# Radiation Dose to Positron Emission Tomography Technologists During Quantitative Versus Qualitative Studies

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Positron emission tomography technologists were monitored with thermoluminescent dosimeters (TLDs) during qualitative and quantitative studies. Doses to technologists during specific tasks were also measured. The technologists received at least twice as much radiation during the quantitative as the qualitative studies. The average dose per study for qualitative studies was 0.017 mSv (1.7 mrem) shallow and 0.014 mSv (1.4 mrem) deep. The average dose per study for the quantitative studies was 0.05 mSv (5 mrem) shallow and 0.04 mSv (4 mrem) deep. The average dose per study was based on the TLD dose accumulated over studies conducted over four 2-mo and one 1-mo intervals. The dose incurred by the technologists each time they drew a radioactive dose was 0.002 mSv (0.2 mrem) shallow and 0.001 mSv (0.1 mrem) deep. The doses received during injection were 0.014 mSv (1.4 mrem) shallow and 0.007 mSv (0.7 mrem) deep. Doses received during blood sampling were 0.016 mSv (1.6 mrem) shallow and 0.014 mSv (1.4 mrem) deep. During quantitative studies, the technologist received a much greater dose than during its qualitative counterpart due to the blood sampling process and increased time in the room with the radioactive patient.

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The use of positron emission tomography (PET) is increasing annually. The radiation doses to the technologists who administer the radionuclides to patients involved in PET studies can vary significantly from facility to facility (*1–2*). This variation may be due to inexperience of the technologists or the types of PET studies which are conducted at various facilities. Both qualitative and quantitative studies are conducted at PET facilities. Technologists at PET facilities are exposed to radiation during the dose drawing, injection and blood pressure monitoring tasks of qualitative studies. A quantitative study is similar to the qualitative study except that a quantitative study involves much more interaction with the radioactive patient, including frequent and prolonged blood sampling, than is required for qualitative, or clinical, studies (*3*). During this blood sampling, the technologist is further exposed to radioactivity.

Determining the dose a technologist receives during each of the various PET tasks will identify tasks from which technologists receive the highest doses. In PET, up to 3700 MBq (100 mCi) of radioactivity are typically injected because of the very short half-lives of the materials used (*4*). Thus, it is particularly important to determine how these quantitative studies compare to qualitative studies in which very little time is spent in the room with the patient.

The objective of this study was to measure radiation doses to PET technologists during qualitative and quantitative studies. These measurements will be used to determine the PET technologist dose per type of study.

## MATERIALS AND METHODS

### Thermoluminescent Dosimeter Reader System

Thermoluminescent dosimeters (TLDs) used in this study were Panasonic UD-802AS (Panasonic, Secaucus, NJ). This four-element dosimeter consists of two elements of natural lithium borate and two elements of calcium sulfate. A Panasonic UD-710 automatic TLD reader was used to read the dosimeters.

The TLD system was calibrated using a $^{137}Cs$ beam irradiator after this radiation source had been calibrated using National Institute of Standards and Technology (NIST) calibrated transfer standard ionization chambers (*5*).

A typical dose algorithm uses ratios of the various elements of a dosimeter to determine the type of radiation to which one is exposed. When the type of radiation is determined, the response of a particular element is modified to determine the dose. A modification of the algorithm presented in the Panasonic user's manual was used for this study (*6*). This dose algorithm calculated the dose to the technologists at the shallow depth (7 mg/cm$^2$) and at the deep depth (1000 mg/cm$^2$) as defined in the ANSI n13.11-1983 standard (*5*).

### Radiation Dose Determination

Technologists were monitored with TLDs at The University of Michigan Hospital PET facility, Ann Arbor, MI. The University of Michigan is primarily a research facility which conducts a mixture of qualitative and quantitative studies using PET. Each technologist was issued two base TLDs per month; one

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worn only during qualitative studies and the other only during quantitative studies. Specific written and verbal instructions were given to each technologist regarding appropriate use of each dosimeter. Each dosimeter was color coded to aid in differentiation. Large, brightly colored signs were placed at the entrance to each imaging room to remind the technologist to check their dosimeters before entering. These signs were changed periodically to keep them noticeable.

After the first 1-mo issuance period, the dosimeters were issued for 2-mo periods. Technologists maintained records on the number of qualitative and quantitative studies in which they participated and wore the appropriate dosimeter. The sum of the doses measured during the qualitative studies in a given dosimeter-issuance period was divided by the number of studies to obtain an average dose per qualitative study. In addition, the sum of the doses measured during the quantitative studies in a given dosimeter-issuance period was divided by the number of quantitative studies to obtain an average dose per quantitative study.

Dosimeters for specific tasks were provided and specific directions given for their use. The four tasks that were monitored included: dose-drawing, injection, blood pressure monitoring and blood sampling. A single dosimeter was assigned for the dose drawing, whereas each of the remaining three tasks had a dosimeter assigned to each patient room. Each of these special dosimeter types had its own unique color to avoid confusion by the technologists. Each technologist was instructed to wear either a qualitative or quantitative dosimeter, depending on the type of study, and a second dosimeter for each of the various tasks conducted during the study.

All of the dosimeters, with the exception of the dose-drawing dosimeter, were stored in the control room of the PET suite at the University of Michigan. A control badge was kept in each storage location to monitor background for later subtraction. The dose-drawing dosimeters were stored in the radiopharmacy for convenience. A separate control dosimeter was stored with these dose-drawing dosimeters.

Technologists maintained records on the number of times a specific task was performed while the correct specific-task dosimeter was worn. During each of the five dosimeter-issuance periods, the sum of the doses measured using the TLDs during a specific task was divided by the number of times that task was performed to obtain the average dose per task.

## RESULTS

Dosimeters were issued to technologists for 2-mo periods, except the first issuance which was for 1-mo. Following collection of the dosimeters, they were processed in the UD-710A Panasonic TLD reader using specified quality control procedures (*6*).

The technologist doses from qualitative studies are shown in Table 1. Also shown in this table are the number of qualitative studies which were conducted and the average dose per qualitative study. Average dose per qualitative study was found to be 0.017 mSv/study (1.7 mrem/study) at the shallow depth and 0.014 mSv/study (1.4 mrem/study) at the deep depth.

Table 2 shows the technologist doses from quantitative studies measured using TLDs during each of the five dosimeter issuance periods. This table also shows the number of studies conducted and the average dose per study during each period. The average dose per quantitative study was found to be 0.05 mSv/study (5.0 mrem/study) at the shallow depth and 0.037 mSv/study (3.7 mrem/study) at the deep depth.

Individual task-specific dosimeters were worn for each dose drawing, injection and blood pressure monitoring during the qualitative studies. In addition to these three task-specific dosimeters, a fourth task-specific dosimeter was worn for blood sampling during quantitative studies. Table 3 shows the average dose per task conducted over the entire study. The highest dose per task was measured during the blood-sampling procedures (only conducted during quantitative studies).

The errors associated in making measurements with TLDs were propagated using standard error propagation

**TABLE 1**
Technologist Doses from Qualitative Studies Measured Using TLDs

| Issuance period | Shallow (mSv) | Deep (mSv) | No. of studies | mSv/Study | |
|---|---|---|---|---|---|
| | | | | Shallow | Deep |
| 5/15/91–6/14/91 | 0.27 | 0.21 | 23 | 0.012 | 0.009 |
| 6/15/91–8/30/91 | 1.47 | 0.9 | 79 | 0.019 | 0.011 |
| 9/1/91–10/31/91 | 1.75 | 1.7 | 89 | 0.02 | 0.019 |
| 11/1/91–1/13/92 | 1.71 | 1.56 | 94 | 0.018 | 0.017 |
| 1/13/92–3/13/92 | 1.95 | 1.78 | 111 | 0.018 | 0.016 |
| Average | | | | 0.017 | 0.014 |

**TABLE 2**
Technologist Doses from Quantitative Studies Measured Using TLDs

| Issuance period | Shallow (mSv) | Deep (mSv) | No. of studies | mSv/Study | |
|---|---|---|---|---|---|
| | | | | Shallow | Deep |
| 5/15/91–6/14/91 | 0.3 | 0.08 | 13 | 0.023 | 0.006 |
| 6/15/91–8/30/91 | 1.7 | 0.78 | 31 | 0.055 | 0.025 |
| 9/1/91–10/31/91 | 2.19 | 1.75 | 24 | 0.091 | 0.073 |
| 11/1/91–1/13/92 | 1.93 | 1.91 | 52 | 0.037 | 0.037 |
| 1/13/92–3/13/92 | 1.5 | 1.41 | 33 | 0.045 | 0.043 |
| Average | | | | 0.05 | 0.037 |

**TABLE 3**
Average Technologist Dose per Task During Qualitative and Quantitative Studies

| Task | No. of uses | Average Dose/Task | |
|---|---|---|---|
| | | Shallow mSv | Deep mSv |
| Dose drawing | 455 | 0.0023 | 0.0012 |
| Injection | 373 | 0.0136 | 0.0075 |
| Blood pressure | 34 | 0.0085 | 0.0096 |
| Blood sampling* | 165 | 0.0163 | 0.0142 |

*Quantitative studies only.

formulae. The overall error associated with the TLD measurements was calculated to be ±6%.

## DISCUSSION

### Qualitative Versus Quantitative Doses

This study presents data which compare the radiation doses measured for a set of technologists from qualitative and quantitative studies using PET. The major difference between these two types of studies is that quantitative studies include blood sampling. The data shown in Table 3 indicate that the blood drawing task has the largest dose per task. Consequently, the dose per study measurements of the quantitative studies are higher than those for the qualitative studies.

In research settings, quantitative studies are quite common due to the need to quantify results to support a conclusion. In medical terms, this usually involves blood sampling. Once the patient is injected with a radioactive substance, they are the source of the radiation dose to the nuclear medicine technologist who performs the study (*1–2*). During arterial sampling, the technologist stands next to the patient's torso. This is the main difference between quantitative and qualitative studies. One other difference that cannot be discounted is the time required to remove the radial arterial line at the end of the study. Pressure must be applied to the site of arterial cannulation for up to 10 min after the line is removed to ensure that all bleeding has stopped before releasing the patient.

One would expect that the radiation dose received by the technologist would be significantly higher for quantitative than for qualitative studies. In the present study, there were at least twice as many qualitative studies each period as quantitative studies, with the exception of the first period. During most dosimeter issuance periods, the dose per study for quantitative studies is over twice that of the qualitative studies. Data obtained during the first issuance period (May 15, 1991–June 14, 1991) are different than those observed during the remaining four issuance periods. Because dosimeters were issued for only 1 mo, doses were low and statistics poor. The data for the other periods are much more reliable.

The data described above were collected for both the qualitative and quantitative studies. Since there may be significant differences in the way a particular study is performed at different facilities, comparing qualitative studies to the quantitative studies at the same facility shows the difference in the doses from these two types of studies accurately.

### Dose-Drawing Dosimeter

Whole body dose from drawing patient doses of the radiopharmaceutical is an area of concern for many technologists, particularly PET technologists (*7*). There is a tremendous amount of variability between facilities depending on how their drawing stations are designed. In the present study, doses received at a particular facility with a particularly unique design were studied. The technologist is separated from the shielded vial and unshielded syringe by 4 in. of leaded glass. The entire body is shielded except for the lower arms and hands. The data show that shallow doses are higher than deep doses and that both are much less than 0.01 mSv/draw (1 mrem/draw). If one compares the dose per task of dose-drawing to the other tasks, it is quite clear that this is the task with the lowest dose to the technologist. Hand doses were not considered in this study.

### Injection Dosimeters

The patient is injected by the PET technologist over a 30-sec period through an intravenous line. The syringe is shielded by at least four half value layers of lead prior to injection, but is completely unshielded during the injection due to the lack of adequate syringe shield availability. Syringe shields are not commercially available for PET radiopharmaceuticals. Most of the 511 keV photons that result from positron transformation would not be stopped by the syringe shields intended for $^{99m}$Tc radiopharmaceuticals.

Due to the large number of injections per day, it is important to determine the approximate dose technologists receive with each injection. The data in Table 3 indicate that the typical technologist receives over 0.01 mSv (1 mrem) shallow and just under 0.01 mSv (1 mrem) deep with each injection. The discrepancy between shallow and deep doses can be attributed to the beta particle, or positron, component. During injection, the only shielding between the radiopharmaceutical and the technologist is the thin plastic wall (220 mg/cm$^2$) of the syringe. Many of the positrons are able to escape the syringe and interact with the skin of the technologist. Because the positron does not penetrate very deeply, it contributes only to the shallow and possibly the eye dose (at 300 mg/cm$^2$). The maximum beta energy of $^{15}$O, the most energetic of the radionuclides used at the facility under study, is 1720 keV and its average beta energy is 573 keV (*8*). These energies correspond to ranges in tissue of 800 mg/cm$^2$ and 190 mg/cm$^2$, respectively. Since the depth of the shallow depth is defined as 7 mg/cm$^2$, and the eye depth is 300 mg/cm$^2$, the average positron never makes it past the eye depth and thus does not contribute to the deep dose which is defined at 1000 mg/cm$^2$ (*9*).

Much of the variability of the data can be explained by the differences in doses administered. The most commonly used PET pharmaceutical is $^{18}$F-fluoro-2-deoxyglucose. A dose of 370 MBq (10 mCi) is typically administered (*4*). Other radiopharmaceuticals such as $^{15}$O-water are administered in much higher doses (up to 3,700 MBq (100 mCi)) because their half-lives are much shorter (*4*). Because the number of each type of injection varies during the various dosimeter issuance periods, it is reasonable that the dose per injection would vary as well.

### Blood Pressure Dosimeters

During the planning stages of this study, it was felt that this task would account for a high radiation dose to the technologist. However, due to a small number of uses

(only 34), the doses on the dosimeters were barely above the controls. For this reason, the dose per use values of these special-task dosimeters are erratic.

### Blood-Sampling Dosimeters

Based on the data shown in Table 3, it is apparent that blood sampling is the task from which the technologist receives the highest dose. If the technologist receives 0.014 mSv (1.4 mrem) from blood sampling, then that task accounts for almost one-third of the total dose per study. This is not surprising since the technologist stands next to the patient for 5–10 min of the study; longer than for any other task. Also, at the end of the study, the technologist must remove the arterial line as previously described.

## CONCLUSIONS

Radiation doses to PET technologists during quantitative studies are at least twice as high as the doses received during qualitative studies. The blood sampling task, which differentiates qualitative studies from quantitative studies, accounts for a higher radiation dose to the technologist than the whole dose per study of the average qualitative study.

During the three specific tasks conducted during a qualitative study (dose-drawings, injections and blood pressures), the injection task accounted for the largest component of the dose per study. If one compares the average dose per study for a qualitative study with the average dose per injection, it is easy to see that the injection task accounts for most of the radiation dose incurred.

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