Absolute Quantitation of Radiotracer Uptake in the Lungs Using a Gamma Camera

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A transmission-emission method for the absolute quantitation of Tc-99m in the lungs with a computerized gamma camera is described. The method requires no measurements of the linear attenuation coefficients of the lung and chest wall, or of their thickness. It yields results of acceptable accuracy for everyday clinical use and offers the great advantage of avoiding the use of a phantom. The method could be extended for the absolute quantification of Tc-99m agents in soft tissue and bone with errors of less than 10%.

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In organ-imaging studies with a radionuclide and gamma camera, the measurement of the tracer uptake in a particular organ or site is of interest as a supplement to the information in the image. The uptake is usually quantitated by comparison with a phantom that resembles the organ in shape, size, depth, and tracer distribution. Alternatively, the counts recorded may be corrected for attenuation in the patient. The correction required is best obtained from measurement of the transmission of the radiation from an external source; a method for correcting the emission counts from Ra-226 in patients was described by Evans (*1*). For measurement of organ activity in profile scanning, Tothill and Galt (*2*) applied a transmission method to correct the emission counts. Fleming (*3*) described a method for the absolute measurement of activity of Tc-99m in the liver and spleen by use of anterior, posterior, and lateral views with a gamma camera. The quantitation of activity in vivo by whole-body counting has been reviewed in detail by Sorenson (*4*).

The present paper describes the use of a transmission method, like that described by Thomas et al. (*5*), to correct the emission counts recorded with a gamma camera. It differs from Fleming's method in that knowledge of the mean depth of the emitter and thickness of the patient are not required. We describe the use of this method to measure pulmonary uptake in perfusion scans with Tc-99m-labeled macroaggregates of human serum albumen. It has also been used to study the uptake into lungs of tin colloid used in liver and spleen scans, and the activity in the lungs of patients during ventilation scans with a Kr-81m generator. These results will be reported elsewhere.

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THEORY

Consider a rod of lung tissue, of length l and unit cross-sectional area, standing perpendicular to the face of the gamma camera; we assume uniform concentration of activity and a linear attenuation coefficient μ_2. The anterior and posterior chest walls are of thickness a and b respectively with a linear attenuation coefficient μ_1. Following the equation of Fleming (*3*), the geometric mean (G) of anterior and posterior count rates per unit area (cps/cm^2) from the lungs, obtained by a gamma camera with a parallel-hole collimator, is given by:

$$G = (N_A \cdot N_P)^{1/2} = \frac{EA}{\mu_2} \cdot e^{-\mu_1(a+b)/2} \cdot (1 - e^{-\mu_2 l}) \qquad (1)$$

where N_A and N_P (cps/cm^2) are the observed anterior and posterior count rates respectively, E is the sensitivity of the camera/collimator system, and A (mCi/cc or MBq/cc) is the activity of the emitter in the lung.

The attenuation correction for the lung and chest wall can be derived from measurement of the radiation transmitted from a uniformity source that emits photons of the same energy as the tracer that is being imaged. If N_O is the count rate from the source held directly in front of the camera and N_T the count rate after transmission through the defined area of lung and chest wall then:

$$\left(\frac{N_O}{N_T}\right)^{1/2} = e^{\mu_1(a+b)/2 + \mu_2 l/2} \qquad (2)$$

Multiplying (1) and (2) the count rate per unit area is:

$$G \cdot \left(\frac{N_O}{N_T}\right)^{1/2} = \frac{EA}{\mu_2} e^{\mu_2 l/2} \cdot (1 - e^{-\mu_2 l})$$

Therefore*

$$EAl = G \cdot \left(\frac{N_O}{N_T}\right)^{1/2} \cdot \frac{\mu_2 l/2}{\sinh(\mu_2 l/2)} \text{ cps/cm}^2$$

The absolute activity in the whole area of a lung would be:

$$\frac{G}{E} \cdot \left(\frac{N_O}{N_T}\right)^{1/2} \cdot \frac{\mu_2 l/2}{\sinh \mu_2 l/2} \text{ mCi}$$

The function $\mu_2 l/2/\sinh \mu_2 l/2$ is plotted against thickness of lung, unit density tissue, and bone density tissue in Fig. 1. For the human lung where l might be of the order of 20 cm, the value of $\mu_2 l/2/\sinh \mu_2 l/2$ is 0.978, indicating that an error of less than 3% would be expected if this function were taken as unity. Even for tissue of unit density, the error in ignoring the sinh function for a 10-cm thickness is only 6%. If the sinh function is taken as 1, the activity of a radionuclide in the lung becomes $G/E \cdot (N_T/N_O)^{1/2}$ mCi.

RESULTS

Phantom measurements. The method was tested with a phantom simulating lung and chest wall. Boxes were used to imitate the chest wall; they were constructed of 3-mm plexiglass and filled with water to provide a 2.6- or 5.2-cm layer of chest wall on each side of the lung. The lung phantom was a rectangular box constructed from 3-mm Plexiglass, 14.6 cm wide and 20.0 cm long, filled with bran to a depth of 15 cm. The bran was mixed with 60 ml of water to which a measured quantity of pertechnetate (Tc-99m) in saline was added. The density of the mixture was made up to 0.3 g/cc with water. The "lung" was positioned with the long or short axis perpendicular to the detector's collimator and counts were recorded from a central area of approximately 5 cm square in the lung image. Measurements of the absolute activity in the lung were made with and without the chest-wall structure in position, using the respective transmission attenuation correction factors. Narrower phantoms were obtained by use of a partition in the box. With chest walls of thickness 0, 2.6, and 5.2 cm, the ratio of observed counts to true counts did not depart from unity by more than 5% when corrected by the relevant transmission factor.

Lung uptake measurements. The validity of the method was tested in vivo by measuring the uptake of Tc-99m-labeled macroaggregates by the lung. In normal subjects almost all the activity injected will be trapped in the lung (6) so there should be good correspondence between the quantities injected and those measured. A gamma camera with a 40-cm field of view, a multihole parallel collimator, and a computer system were used. The patient was seated with his back to the detector and a uniformity source 45 cm in diameter and containing 5 mCi (185 MBq) of Tc-99m was held in front of the chest. A transmission image was

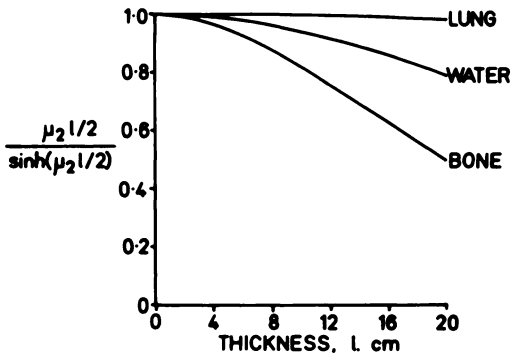

FIG. 1. Variation of $\mu_2 l/2/\sinh \mu_2 l/2$ with thickness, l, of source. Values for lung (density 0.3 g/cc), soft tissue (unit density), and bone (density 1.8 g/cc).

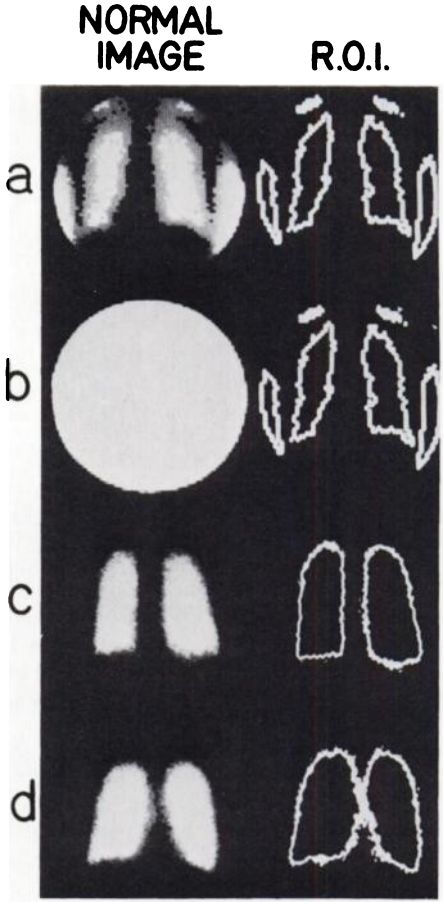

FIG. 2. Gamma-camera images from which lung radioactivity was calculated. Regions of interest were selected with 20% threshold:

a) transmission image with subject placed between uniformity source and camea;
b) uniformity source;
c) posterior image of lungs after injection of Tc-99m-labeled macroaggregates;
d) anterior image.

obtained [(Fig. 2(a)] and an image of the source alone was then recorded [(Fig. 2(b)]. The activity of the Tc-99m macroaggregates injected into the patient was measured with a radionuclide calibrator and corrected for the amount remaining in the syringe. After allowing a few minutes for trapping of the macroaggregates in the lungs, anterior and posterior images of the lungs were recorded [(Fig. 2, (c) and (d)]. The lung fields on the transmission image were taken as the area inside the 20% isocount line after interpolation and smoothing, and the count rate is then N_T. The count rate within the same region was then measured for the image of the uniformity source (N_O). The emission count rate was also recorded with a region of interest defined by a 20% threshold in the anterior and posterior views; the geometric mean of these values was calculated. The efficiency of the camera/collimator system for a thin source was measured by moistening a filter paper, 12.5 cm in diameter, with pertechnetate in about 2 ml of water. The filter paper was protected by a thin polythene film. The activity of the paper was measured with the same radionuclide calibrator; it was then placed on the collimator of the gamma camera and the count rate recorded. Table 1 shows the results obtained in measurements made on five consecutive patients with normal perfusion lung scans.

TABLE 1. QUANTITATION OF LUNG UPTAKE OF Tc-99m MACROAGGREGATES

Patient	Activity injected (mCi)	Activity estimated $\frac{G}{E}\left(\frac{N_O}{N_T}\right)^{1/2}$ (mCi)	Estimated / injected %
HA	2.43	2.32	95.4
FE	3.08	3.15	102.1
JE	2.67	2.61	97.8
CH	2.57	2.58	100.3
DE	2.86	2.91	101.8
Mean			99.5
s.d. of a single observation			2.9

DISCUSSION

The good agreement shown in the table between the quantity of tracer injected and that estimated from gamma-camera measurements demonstrates that the method can provide useful clinical information, in spite of the number of assumptions made in the derivation of the equations. Some of these are:

1. The distance function for a gamma camera collimator system is unity. This is valid for multihole parallel collimator systems.
2. The linear attenuation coefficients for the emission and transmission equations are similar. In practice μ for emission = 0.124/cm and μ for transmission = 0.126/cm.
3. The degradation in spatial resolution with depth in tissue can be ignored.
4. The tissue overlying the lung contains a negligible amount of activity. This is true for Tc-99m-labelled macroaggregates but not necessarily with e.g. Tc-99m tin colloid in the lungs.
5. There is some compensation for nonuniformity in the distribution in depth of activity in the lungs when the geometric mean of anterior and posterior count rates is used.
6. The thickness of the chest wall overlying and underlying the lung can be represented by a mean value. (To be rigorous the geometric mean of each element or pixel of the image should be used with the appropriate transmission correction, but for routine clinical use a simplified correction method is adequate.)

The uptake of Tc-99m by organs other than the lung can also be quantitated by the derived equation, but with less accuracy. Figure 3 shows the percentage error involved in assuming that the sinh function equals unity for lung of density 0.3, for unit density tissue, and for bone of density 1.8 g/cc. Figure 4 shows that the error in calculating the activity in various thicknesses of water (corrected by the transmission equation and assuming that the sinh function equals 1) is in agreement with the predicted curve. Thus for unit-density tissue (e.g., liver or spleen) the error involved in assuming that the sinh function equals 1 is only about 6% for unit-density tissue of thickness 10 cm, or for bone of thickness 5 cm.

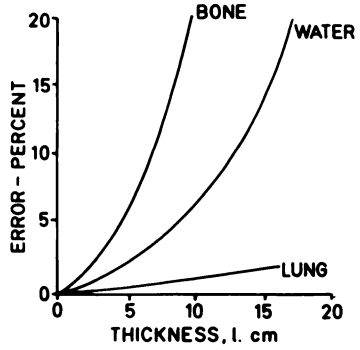

FIG. 3. Error in assuming that factor $\mu_2 l/2/\sinh(\mu_2 l/2) = 1$ for lung (density 0.3 g/cc), soft tissue (unit density), and for bone (density 1.8 g/cc).

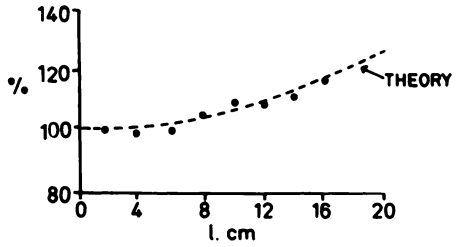

FIG. 4. Variation of observed counts, expressed as percentage of true counts, with thickness, l, of unit-density tissue.

In conclusion, the method described for quantitation of uptake of a radionuclide in the lung using a gamma camera is easy to apply as a routine clinical procedure. It does not require a knowledge of the attenuation coefficients of lung or soft tissue, or of the thickness or composition of the lung and chest wall, or a special computer program. In spite of the assumptions made in applying the transmission correction to the emissions, it yields data with more than adequate accuracy for everyday clinical use. This transmission-attenuation method should also be applicable to quantitation of radionuclide uptake in unit-density tissue and in bone, and will offer better accuracy for measurements of the uptake into the thyroid, liver, and other organs than the standard technique of comparison with measurements in phantoms.

FOOTNOTE

* $e^{\mu l/2}(1 - e^{-\mu l})$
$= e^{\mu l/2} - e^{-\mu l/2}$
$= 2\sinh(\mu l/2)$

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