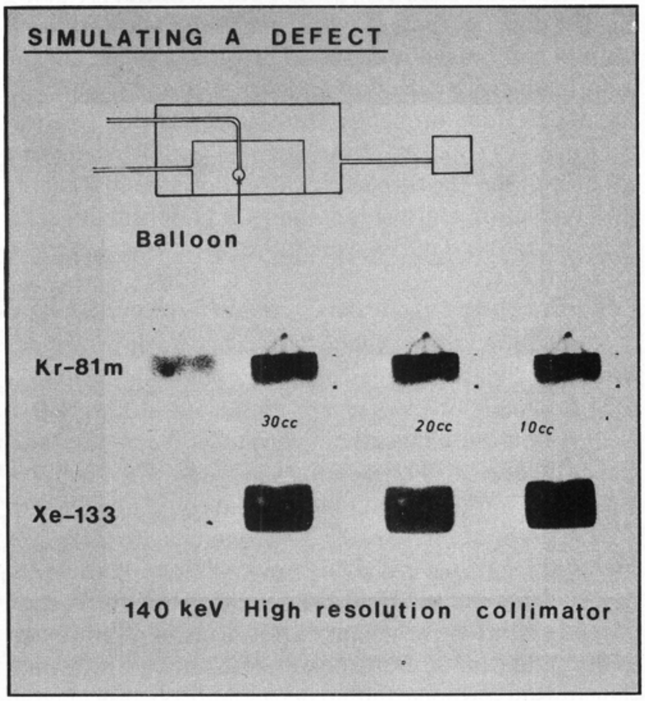

FIG. 6. Extreme left image of Kr-81m is obtained by injecting radioactive gas into balloon of catheter to indicate relative position in "lung."

polyethylene tube (the "trachea") through a sealed porthole in one of the sides of the lucite box. A Bird Mark 8 respirator (Bird Corp., Palm Springs, CA) was connected to a porthole on the opposite side of the box (Fig. 4). The respirator was connected only to the lucite box and not to the lung.

In this manner the foam was sealed within an airtight container (the "thorax") with an outlet that could be connected by means of a three-way valve to the atmosphere or to a closed circuit containing a radioactive gas mixture. Positive pressure applied to the lucite box by means of the respirator simulated expiration; negative pressure simulated inhalation. A third, well-sealed porthole allowed an inflatable balloon catheter to be introduced into the foam to simulate defects of variable size. The middle of the three bronchi could also be obstructed by passing an inflatable balloon catheter through a small hole in the "extrathoracic" portion of the trachea. We then performed various experiments to illustrate the effects of the different physical properties of Xe-133 and Kr-81m on lung imaging.

Ventilation with Xenon-133: A 10-l plastic bag containing 20 mCi of Xe-133 in air was connected by means of a closed circuit to the three-way valve on the trachea. A series of normal wash-in scintigrams were then recorded using a Searle Pho/Gamma IV scintillation camera with a low energy high resolution parallel hole collimator, as well as a low energy high sensitivity collimator (Searle Radiographics, Des Plaines, IL). After equilibration (approximately 10 min) an image was recorded without stopping respiratory motion of the lung. The inlet of the three-way valve was then opened to atmosphere and a series of washout scintiscans recorded. The whole procedure was then repeated with 10-ml, 20-ml, and 30-ml size defects in the phantom obtained by inflating the balloon of the catheter; and after obstruction of the "middle lobe bronchus."

Ventilation with Krypton-81m: Similarly, using Kr-81m from a Rb-81/Kr-81m generator, wash-in, equilibrium, and washout images were obtained in a normal lung, a lung with defects of different size, and a lung with the middle lobe bronchus obstructed. The Kr-81m was continuously supplied to the closed circuit by means of a connection on the three-way valve. Both the low energy high resolution and the low energy high sensitivity collimators were used during ventilation with Kr-81m.

Results

Ventilation with Xenon-133: The wash-in, equilibrium, and washout phases of our study with the middle lobe bronchus obstructed are illustrated in Fig. 5. It is clear from these images that, apart from the middle lobe, the distal one-third of the lung was also relatively hypoventilated and that total lung volume could only be seen after equilibration. On the washout images there was marked trapping of gas in this region while gas was cleared rapidly from the well-ventilated areas. Also, obstruction of the middle lobe bronchus caused decreased ventilation in the middle lobe during the wash-in study, marked trapping during washout, but no defect in this region at equilibrium. All three simulated defects were clearly seen when the high resolution collimator was used but not with the high sensitivity collimator (Figs. 6 and 7).

Ventilation with Krypton-81m: As we expected, there was no difference in the appearance of the wash-in and equilibrium images during ventilation with Kr-81m (Fig. 8). Even after 10 min of constant ventilation, no radioactivity was detected in the poorly ventilated region of a normal lung. The scintiscans at equilibrium closely resembled the wash-in scintiscans during ventilation with Xe-133 (Fig. 5). Washout images with Kr-81m were not feasible because the very short physical half-life (13 sec) of the gas causes the images to disappear with an even shorter effective half-life.

The smallest defect was seen less clearly during ventilation with Kr-81m than with Xe-133 (Fig. 6).

When the study was repeated with the high sensitivity collimator, few of the defects were visible (Fig. 7). Obstruction of the middle lobe bronchus produced equilibrium images closely resembling the Xe-133 wash-in images (Fig. 5), but when a high sensitivity collimator was used an image of inferior quality was obtained.

Discussion

We have constructed a practical dynamic lung phantom in which ventilatory abnormalities closely resembling those in the human lung can be imitated. Different radioactive gases may also be used in the phantom to illustrate the effect of their physical characteristics on image quality. Moreover, the effects of collimation on the images may be studied under the same experimental conditions.

Using Xe-133 and Kr-81m, we find:

- The very short physical half-life of Kr-81m has an effect on the appearance of the scintiscans. Hypoventilated areas were never shown as radioactive regions and even during extended periods of ventilation, only well-ventilated areas were imaged. Xenon-133, on the other hand, slowly diffused into poorly ventilated regions and predictably, the equilibrium images only represented total lung volume. Washout images were obtained only with Xe-133 yeilding a "negative" image caused by trapped activity in poorly ventilated regions.

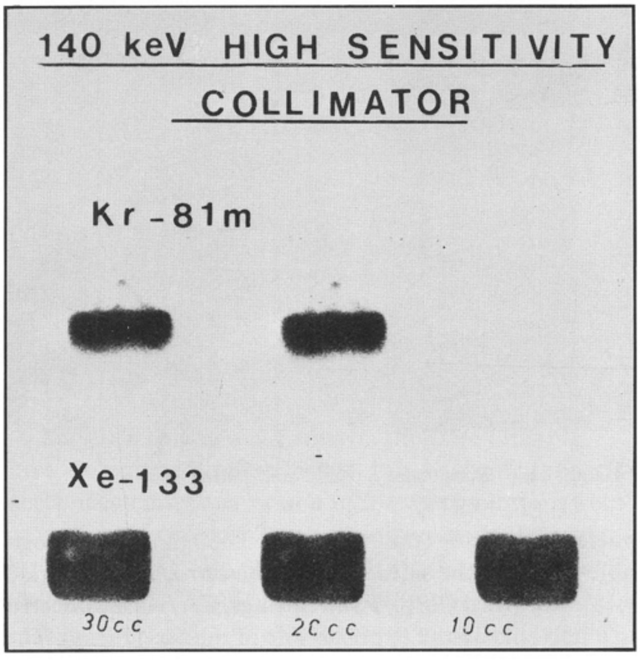

FIG. 7. Note very poor resolution of defects with Kr-81m.

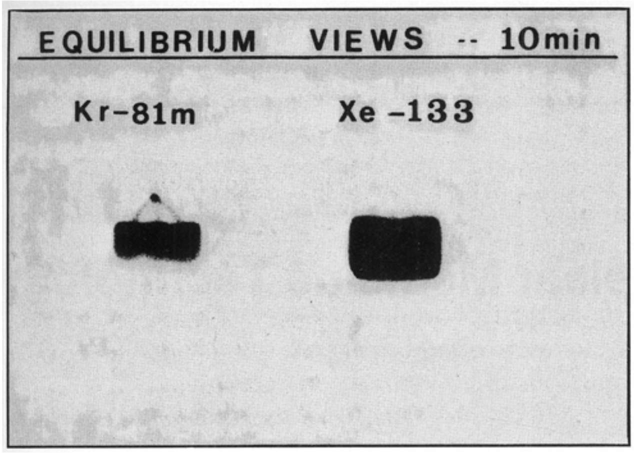

FIG. 8. Equilibrated images of "lung" with no simulated defects and without occlusion of the "middle lobe bronchus."

- Small defects were better visualized with Xe-133 than with Kr-81m when the high resolution collimator was used. This was probably due to some septal penetration by the 190-keV gamma photons of Kr-81m. This was even more evident when the high sensitivity collimator was used.
- Slow diffusion of gas into underventilated regions of the phantom resembled the same phenomenon found in poorly ventilated regions of the intact human lung.

We did not use scattering material in our study, but layers of material may easily be introduced between the lung and the camera's detector to study and illustrate the effect of predetector scattering on the lower energy gamma photons of Xe-133. In this manner the advantages of using Xe-127 might be effectively illustrated.

Conclusion

Our phantom gave a fair approximation of the different ventilatory abnormalities found in day-to-day clinical ventilation studies. It is a practical tool to explain and illustrate the influence of detector collimation, as well as the effects the half-life and photon energy of various gases have, on image quality to technologists and students of nuclear medicine.

References

1. Gottschalk A, Hoffer PB: Stationary detectors. In *Golden's Diagnostic Radiology*, Robbins LL, ed, Baltimore, Williams & Wilkens, 1976, pp 94–103

2. Coates G, Nahmias C: Xenon-127, a comparison with xenon-133 for ventilation studies. *J Nucl Med* 18: 221–225, 1977