Patient and Occupational Radiation Exposure from SPECT Transmission Imaging

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Objective: SPECT attenuation correction by transmission imaging has attracted interest as a method to reduce tissue attenuation artifacts in myocardial perfusion imaging. A technique has been developed to perform Simultaneous Transmission Emission Protocol (STEP)™ imaging using a line-source of radioactivity positioned at the focal line of a fan-beam collimator. The line-source yields a transmission scan of the patient's chest to measure individual points of body attenuation which provides an attenuation correction technique for radionuclide imaging. This investigation measured the increase in patient and occupational radiation dose due to the transmission source.

Methods: Using a 19.4-mCi ^{99m}Tc transmission source and thermoluminescent detector (TLD) crystals at various locations on a phantom, we measured radiation dose to a simulated patient and to the technologist.

Results: For a 2-hr exposure period, the maximum dose equivalent was 20 mrem which occurred at the lateral aspects (both left and right) of the chest. The regions of the anterior and posterior mid-chest, thyroid and umbilicus, each measured 10 mrem. The gonads and symphysis pubis doses were less than 3 mrem. All occupational locations measured less than 3 mrem for the 2-hr exposure period.

Conclusion: The maximum radiation surface dose equivalent received by the patient, in a normal 30-min scanning period, would be no greater than 5 mrem. The occupational dose equivalent for the same period is less than 1 mrem from the transmission source. The addition of a transmission source of approximately 20 mCi does not appreciably increase either the patient or technologist radiation dose.

Key Words: attenuation correction; SPECT; radiation exposure

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SPECT requires the application of attenuation correction techniques to produce quantitative images (*1–10*). To date, attenuation correction techniques available on commercial nuclear medicine SPECT cameras and computer systems use mathematical algorithms for attenuation correction based on the assumption of uniform attenuation by the body (*1–3*). SPECT myocardial perfusion imaging involves the complex attenuation represented by the heart and vascular structures, lungs, bone, muscle and, in females, breast tissue. Experimental transmission imaging techniques have been applied both to phantoms and patients, using radioactivity configured as sheet-source, point-source, scanning line-source and fixed line-source (*8–10*). We have adapted transmission imaging for attenuation correction using a line source of radioactivity and fan-beam collimators on a triple-detector camera (*10*). Using multiple energy windows, we are able to acquire emission and transmission image data simultaneously. Simultaneous imaging techniques have been developed using a transmission source of either ^{99m}Tc or ^{57}Co for use with ^{201}Tl or using a source of ^{153}Gd for ^{99m}Tc-sestamibi perfusion imaging. Simultaneous Transmission Emission Protocol (STEP)™ imaging has been performed using an experimental line-source holder and a commercially available collimated line-source holder. The purpose of this investigation was to measure the patient and occupational radiation doses from these two line-source holders during STEP imaging.

METHODS

Experimental Line-Source Holder

STEP imaging was performed using an experimental device consisting of a fillable line-source (Data Spectrum Corp, Hillsborough, NC) of radioactivity filled to a length of 15 in. The line-source was held in an experimental prototype device with 1/16 in of lead on three sides. The open side of the shield provided a beam of gamma rays directed toward the scintillation camera (Fig. 1). Technetium-99m was used as the radionuclide for transmission imaging and the activity measured 19.4 mCi immediately prior to performing the experiment.

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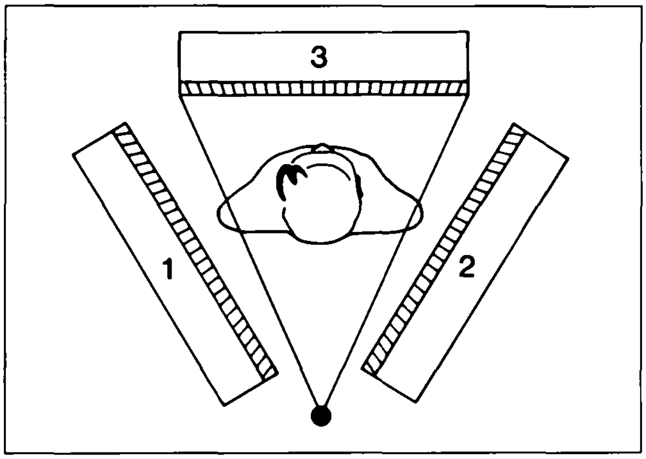

FIGURE 1. A shielded line source is positioned at the focal line of one fan-beam collimator using a triple-detector camera. A transmission scan is obtained from this source simultaneously with emission acquisition from all three detectors.

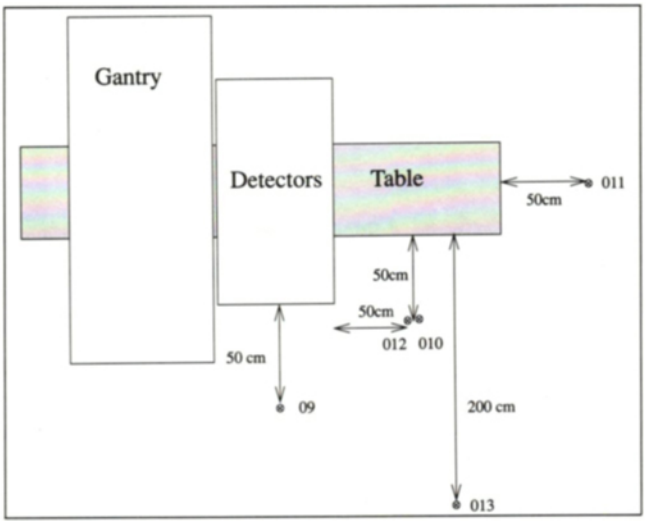

FIGURE 3. TLD positions for the measurement of occupational exposure relative to the detector orbit and imaging table.

An x-ray anthropomorphic torso phantom (Landauer, Inc., Glenwood, IL) and anthropomorphic abdomen phantom were placed on the scanning table to simulate patient attenuation and scatter. The SPECT device was a triple-detector camera (Prism 3000, Ohio Imaging Division, Picker International Inc., Bedford Heights, OH) fitted with 65-cm focal length fan-beam collimators. Thermoluminescent detector (TLD) crystals (LiF, Landauer Inc., Glenwood, IL) in protective plastic bags were taped at various locations on the two phantoms as noted in Figure 2. These points of dose measurement correspond to the surface of the following locations: posterior chest, anterior chest, left lateral chest, right lateral chest, thyroid, mid-abdomen (umbilicus), gonads and symphysis pubis. The phantoms were scanned with the triple-detector camera system so as to rotate the radiation transmission line-source about the phantom to simulate actual patient radiation dose during STEP imaging.

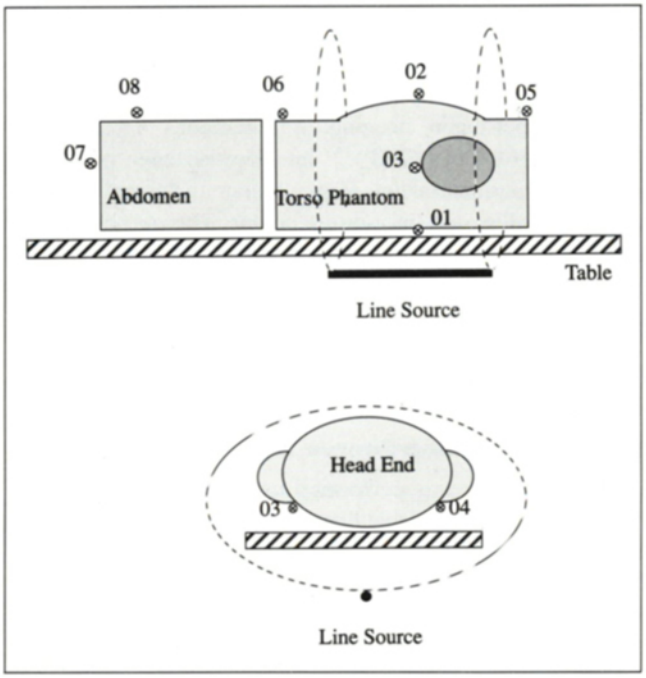

FIGURE 2. TLD positions on the anthropomorphic chest and torso phantoms as shown from the lateral projection (above) and transverse projection (below). The body contour orbit of the line source is shown by the dotted line.

Occupational radiation exposure received by the technologist was measured at imaging table height by placing LiF TLD crystals at four lateral locations to the gantry as shown in Figure 3: 50 cm to the side of the radiation detectors; 2 LiF TLDs were located 50 cm from the side of the imaging table and 50 cm from the radiation detectors; 50 cm from the end of the patient imaging table; and 200 cm lateral to the patient imaging table (the location of the computer console for camera operation). The first three of these operator locations were thought to be the closest proximity the technologist might occupy while imaging a patient, and the final location at the operator console might be the typical operator location during imaging.

With the LiF TLDs in position, the line-source of radioactivity was loaded onto the camera gantry and imaging was started immediately. The gantry motion control program was set to complete one 360-degree rotation in 2 hr, four times the typical time for a 30-min scan. Following data acquisition the scan was stopped, the line-source removed promptly and the LiF TLDs sent for analysis.

Commercial Line-Source Holder

Radiation measurements were also made using a commercial line-source holder (Picker STEP™, Ohio Imaging Division, Picker International Inc., Bedford Heights, OH) attached to the triple-detector camera (Fig. 4) at the factory. This line-source holder assembly is detachable from the system and is shown in Figure 5. This assembly consists of a source, cylindrical shaped lead-source holder, an electromechanical shutter mechanism and a collimator with tin vanes. The line source is changeable and consists of a stainless steel

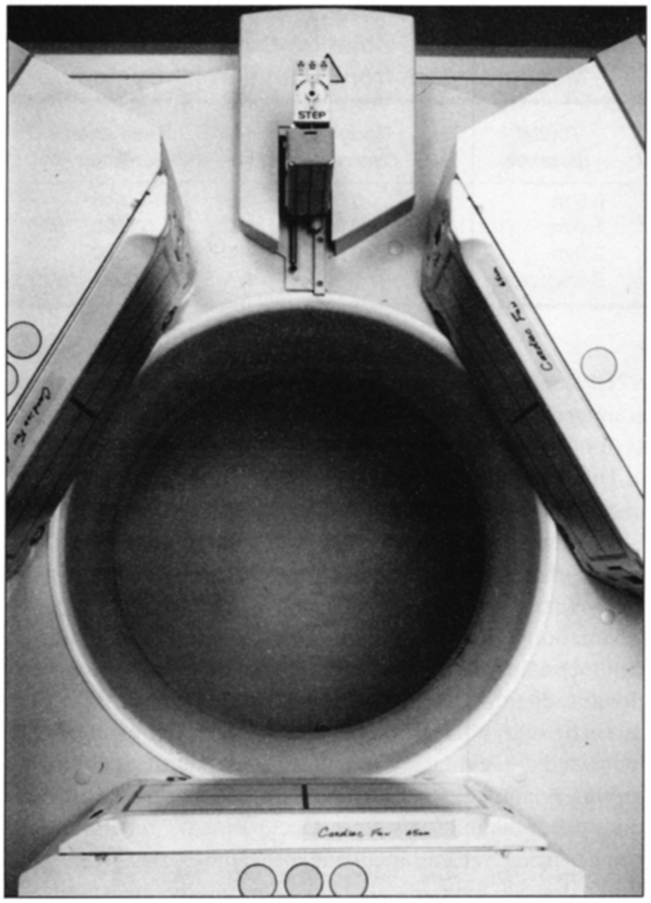

FIGURE 4. Triple-detector camera fitted with fan-beam collimators. The transmission source holder assembly is opposed to one detector which will acquire both transmission and emission images simultaneously. A motor drive maintains the radioactive source at the focal line of the fan-beam collimator during scanning.

tube (235 mm in length) which contains either ^{153}Gd or ^{57}Co radioactive material. The source holder can also accept a similar, fillable glass tube liquid source of ^{99m}Tc.

Patient radiation dose and scatter dose to the technologist were simulated by making measurements using standard CT head and body phantoms as defined in the CDRH Standard (21-CFR 1020.33, section (b)). These radiation dose measurements were made using aluminum oxide TLDs (5-mm diameter, 1-mm thick) (Victoreen, Cleveland, OH) at 15 locations inside the phantoms. Three of these measurement locations were on the central axis of the system and phantom (centered and +/− 6 cm from the center). The remaining 12 measurement points were located symmetrically in the planes of the axis points at 1 cm below the surface of the phantoms.

Simulated patient orbit scans were performed on the phantoms using a 360° orbit and a 1-hr exposure time. A 20-mCi source of ^{153}Gd was used in two experiments using the body phantom and body contour orbits and for two more scans using the head phantom and circular head orbits. A 20-mCi source of ^{57}Co was used to do one simulated body scan and one simulated circular head scan. One body phantom scan was done using a 20-mCi ^{99m}Tc source in a body contour orbit.

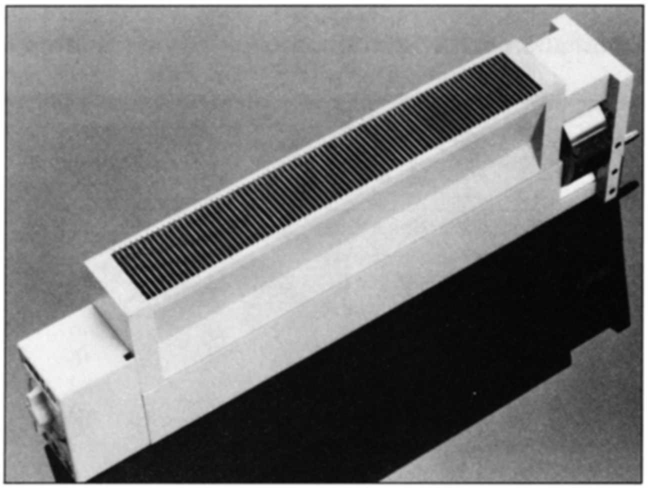

FIGURE 5. Commercial line-source holder. A shutter shields the source and vaned collimator limits the radiation beam to the field of view of one detector fitted with a fan-beam collimator.

Scatter radiation measurements were also made radially from the central-axis of the STEP radiation field to determine operator exposure at 0.5, 1 and 2 m. A Victoreen Model 470-A survey meter (Victoreen, Inc., Carle Place, NY) and an Eberline Model E-120 (Eberline Instrument Corp., Santa Fe, NM) GM counter with pancake probe were used for these low-level scatter experiments.

RESULTS

Experimental Line-Source Holder

The LiF TLD dosimeters, together with a background control, were returned to the vendor for determination of the radiation dose at various locations shown in Figures 2 and 3. The results for the various numbered locations identified in these figures are given in Table 1. There was no correction for radioactive decay.

These LiF TLD readings represent exposures over a 2-hr period. Normally, the technologist would perform one patient scan in 30 min; therefore, the patient and occupational exposures should be reduced by 1/4 to compute the normal dose equivalent per scan. It should be noted that the LiF TLD readings for detectors 07–013 do not represent exact values due to the precision of the LiF TLD detectors used in the investigation. Also, the accuracy of the LiF TLD crystals at dose levels less than 10 mrem are accurate to ±25%.

Commercial Line-Source Holder

The averaged dose equivalent measurements for 1-hr scans are tabulated in Table 2 for various commercial STEP sources and phantom types used. It should be noted that Al_2O_3 TLD chips were used and thus no correction for their nonlinear response was made. In the energy region of 100–140 keV used in the experiment, however, the response/R was close to 1.0 (Prudie Rupp, personal communication). Thus the error due to energy dependence is small and less than the statistical error in the measurements.

TABLE 1
Radiation Dose from Experimental Line Source Holder and ^{99m}Tc

TLD number	LiF TLD location	Dose equivalent/ 2 hr (millirem)*
01	Patient, posterior mid-chest	10
02	Patient, anterior mid-chest	10
03	Patient, left lateral chest	20
04	Patient, right lateral chest	20
05	Patient, thyroid	10
06	Patient, umbilicus	10
07	Patient, gonads	<3
08	Patient, symphysis pubis	<3
09	Occupational, 50 cm lateral to detectors	<3
010	Occupational, 50 cm lateral to table, 50 cm from detector	<3
011	Occupational, 50 cm from end of imaging table	<3
012	Occupational, same location as TLD 010	<3
013	Occupational, 200 cm lateral of imaging table	<3

*The minimum sensitivity is 3 mrem and dose equivalent below this level is reported as <3 mrem.

Operator exposure measurements from the commercial line-source holder using the survey meter and GM counter are shown in Table 3.

DISCUSSION

In these experiments, the maximum radiation surface dose equivalent was no greater than 5 mrem. This dose would be delivered to the chest in a 30-min imaging period.

The radiation dose equivalent the patient receives from 4 mCi of ^{201}Tl-thallous chloride or 30 mCi of ^{99m}Tc-sestamibi for myocardial perfusion imaging are listed in Table 4. The total body dose equivalent is over two orders of magnitude higher than the STEP source dose. The radiation dose from STEP imaging, therefore, represents a negligible increase compared to the radiation exposure from the internal exposure of ^{201}Tl-thallous chloride or ^{99m}Tc-sestamibi.

TABLE 2
Patient Radiation Dose Equivalent Measurements (Al_2O_3 TLDs) for Transmission Scans with Commercial System

Experiment number	Phantom	Source	mrem/ hr*
1	Body	^{153}Gd	1.95
2	Body	^{153}Gd	1.65
3	Head	^{153}Gd	1.83
4	Head	^{153}Gd	1.54
5	Head	^{57}Co	1.04
6	Body	^{57}Co	1.19
7	Body	^{99m}Tc	0.62

*The recorded mrem/hr values are the average of fifteen measurements for each scan; the statistical uncertainty of these numbers is estimated to be ±0.55 mrem/hr.

TABLE 3
Occupational Radiation Dose Equivalent Measurements from Commercial System

Radial distance	Body scan mrem/hr	Head scan mrem/hr
0.5 m	0.052	0.048
1.0 m	0.036	0.028
2.0 m	0.024	0.020
Background	0.022	0.022

The maximum dose level received by a technologist using the experimental source in performing 2 hr of STEP imaging was less than 3 mrem at a distance of 0.5 m. Due to these low exposure levels, we are unable to provide an accurate measurement using LiF TLD detectors of occupational dose to nuclear medicine personnel. With the commercial system and using GM counters the occupational radiation dose at 0.5 m was approximately 0.02–0.03 mrem/hr above background. The commercial system with increased shielding, collimator and shutter obviously provides improved occupational radiation protection over the experimental system. Occupational radiation exposure from nuclear medicine procedures has been published by Sloboda, et al. (*11*). This study measured the occupational dose equivalent to the technologist to be 0.04 mrem per ^{201}Tl myocardial perfusion imaging study using 2.2 mCi. Thus, our study shows the occupational

TABLE 4
Patient Radiation Exposure from [^{201}Tl]-Thallous Chloride and ^{99m}Tc-Sestamibi

Tissue	^{201}Tl-thallous chloride rems/4 mCi	^{99m}Tc-sestamibi rems/30 mCi
Total body	0.76	0.5
Heart wall	1.81	0.5
Liver	2.00	0.6
Kidneys	4.36	2.0
Testes	1.81	0.3
Ovaries	1.70	1.5
Thyroid	2.36	0.7
Gastrointestinal tract		
Stomach wall	1.52	0.6
Small intestine	1.38	3.0
Upper large intestine wall	0.90	5.4
Lower large intestine wall	0.76	3.9

Sources: Technical product data sheet, Thallous Chloride ^{201}Tl injection, Mallinckrodt Medical Inc., St Louis, MO and Technical product data sheet, Cardiolite, DuPont Merck Pharmaceutical Co., Billerica, MA.

dose equivalent is not significantly increased by the use of the STEP source.

In conclusion, we have measured both patient and occupational dose from a radioactive line-source while performing STEP imaging on a triple-detector SPECT system. Maximum patient radiation dose equivalent was no greater than 10 mrem/hr over the chest and less than half that amount for any other area of the body. In addition, the worst case occupational dose equivalent near the patient from the commercial line-source would be on the order of 1 mrem/hr.

REFERENCES

1. Sorenson JA. Quantitative measurement of radioactivity in vivo by whole-body counting. In: Hine GJ, Sorenson JA, eds. *Instrumentation in nuclear medicine, vol. 2*. New York, NY: Academic Press; 1974.
2. Budinger TF, Gullberg GT, Huesman RH. Emission computed tomography. In: Herman GT, ed. *Image reconstruction from projections: implementation and application*. New York, NY: Springer-Verlag; 1979.
3. Chang LT. A method for attenuation correction in radionuclide computed tomography. *IEEE Trans Nucl Sci* 1978;25:638–643.
4. Gullberg GT, Budinger TF. The use of filtering methods to compensate for constant attenuation in single-photon emission computed tomography. *IEEE Trans Biomedical Eng* 1981;28(2):142–157.
5. Tsui BM, Gullberg GT, Edgerton ER, et al. Correction of nonuniform attenuation in cardiac SPECT imaging. *J Nucl Med* 1989;30:497–507.
6. Bailey DL, Hutton BF, Walker PJ, et al. Improved SPECT using simultaneous emission and transmission tomography. *J Nucl Med* 1987;28:844–851.
7. Malko JA, Van Heertum RL, Gullberg GT, et al. SPECT liver imaging using an iterative attenuation correction algorithm and an external flood source. *J Nucl Med* 1986;27:701–705.
8. Jaszczak RJ, Gilland DR, Hanson MW, et al. Fast transmission CT for determining attenuation maps using a collimated line source, rotatable air-copper-lead attenuators and fan-beam collimation. *J Nucl Med* 1993; 34:1577–1586.
9. Tan P, Bailey DL, Meikle SR, et al. A scanning line source for simultaneous emission and transmission measurements in SPECT. *J Nucl Med* 1993;34:1752–1760.
10. Tung C-H, Gullberg GT. Emission and transmission noise propagation in cardiac SPECT imaging with nonuniform attenuation correction [Abstract]. *J Nucl Med* 1992;33:902.
11. Sloboda RS, Schmid MG, Willis CP. Technologist radiation exposures from nuclear medicine imaging procedures. *J Nucl Med Technol* 1987;15: 16–24.