Workflow and Radiation Safety Implications of ^{18}F-FDG PET/CT Scans for Radiotherapy Planning

Sithoeun Sam[1,2], Ivan Ho Shon[1,3], Shalini K. Vinod[4,3], Peter Lin[1], and Michael Lin[1]

[1]*Department of Nuclear Medicine and PET, Liverpool Hospital, Liverpool, Australia;* [2]*University of Sydney, Sydney, Australia;* [3]*University of New South Wales, Kensington, Australia; and* [4]*Cancer Therapy Centre, Liverpool Hospital, Liverpool, Australia*

The use of ^{18}F-FDG PET/CT for radiotherapy planning may lead to better tumor volume definition. Reproduction of the patient's position when setting up an ^{18}F-FDG PET/CT scan for radiotherapy planning is more accurate if a radiation therapist is involved. The aim of this study was to compare setup time and staff radiation dose between radiation therapists and nuclear medicine technologists. **Methods:** Forty patients with newly diagnosed head and neck or non–small cell lung cancer were prospectively recruited into this study. Twenty patients (10 with head and neck cancer and 10 with non–small cell lung cancer) underwent ^{18}F-FDG PET/CT for radiotherapy planning, and 20 patients (10 with head and neck cancer and 10 with non–small cell lung cancer) underwent ^{18}F-FDG PET/CT for staging. Setup time was measured, and a radiation monitor recorded the highest dose (μSv/h) to staff during setup. **Results:** For radiation therapists, the mean setup time for a lung scan (in min:s) was 5:22 ± 2:11 (range, 2:22–9:23), with a highest dose of 4.94 ± 3.78 μSv (range, 2.02–15.23 μSv), and the mean setup time for a head and neck scan was 4:49 ± 1:45 (range, 2:03–8:21), with a highest dose of 3.93 ± 1.45 μSv (range, 1.19–6.83 μSv). For nuclear medicine technologists, the mean setup time for a lung scan was 1:58 ± 0:24 (range, 1:17–2:38), with a highest dose of 3.30 ± 1.28 μSv (range, 1.92–5.47 μSv), and the mean setup time for a head and neck scan was 2:12 ± 0:38 (range, 1:03–3:16), with a highest dose of 3.10 ± 1.78 μSv (range, 1.56–7.49 μSv). **Conclusion:** This study showed that setup time and operator radiation dose were greater for radiation therapists setting up planning ^{18}F-FDG PET/CT scans than for nuclear medicine technologists setting up routine ^{18}F-FDG PET/CT scans. These results have implications for scheduling of radiotherapy planning PET/CT; however, the additional radiation dose was not considered to be significant.

Key Words: radiotherapy treatment; ^{18}F-FDG PET/CT; radiation dose

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PET enables visualization of the various molecular pathways of tumors, including metabolism, proliferation, oxygen delivery, and receptor expression (*1*). The predominant tracer for PET is ^{18}F-FDG, because of its favorable imaging characteristics and availability. Methods of identifying tumor volume that incorporate functional information can be used to target the dose to metabolically active sites (*2*) and are thus attractive for radiotherapy planning. This is best performed with a specific radiotherapy-planning PET/CT scan with the patient in the treatment position, as it allows accurate registration of scans and provides contemporaneous staging information.

Volume delineation using ^{18}F-FDG PET/CT has the potential to spare radiation dose to normal tissue and increase dose to target sites (*3–5*), avoid a geographic miss (inadequate coverage of the tumor by the radiation beam, resulting in delivery of a dose less than that prescribed), and improve interobserver variability (*6*). There are limited data showing that, compared with diagnostic staging PET alone, PET performed with the patient in the treatment position may allow for better fusion with planning CT simulation and modification of radiotherapy target volumes (*7,8*).

Reproduction of the radiotherapy-planning position may be more accurate if a radiation therapist is involved during the PET/CT setup. There are many factors that must be considered, as imaging for radiotherapy planning is different from imaging for staging or diagnosis (*6,9*). Before the patient enters the camera room, time is required to clear the scanning bed and place a flat bed insert. Patient positioning is of the utmost importance, as this is the position the patient must maintain during the course of radiotherapy. The radiation therapist utilizes immobilization devices such as an s-frame, wing boards, vacuum bags, thermoplastic masks, and knee cushions to secure the patient. In addition to immobilization devices, lasers and external markers may be needed to ensure accurate reproduction of the position. The time required for the setup potentially increases the radiation dose to the radiation therapist, who remains close to the radioactive patient during the entire process.

Our study had 2 aims: to determine whether there was a difference between the time required for a radiation therapist to set up a radiation-planning PET/CT scan and the time required for a nuclear medicine technologist to set up a routine PET/CT scan, and to determine whether there was a difference in radiation dose to the setup staff.

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For correspondence or reprints contact: Sithoeun Sam, Department of Nuclear Medicine and PET, Liverpool Hospital, Liverpool, NSW 2170, Australia.
E-mail: sithoeun.sam@sswahs.nsw.gov.au
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MATERIALS AND METHODS

In this prospective study, patients were selected consecutively from July 2008 until January 2009. During the study period, the main use of radiotherapy-planning PET/CT in our department was for patients with histologically proven non–small cell lung cancer or carcinoma of the head and neck before radiotherapy or chemoradiotherapy with curative intent. Twenty patients with these cancers whose radiation oncologist had requested an ^{18}F-FDG PET/CT scan in the radiotherapy-planning position formed the radiation therapist group. Twenty other patients undergoing ^{18}F-FDG PET/CT scans for the same clinical indications but not for radiotherapy planning formed the nuclear medicine technologist group. Each group included 10 patients with head and neck cancer and 10 with lung cancer. All scanning was performed according to departmental protocol, the only exception being that the radiation therapist group of patients was set up in radiotherapy-planning position.

^{18}F-FDG PET/CT

Before undergoing scanning, patients fasted for 6 h but were allowed to drink plain water. They were to refrain from strenuous exercise for 12 h before the test and to wear warm, nonmetallic clothing. They were weighed, their capillary blood glucose was measured to ensure that it was less then 10 mmol/L, and a peripheral intravenous cannula was inserted. ^{18}F-FDG was then administered (5.18 MBq/kg; minimum, 184 MBq; maximum, 444 MBq). After a 60-min uptake period, the patients were asked to void and then were scanned on a Gemini GXL 6 PET/CT system (Philips). Patients with lung cancer were scanned from the proximal femora to the midbrain with arms up, using a minimum of 1.5 min and a maximum of 2 min per bed position, depending on patient weight. The CT settings were 120–140 kVp and 30–40 mAs. The same parameters were used for patients with head and neck cancer, except that scanning was performed from the vertex to the proximal femora with arms down.

Patients in the radiation therapist group underwent a radiotherapy-planning CT simulation in the Cancer Therapy Centre of Liverpool Hospital immediately before radiotherapy-planning ^{18}F-FDG PET/CT. A nuclear medicine technologist prepared each patient and administered the radiopharmaceutical; once the patient had been moved to the PET/CT room, a radiation therapist took over, positioning the patient on the flatbed pallet with immobilization devices. A stopwatch was used to measure the scan setup duration. The watch was started upon entry of the staff member into the scan room and was stopped when that person exited into the control room. A radiation monitor (Inspector^{+} Geiger–Müller survey meter; SE International Inc.) recorded the highest reading (μSv/h) to the staff member setting up the procedure. The radiation monitor was calibrated 2 mo before the study began, and precision was certified to ±10%. A measurement was obtained by placing the monitor next to the lead operator (the setup staff member closest to the patient). For the purposes of this study, an estimated maximum dose was calculated. This was the maximum dose reading multiplied by the total setup duration.

RESULTS

The setup time was greater in the radiation therapist group. In lung cancer patients, average setup time (in min:s) was 5:22 ± 2:11 (range, 2:22–9:23) for radiation therapists and 1:58 ± 0:24 (range, 1:17–2:38) for nuclear medicine technologists (P = 0.0004). In head and neck cancer patients, average setup time was 4:49 ± 1:45 (2:03–8:21) for radiation therapists and 2:12 ± 0:38 (range, 1:30–3:16) for nuclear medicine technologists (P = 0.001) (Table 1).

The increased time spent by the radiation therapists in setting up the patient caused an increase in the estimated average dose, but the difference was not statistically significant. In lung cancer patients, the average was 4.94 μSv for radiation therapists and 3.30 μSv for nuclear medicine technologists (P = 0.251). In head and neck cancer patients, the average was 3.93 μSv for radiation therapists and 3.10 μSv for nuclear medicine technologists (P = 0.238). Table 2 shows that the radiation therapist's level of experience did not affect mean dose. Radiation therapists who had set up 5 or more radiotherapy-planning PET/CT scans (n = 13) received an average dose of 4.91 μSv, and radiation therapists who had set up fewer than 5 (n = 7) received an average dose of 3.66 μSv (P = 0.474).

DISCUSSION

The results show that, in the clinical settings of both lung cancer and head and neck cancer, PET/CT performed with patients in the radiotherapy-planning position has an increased setup time that can affect workflow. This extra time may adversely affect scheduling and may delay subsequent studies. The average duration of routine ^{18}F-FDG studies is approximately 20 min; if patients are booked into 30-min intervals, 10 min would be left for room preparation and patient changeover. Scheduling radiotherapy-planning PET/CT for times that have a minimal impact on other patients who have already been injected allows radiation therapists more time to set up their patients. Scheduling for late morning or afternoon would allow the patient to have the simu-

TABLE 1
Mean Setup Time and Estimated Mean Setup Dose

Group	Cancer type	Mean setup time (min:s)	SD (min:s)	Estimated mean setup dose (μSv)	SD (μSv)
Radiation therapists	Lung	5:22	2:11	4.94	3.78
	Head and neck cancer	4:49	1:45	3.93	1.51
Nuclear medicine technologists	Lung	1:58	0:24	3.30	1.28
	Head and neck cancer	2:12	0:38	3.10	1.78

TABLE 2
Setup Experience and Mean Setup Dose

Number of scans performed	Mean setup dose (μSv)	*n*
≥5	4.91	13
<5	3.66	7

lation scan and radiotherapy-planning PET/CT scan on the same day instead of having to make a return trip to the facility.

The large SD among radiation therapists in both tumor groups may be due to varying levels of experience in setting up radiotherapy-planning PET/CT scans (range, 0–10 scans). The nuclear medicine technologists had vast experience in setting up PET/CT scans (minimum of 3 y) and therefore had a smaller SD. However, as seen in the results, the level of experience did not equate to lower setup doses. A further area to investigate is the possibility of having nuclear medicine technologists perform the radiotherapy-planning PET/CT and check the accuracy of the positioning. The estimated radiation dose in this study may over- or underestimate the true absorbed dose, as the maximum reading may change depending on the position of the staff member in relation to the patient. The maximum reading was used in this study, which was primarily a comparison of radiation dose between the 2 groups of staff and not an in-depth analysis of radiation dose. To overcome this potential problem, a personal pocket dosimeter could be used to obtain the real-time radiation dose to the setup staff. The variation in staff level of experience could affect setup duration and, potentially, radiation dose as well. An evaluation in which all staff members have the same level of experience would be an area for further investigation. Australian Radiation Protection and Nuclear Safety Agency guidelines for radiation therapists set an annual benchmark of 228 μSv per annum. Depending on site-specific workload, in our institution a radiation therapist could comfortably perform 1 radiotherapy-planning PET/CT setup per day for a year and still be well below the benchmark. This assumption is based on our institute records with an average annual dose per annum of 58 μSv and an estimation of an extra 100 μSv per year. Carson et al. (*10*) measured radiation dose in 28 non–small cell lung cancer patients being scanned in radiotherapy-planning position and found a mean total radiation dose of 5.1 μSv to a radiation therapist during the acquisition. This finding is similar to the 4.94 μSv seen in our study for the 10 non–small cell lung cancer patients. Carson's group performed the most time-consuming part of the radiotherapy-planning positioning earlier in the morning, termed a cold setup session, and this technique is similar to that used in our study except that our patients had the cold setup session in the Cancer Therapy Centre. The hot setup session (while the patient is radioactive) was done in the Nuclear Medicine Department, where the PET/CT scanner is situated.

CONCLUSION

When scheduled efficiently into a department's daily workflow, radiotherapy-planning ^{18}F-FDG PET/CT can be adequately performed with minimal impact on other routine ^{18}F-FDG PET/CT studies. Radiation dose is not considered a significant issue for radiation therapists setting up the radiotherapy-planning position after radioisotope injection, as regulatory radiation safety benchmarks are not exceeded even in a hypothetical scenario of 1 radiotherapy-planning PET/CT scan per day.

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