Transmission Scanning: A Useful Adjunct to Conventional Emission Scanning for Accurately Keying Isotope Deposition to Radiographic Anatomy[1]

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In 1952 Mayneord (1) proposed the usefulness of a transmission counter for plotting outlines of organs. Later, he produced images of lead letters by recording the transmitted beam from a Tm^{170} (84 keV) source which was maintained in direct alignment with the aperture of a scintillation detector during scanning (2, 3). In 1963, Cameron and Sorenson reported use of Am^{241} (60 keV) and I^{125} (30 keV) sources to determine bone mineral content by measuring the change in intensity of a transmitted photon beam moved across a bone (4). No clinical application of transmission scanning for forming images of body structures was reported by these authors.

We have explored transmission scanning as a means of improving the orientation of the radionuclide emission scan (5). Accurate evaluation of a radionuclide distribution in the body requires that the spatial relationships of emission scan data be oriented to the anatomy of the patient. Usually, data on the scan record are keyed to anatomy either by using reference marks to represent external features or by superimposing a roentgenogram of the part (6). These methods may introduce inaccuracy due to geometric distortions; also, if the patient moves during the scan, counting data and anatomic reference may no longer correspond.

Transmission scanning can be employed to reduce these inaccuracies. During a conventional emission scan, a small radioactive source of either Am^{241} or I^{125} is made to move under the patient so as to follow the motion of the detector (Fig. 1). The photons from this source are collimated and directed through the patient to the detector. Pulse-height analysis is used to separate the emission and transmission counting data which are then recorded separately. As the scan progresses, the point-to-point variation of count rate from the transmitted beam depends on attenuation by anatomic structures. The transmission scan image that is reconstructed from these data is similar to a roentgenogram of the scanned part and can be oriented to the corresponding emission scan image with no geometric distortion. Any patient movement during the study is apparent in both records.

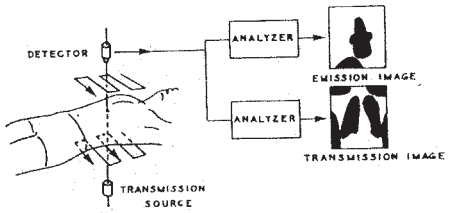

Fig. 1. Transmission scanning. A collimated radioactive source is made to move under the patient so as to follow the motion of the detector during a conventional emission scan. The intensity of the transmission beam directed through the patient varies from point to point according to attenuation by body structures. Pulse-height analysis is used to separate the emission and transmission data which are recorded separately. The emission picture is an image of radionuclide distribution—the transmission picture is an image of associated anatomy, similar to a roentgenogram.

METHOD

1. Scanning and Read-Out System: The scanning and read-out system used in this study is described in detail elsewhere (7–9). The patient is supported on a cantilever aluminum pan 0.6 cm thick. A pair of opposed scintillation detectors, mechanically coupled by a yoke, scan both sides of the body at the same time. A maximum field size measuring 35 cm wide and 115 cm long can be scanned on any plane parallel to the long axis of the body.

The crystal of each detector is 5.1 cm thick and 7.6 cm in diameter. Focused collimators with either low-energy or high-energy designs are used, depending on the choice of radionuclide for the emission scan (10).

During the study, counting and position data are recorded in binary code on perforated paper tape. Each character on the paper tape is made to represent counts integrated in a predetermined elapsed detector travel distance. Three separate picture channels can be accommodated on a single perforated tape. After the study, rapid playback converts these data to gray shade pictures on the Polaroid film of an oscilloscope camera.

2. Choice of Transmission Source: The required properties of an ideal transmission source include:

(*a*) The energy of the principal photon emission should be in the 25 to 60 keV range. In this energy range there will be effective differential absorption in bone, soft tissue, and air, assuring optimum contrast between these structures in the record (11).

(*b*) The principal photon emission should not be accompanied by any significant number of emissions at higher energies. Higher energy photons produce scattered radiation that may not be distinguished from the emission signal.

(*c*) The physical half-life (*i.e.*, useful life), of the transmission source should be long.

(*d*) The specific activity of the source material should be high, so that source dimensions can be small. This requirement is less stringent than if the source were to be used for transmission radiography.

(*e*) The necessary quantity of radionuclide should be available at an acceptable cost.

The physical properties of I^{125} satisfy many of these requirements. It decays by electron capture with a sixty-day half-life, emitting 1.36 photons per disintegration at 27.4 keV and 0.07 photons per disintegration at 35.4 keV. These photons can all be counted in a scintillation spectrometer window set at about 30 keV (12). Iodine 125 can be produced by deuteron irradiation of natural tellurium with a specific activity of 17.4 curies per milligram. However, practical use of I^{125} for transmission scanning of thicker body parts, such as the chest, is limited at present by economic considerations. A very active, and expensive, source would be required to produce good count rates. Furthermore, the sixty-day half-life would necessitate periodic source renewal.

For general use, the properties of Am^{241} are more favorable. Americium 241 is an alpha particle emitter with a half-life of four hundred and seventy years. The principal gamma ray has an energy of 59.6

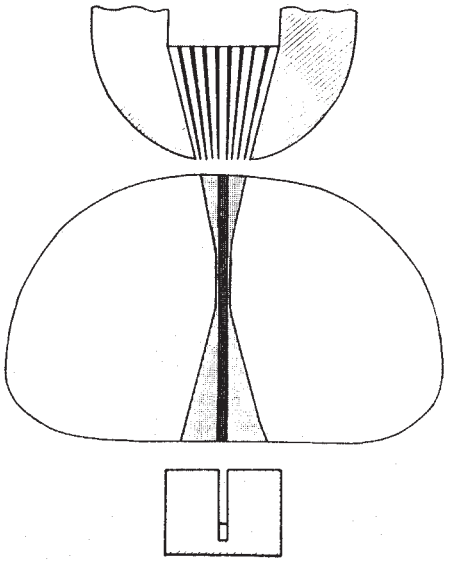

Fig. 2. Detector and source collimators. The Am^{241} source below the patient is collimated with a straight-bore channel measuring 4.5 cm in length and 0.63 cm in diameter. A hole with the same diameter is drilled through the center of the focused collimator of the detector above to admit the transmission beam. These collimators restrict the volume of tissue examined by the transmission beam to a cylinder through the body measuring 0.63 cm in diameter.

[1] From the Department of Radiology of the School of Medicine and the Hospital of the University of Pennsylvania, and the William H. Donner Center for Radiology, Philadelphia, Penna. Accepted for publication in March 1966.

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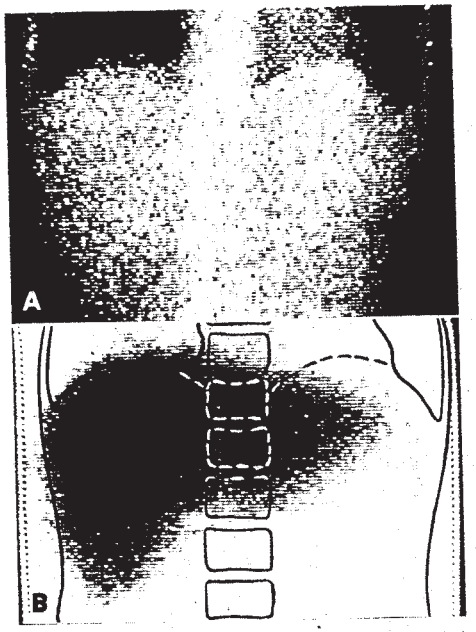

Fig. 3. Simultaneous Am^{241} transmission scan (A) and Au^{198}-colloid emission scan (B) of normal liver. Anatomic landmarks in the transmission picture can be traced directly onto the emission picture, since there is a 1:1 correspondence. The relation of the liver to the diaphragm is shown accurately.

keV and a frequency (photons per alpha) of 0.359. The only other significant gamma ray is at 26.4 keV with a frequency of 0.025. In addition, characteristic x-rays from neptunium between 14 and 21 keV have a frequency of 0.376 (13). Americium 241 is produced by neutron irradiation of plutonium 240 with a specific activity of approximately 3.2 curies per gram. Source material sufficient to produce good count rates through the chest is relatively inexpensive, and the four hundred and seventy-year half-life makes periodic source renewal unnecessary.

3. Transmission Scanning with Am^{241}: For transmission scanning, a 100-millicurie source of Am^{241} is encapsulated in a steel cylinder measuring 0.95 cm in outside diameter and 1.27 cm in height.[2] In one end of this cylinder is a recessed stainless-steel window measuring 0.0025 cm thick and 0.67 cm in diameter. This source capsule is encased in a lead shield that has a straight-bore channel for beam collimation measuring 0.63 cm in diameter and 4.5 cm in length (Fig. 2, below). When not in use, the outlet hole is shielded with a removable brass plug.

[2] Fabricated by Nuclear Materials and Equipment Corporation, Apollo, Penna.

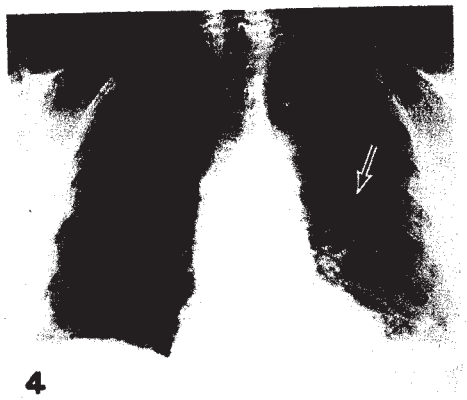

Fig. 4. Roentgenogram of patient with pneumonia adjacent to left hilus.

On the exit side of the patient, the transmission beam is further collimated by a straight-bore channel measuring 0.63 cm in diameter which is drilled through the center of the focused collimator of the detector (Fig. 2, above). Together, the source collimator and the detector collimator define the volume of tissue which is examined by the transmission beam—a cylinder through the body measuring 0.63 cm in diameter.

The half-value thickness for the Am^{241} beam measures 3.7 cm of water. The transmission count rate varies as the inverse square of the separation between source and detecting crystal. If there were a 35.5 cm source-to-crystal distance and a 20 keV analyzer window were centered on the 60 keV photopeak, 1.6×10^4 counts per second would be measured through the stretcher top (0.63 cm thick Al). In practice, the beam is attenuated by the patient, and added copper foils are used to reduce the transmission count rate to about 300 counts per second over the most radiolucent body part in the scan field. Cross-talk to the emission data channel is negligible when this source is employed for simultaneous counting with Tc^{99m} (140 keV), I^{131} (364 keV), or Au^{198} (412 keV).

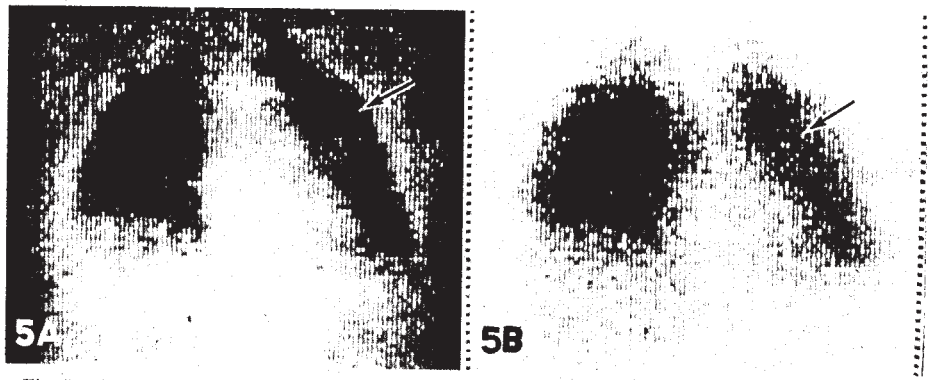

Fig. 5. Simultaneous Am^{241} transmission scan (A) and I^{131}-MAA emission scan (B) corresponding to roentgenogram shown in Figure 4. The region of hypoaeration can be identified clearly in the transmission scan and compared with the corresponding region of diminished arterial perfusion in the emission scan.

The maximum dose from the Am^{241} source to a point on the skin of a patient for an entire scan pattern made at a scan speed of one centimeter per second is about 0.27 millirads.

Outlines of selected structures in the transmission picture are traced on clear acetate film and superimposed directly on the emission picture for correlation. For example, we carefully trace the diaphragm in liver scanning (Fig. 3), the pulmonary boundaries and any opaque lesion in lung scanning (Figs. 4 and 5), the cardiac silhouette in pericardial effusion scanning, and any skull structure associated with a suspected lesion in brain scanning (Fig. 6).

4. Transmission Scanning with I^{125}: Since our scanner has two opposed detectors, there is the potential for performing two emission scans, one above and one below the patient, simultaneously with a transmission scan. A back-shielded transmission source can be mounted directly within the collimator of one detector so that the beam will pass through the patient and enter the central collimator hole of the other detector. This configuration is feasible with an I^{125} source—there is excessive backward transmission of radiation with our Am^{241} source.

One millicurie of I^{125} is encapsulated at the base of a brass tube collimator that is 0.5 cm in diameter and 5.7 cm long. The plastic exit window is 0.15 cm thick. There is a back-shield of lead measuring 1.3 cm thick. When the tube is inserted into the central hole of one of the opposed detectors, the back shielding is sufficient to prevent interference with emission counting.

The half-value thickness for the I^{125} beam measures 1.8 cm of water. The count rate is 1,400 counts per second when there are a 35.5 cm source-to-crystal distance, no added attenuator, and a 16 keV analyzer window centered on the 30 keV photopeak.

This configuration can be employed with a three-channel data system in brain scanning to produce simultaneously an emission picture of each side of the head and a transmission picture of the head outline (Fig. 7). Internal structure can be distinguished when the scanned part of the patient is thin (Fig. 8) and when radionuclide distributions are to be localized in small laboratory animals (Fig. 9).

DISCUSSION

Our experience suggests some clinical

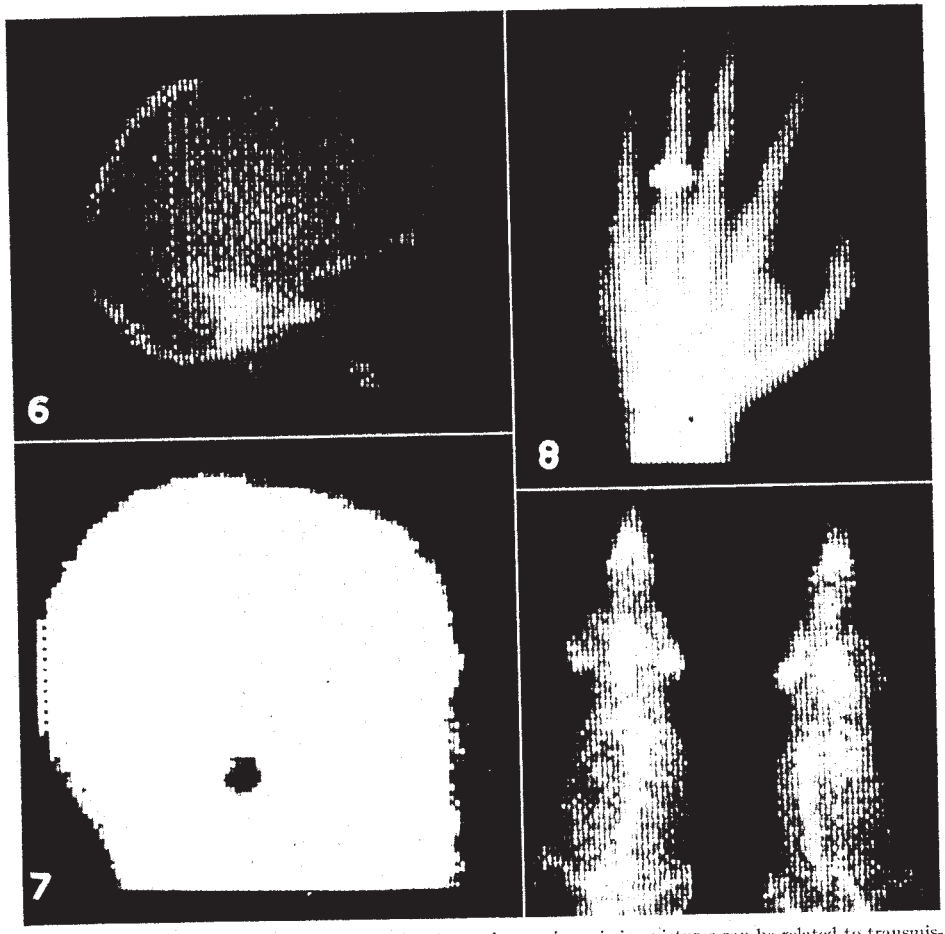

Fig. 6. Am^{241} transmission scan of the head. Tumor images in emission pictures can be related to transmission images of the calvaria, base of the cranial vault, paranasal sinuses, auditory meatus, orbital margins, and nasopharynx.

Fig. 7. I^{125} transmission scan for head outline. The external auditory meatus is marked with an accessory I^{125} source in a rubber ear-plug.

Fig. 8. I^{125} transmission scan of hand with ring on finger.

Fig. 9. I^{125} transmission scan of two rats for orientation of simultaneous Tc^{99m} emission scan in body-distribution study.

applications of transmission scanning should be adopted as routine, some nurtured as promising, and others abandoned as unnecessary.

We employ Am^{241} transmission scanning as routine to identify the cardiac border for comparison with the edge of cardiac blood pool in pericardial effusion scanning. In our hands, the method is accurate and more dependable than radiographic comparison.

In liver scanning (Fig. 3), the Am^{241} transmission image is of value for correlating the superior margin of the liver image with that of the overlying diaphragm. This is especially important in assessing the presence or absence of a subdiaphragmatic abscess. The transmission scan also helps identify such irregularities of the superior margin of the liver image as those caused by respiratory motion. Respiratory artefact is apparent in both the liver-emission picture and the diaphragm-transmission picture—irregularities due to lesions in the liver do not influence the diaphragm image.

In brain scanning, the transmission picture (Fig. 6) can be useful for localizing abnormal uptake, especially at the base of the cranial vault. This additional information, however, is not usually required since with newer brain-scanning agents, such as Tc^{99m}-pertechnetate, emission pictures alone contain considerable anatomic information.

In lung scanning with I^{131} macroaggregated albumin, the Am^{241} transmission scan aids correlation of pulmonary lobar anatomy and emission mapping of regional pulmonary arterial perfusion. Together, the transmission and emission lung pictures permit an accurate comparison between the apparent extent of a radiographic lesion and the corresponding defect in pulmonary arterial perfusion (Figs. 4 and 5).

Transmission scanning should be a valuable adjunct for quantitative analysis of emission scan data. When counts making up an emission image of a body structure are integrated, the sum is proportional to the amount of radionuclide in the structure. Count sums from different body parts pictured on the scan record can be compared as a measure of the differential deposition of radionuclide. Quantitative analysis of I^{131}-MAA pulmonary scan data, for example, has been demonstrated to be a reliable alternative to the differential oxygen uptake method for estimating relative distribution of pulmonary arterial blood flow to each lung (17, 18). When the regional counting data are to be selectively integrated, transmission and emission pictures made simultaneously should be useful for delineating the beginning and the end of structures such as pulmonary lobes.

Transmission pictures should be valuable also for relating transverse-section emission pictures (7, 8, 15, 16) to cross-sectional anatomy of the body. When the radioactivity in a thin body cross-section is displayed in the transverse-section emission scan, anatomic orientation is sometimes difficult. The transverse-section emission scan is relatively easy to orient when the brain is scanned—the mediastinal scan is difficult to orient. Although limited to single detector performance, our studies suggest that the transverse-section Am^{241} transmission scan will accurately orient a transverse-section emission scan of the thorax made at the same time (Fig. 10).

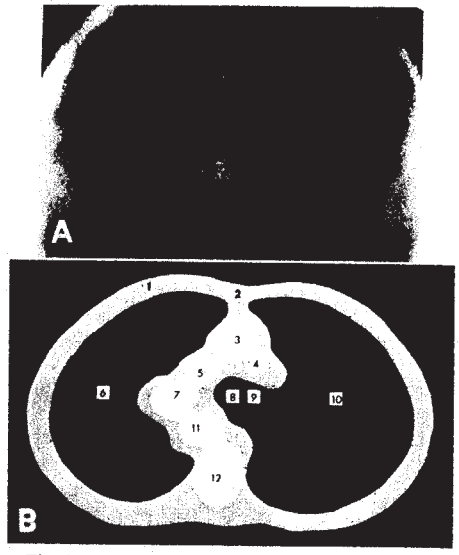

Fig. 10. Am^{241} transverse section transmission scan through hilar region of human thorax (A), and diagrammatic explanation (B) for anatomic orientation of a simultaneous transverse-section emission scan.

1, chest wall; 2, sternum; 3, ascending aorta; 4, superior vena cava; 5, pulmonary trunk; 6, left lung; 7, left hilar complex; 8, left main bronchus; 9, right main bronchus; 10, right lung. Compare with Figure 41 of Reference 14.

SUMMARY

Transmission scanning is introduced as a means of improving the anatomic orientation of the radionuclide emission scan. During a conventional emission scan, a small radioactive source of either Am^{241} or I^{125} is made to move under the patient so as to follow the motion of the detector.

The photons from this source are collimated and directed through the patient to the detector. Pulse-height analysis is used to separate the emission- and transmission-counting data which are then recorded separately. As the scan progresses, the point-to-point variation of count rate from the transmitted beam depends upon attenuation by anatomic structures. The transmission scan image that is reconstructed from these data is similar to a roentgenogram of the scanned part and can be oriented to the corresponding emission scan image with no geometric distortion. Any patient movement during the study is apparent in both records. The method has been applied to rectilinear scanning of the heart, lungs, liver, and brain, and to transverse-section scanning of the thorax.

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