Radiation Exposure from Gallium-67-Citrate Patients

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Objective: Serial monitoring of patients was performed to determine the radiation exposure contributed by patients injected with ^{67}Ga-citrate to their surroundings. Radiology and nursing staff distance exposure estimates were made for various patient care tasks and imaging tests.

Methods: Fifteen adult patients were surveyed early (mean 4.3 min) and 11 of the 15 were surveyed at 3 d (mean 68.8 h) postinjection. The standard adult lymphoma imaging activity of 333–407 MBq (9–11 mCi) resulted in a range of 3.7–8.1 MBq/kg (0.1–0.22 mCi/kg). Dose rate measurements were made in the anterior, posterior, and left and right lateral projections at the level of the umbilicus, at distances of patient's surface and at 30.5 cm and 100 cm with a calibrated ion chamber. Time of contact-routine task analyses also were obtained for nursing and radiology personnel. Using a radiation survey-derived biexponential pharmacokinetic relationship, radiation exposures were determined for hospital personnel and family members at various times after injection.

Results: Based on the study population survey results, the mean instantaneous exposures (µSv/h) for an administered activity of 370 MBq (10 mCi) ^{67}Ga-citrate were determined. The task analyses revealed the maximum patient contact time for any procedure performed at a distance equal to, or less than, 30.5 cm was 30 min.

Conclusion: The quantitation of radiation exposure scenarios from ^{67}Ga-citrate patients has determined that no special precautions are necessary for medical personnel when performing routine tasks associated with these patients.

Key Words: gallium-67-citrate; radiation exposure of nurses; radiation exposure of radiologic technologists; radiation monitoring; pharmacokinetic prediction of radiation dose

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Patients administered radiopharmaceuticals become a source of radiation exposure to individuals around them. The radiation exposure received by those in the near vicinity will be a function of the radionuclide emissions, administered activity, effective half-life, and time spent at a particular distance. Exposure would be maximum immediately after tracer administration and is most apparent with photon-emitting radiotherapy agents (*1*). This patient population is usually sequestered in a private hospital room until a predetermined exposure rate is attained.

Patients receiving radiodiagnostic agents have no such restrictions, thus exposing health care workers as well as members of the public (*2*). Several investigators have reported radiation exposures from nuclear medicine patients to hospital staff and family members (*3–6*). Similar studies concluded, for example, that separate waiting areas for radiodiagnostic patients were unnecessary (*7–9*).

Recent reports have detailed the use of ^{67}Ga-citrate in staging lymphoma patients (*10,11*). In our institution we administer approximately 370 MBq (10 mCi) ^{67}Ga-citrate for SPECT imaging for this purpose, which is twice the quantity indicated for tumor and abscess localization in 1978 (*12*). These patients usually have additional CT scans with occasional MRI and ultrasound testing to aid in their staging. In some cases the additional testing is performed immediately after the ^{67}Ga-citrate injection. Does this represent a significant risk to the health care personnel involved? Are radiation restrictions warranted under these circumstances? Should we consider family members and the general public? To answer these questions, we undertook an investigation of the time-related radiation exposure surrounding these ''higher-dose'' ^{67}Ga patients.

MATERIALS AND METHODS

Fifteen oncology patients (8 women, 7 men) scheduled for ^{67}Ga-citrate SPECT imaging consented to this study. Radiation exposure rates from these patients were measured immediately after injection and 11 of the 15 patients were measured at approximately 3 d, at the time of their SPECT scan. All measurements were at the level of the patient's umbilicus at the body surface, at 30.5 cm, and 100 cm, for the right lateral, left lateral, anterior, and posterior projections. The survey instrument was a calibrated ion chamber (Model 450P; Victoreen, Cleveland, OH) which was source checked and corrected for ambient radiation levels before each measurement. Units of exposure were assumed to be equal to the dose equivalent for this study (1 mr = 1 mrem = 10 µSv).

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A time of contact-task analysis was obtained for routine procedures performed by nurses and non-nuclear medicine staff technologists associated with testing lymphoma patients. The time interval between ultrasonography, MRI, and CT studies and the ^{67}Ga scan was queried in the departmental computer scheduling system for the study population (N = 15) and for an equal randomly selected group of 30 additional patients. An estimate of their exposures, based on typical time-distance intervals, was determined in combination with their documented radiation badge history. These exposures were compared to nuclear medicine technologists who served as controls.

The exposure data were further analyzed, in combination with published pharmacokinetic data (*13–15*), to derive a biexponential formula for predicting instantaneous ^{67}Ga exposure as a function of time after injection. A series of patient scenarios is presented using the latter formula.

RESULTS

The adult patient population (N = 11–15) received a mean of 384.8 ± 14.8 MBq (10.4 ± 0.4 mCi) ^{67}Ga. The first survey was at 4.3 ± 2.9 min and the second at 68.8 ± 2.9 h after dosing. Different body masses of the patients resulted in an administered activity/weight of 5.5 ± 1.2 MBq/kg (0.15 ± 0.03 mCi/kg) ^{67}Ga-citrate.

The survey results at the two measurement times for the four standard projections are shown in Table 1. The exposures are not significantly different ($P > 0.05$) per time period/distance across all projections. The exposure reduction relative to distance does not approximate a $1/d^2$ relationship. This is because the patient is not a point source, but an elongated radioactive source, as previously discussed for ^{131}I (*1*).

The pharmacokinetic equation that calculates the ^{67}Ga instantaneous exposure rate relative to time, t, after injection (*13–15*) is:

$$E_t = [E_o F(t)] = (E_o)(0.17\, e^{-0.032t} + 0.83\, e^{-0.00921t}), \quad \text{Eq. 1}$$

where:

E_t = instantaneous exposure rate (μSv/h) at time = th

E_o = instantaneous exposure rate (μSv/h) at injection, t_oh

F(t) = fraction of exposure relative to time, th, after administration.

TABLE 2
Nursing and Radiologic Technologist Task Exposures from 370 MBq (10 mCi) Gallium-67-Citrate*

	Task (projection)	Exposure time (min)	μSv†
	Nursing tasks		
Moderate care	Greet, shift rounds (Ant)	2	1.3
	Complete visit (Ant)	5	3.3
	Give medicines (Ant)	2–5	1.3–3.3
	Straighten linen (Ant)	2–5	1.3–3.3
	Backrub (Post)	2	1.6
Moderate to intense care	Patient assessment (Ant)	5	3.3
	Ambulate to and from bathroom (Lat)	5	2.9
	Intravenous mainline (total care) (Lat)	15	8.7
	"Piggyback" intravenous dose and resetting mainline (Lat)	5	2.9
	Central venous pressure or subclavian dressing change (includes total parenteral nutrition) (Ant)	20–45	11.6–26.1
	Assess for and administer cardiac medicines (Ant)	2–5	1.3–3.3
	Chest physiotherapy (Ant)	20	13.2
	Endotracheal or tracheotomy suctioning (Ant)	10	6.6
	Troubleshoot problems (intravenous site) (Lat)	5–10	2.9–5.8
	12-lead ECG (Ant)	10	6.6
	Radiologic technologist tasks‡		
Plain films	Femur, ribs, L-spine	10	1.5
CT	Chest, abdomen	6	0.90
MRI	Abdomen, with IV contrast	10	1.5
CT/MRI	Average of all procedures	18	2.7
Sonogram	Average of all procedures	21	3.2

*Assume 30 min post ^{67}Ga injection at 30.5 cm.

†1 μSv = 0.1 mrem.

‡Reflects patient assessment, preparation and assistance.

TABLE 1
Gallium-67-Citrate Exposures in Study Population*

Post-dosing time	Distance	Projection (mean μSv/h ± s.d.) Anterior	Posterior	Right lateral	Left lateral
4.3 ± 2.9 min.	Surface	48.27 ± 14.03	56.94 ± 13.72	44.45 ± 9.17	40.48 ± 10.44
	30.5 cm	15.43 ± 2.05	17.03 ± 2.60	11.77 ± 1.43	10.60 ± 1.59
	100 cm	4.24 ± 0.52	4.35 ± 0.45	3.03 ± 0.41	2.95 ± 0.51
68.8 ± 2.3 h	Surface	25.54 ± 6.94	25.65 ± 4.72	21.36 ± 8.04	17.79 ± 4.91
	30.5 cm	8.36 ± 2.35	7.40 ± 1.06	5.08 ± 1.31	4.67 ± 0.94
	100 cm	1.88 ± 0.70	1.87 ± 0.52	1.45 ± 0.52	1.26 ± 0.42

*N = 11–15 patients; dose = 384.8 ± 14.8 MBq (10.4 ± 0.4 mCi); 1 μSv/h = 0.1 mrem/h.

TABLE 3
Annual Badge Readings for Technologist Groups

Year	Number of diagnostic nuclear medicine studies	Number of ^{67}Ga-citrate studies	Annual average badge exposure (μSv)*			
			Nuclear medicine whole-body badge (N)	Computed tomography collar badge (N)	Inpatient x-ray collar badge (N)	Outpatient x-ray collar badge (N)
1993	10,079	897	2800 (11)	480 (38)	370 (59)	160 (33)
1997	10,585	434	2580 (8)	670 (34)	960 (51)	120 (33)

*The Landauer Co. (Glenwood, IL) cumulative monthly badge reading over year stated; reading includes x-ray exposure (1 μSv = 0.1 mrem).
N = number of personnel in badged group.

Hypothetical exposure levels at 30.5 cm for radiology and nursing personnel at 30 min. postinjection of ^{67}Ga-citrate per task are shown in Table 2. As shown, these conservative assumptions produce exposures typical of other radiodiagnostic studies (*15*). Similar results have been reported for nurses handling radiodiagnostic patients (*8,16*). For radiology personnel, a review of the departmental scheduling system (N = 23 of 45 patients) to determine the time between ^{67}Ga-citrate administration and other imaging procedures indicated intervals greater than 30 min. postinjection (mean 67.9 h; range 0.25–168.5 h).

Most patients injected with radiodiagnostic agents, including ^{67}Ga-citrate, usually move freely within the health care facility. Occasionally these patients undergo additional radiology testing. Table 3 illustrates the annual neck radiation exposures for radiology personnel involved in correlative nuclear medicine imaging, including ^{67}Ga-citrate patients, for two time periods. Nuclear medicine whole-body badge readings serve as controls. The collar badges worn by personnel are not shielded (as opposed to the body badges which are worn under the apron and, thus, are shielded) nor do they easily discriminate between radiodiagnostic and machine x-ray exposures. Nevertheless, the total radiation doses listed approximate 10% of that obtained from natural background radiation.

Pharmacokinetic methodology has been used for predicting radiation exposures from ^{131}I and ^{99m}Tc patients (*18,19*). Equation 1 allows a hypothetical ^{67}Ga patient to be followed at the hospital, when traveling, and at home. The instantaneous exposure at any time, t, after injection, Et_1, is determined relative to the initial rate, Et_o, by using Equation 1. The

TABLE 4
Summary of Gallium-67-Citrate Patient Radiation Exposure Following Administration of 370 MBq (10 mCi)*

Hours postadministration	Subject	Place	Distance (cm)	Exposure time (h)	Projection	Exposure (μSv (mrem))
0.083–1.083	Another patient	Waiting room	100	1.0	Rt lat	2.97 (0.3)
1.25–4.25	Daughter	Brunch	100	3.0	Ant	12.3 (1.2)
4.50–5.00	Occupants	Elevator	30.5	0.5	All (av)	6.44 (0.64)
5.50–5.68	CT tech	CT unit	30.5	0.18	Ant & Rt lat	2.17 (0.22)
6.75–6.25	Physician	Office†	30.5	0.50	Ant	7.13 (0.71)
7.00–11.00	Daughter	Automobile	100	4.0	Rt lat	10.5 (1.1)
11.50–12.00	Grandchild	Home	30.5	0.5	Ant	6.65 (0.67)
14.00–22.00	Wife	Bed	30.5 (av)	8.0	All (av)	82.4 (8.2)
24.00–28.00	Coworker	Air flight (depart)	100	4.0	Rt lat	8.57 (0.86)
32.00–36.00	Coworker	Air flight (return)	100	4.0	Rt lat	7.80 (0.78)
37.00–45.00	Wife	Bed	30.5 (av)	8.0	All (av)	63.2 (6.3)
48.00–48.50	Wife	Breakfast	100	0.5	Ant	1.20 (0.12)
52.00–52.50	Wife	Lunch	100	0.5	Ant	1.15 (0.12)
60.00–60.50	Wife	Dinner	100	0.5	Ant	1.06 (0.11)
62.00–70.00	Wife	Bed	30.5 (av)	8.0	All (av)	48.4 (0.48)
74.00–86.00	Nuc med tech	^{67}Ga-scan	100 (av)	2.0	Rt lat	5.01 (0.50)
96.00–100.00	Surgeon‡	Operation	30.5 (av)	4.0	Ant	21.1 (2.1)
120.00–124.00	Pathologist§	Autopsy	30.5 (av)	3.0	Ant	12.6 (1.3)

*Dose equivalent based on patient exposure summary contained in Table 1.
†10-ml blood sample taken: 0.6 MBq (0.016 μCi) in sample; 1.17 μSv/min. (0.12 mrem/min.) at 1 cm (*16*).
‡Patient has a heart attack and undergoes an operation.
§Patient dies and pathologist performs an autopsy.

determination of the cumulative exposure for a defined period, (t_1 - t_2), is possible by integrating Equation 1 between the two time periods, producing the following biexponential relationship:

$$E_T = (E_{t1})[5.31(1 - e^{-(0.032)T}) + 90.2(1 - e^{-(0.00921)T})], \quad \text{Eq. 2}$$

where:

ET = cumulative dose equivalent during exposure period, Th

E_{t1} = instantaneous dose equivalent at beginning of exposure period, t_1 (as obtained from Equation 1)

T_T = total exposure period, h.

The exposures received by individuals who encounter a hypothetical ^{67}Ga-citrate patient, using Equations 1 and 2, are shown in Table 4. Appendix A provides a calculation example.

CONCLUSION

The acceptance of an ALARA philosophy is basic to radiation safety training. Its implementation with the general public is almost exclusively for radiotherapeutic patients. This is emphasized in quality management programs, as initially required by the NRC (*20*,*21*). With the advent of higher radiodiagnostic doses of ^{67}Ga-citrate, questions arose at our institution concerning exposures to others encountering these patients.

The effects on occupational exposure from changing practice patterns and diffusion of newer technologies, such as PET, have been examined periodically and reported (*9*). Myocardial perfusion imaging, for example, uses higher doses of ^{99m}Tc-labeled agents along with increased patient contact. This has led to exposure investigations where the average technologist radiation dose, after handling ^{99m}Tc-MIBI or tetrofosmin, was 5.5 μSv (0.55 mrem) per stress-rest study (*22*). In a separate study, the principal factor affecting whole-body exposure of nuclear medicine personnel was direct patient contact time (*23*). In ultrasonography the technologist is in close proximity to the patient. For example, ultrasonographers received whole-body exposures of 16–18 μSv (1.6–1.8 mrem) per examination when handling renal transplant patients 1 h after ^{99m}Tc-DTPA administration (*24*). These individuals, such as nurses and other non-nuclear medicine technologists, however, have only occasional contact with nuclear medicine patients. Their radiation dose is only a fraction of that received by nuclear medicine technologists (Table 3). The short amount of time generally needed to attend to these patients results in low radiation doses. For this reason, most hospital employees are not considered to be occupationally exposed workers because there is a low probability that they will receive at least 10% of the occupational limit of 5000 μSv (500 mrem).

This study reinforces that, in general, no radiation restrictions should be applied to ^{67}Ga-citrate patients. This does not include breast feeding, where a 1-mo interruption of nursing is recommended after 150 MBq (4 mCi) or more of ^{67}Ga-citrate (*25*). If a patient receives 370 MBq (10 mCi) ^{67}Ga-citrate, nursing would be discontinued. Under radiotherapeutic quality management programs the licensee is required to provide the released individual with instructions if the total effective dose equivalent to any other individual is likely to exceed 1000 μSv (100 mrem) (*20*). Under no circumstances did any individual receive close to this limit in the example cited (Table 4).

The NRC has recommended that patient/family instruction be required at a ^{67}Ga dose rate above 40 μSv/h (4 mrem/h) at 100 cm (*25*). Our data (Table 1) equates this limit to 3,630 MBq (98.1 mCi), an unrealistic ^{67}Ga radiodiagnostic dose. Nevertheless, in keeping with our institutional ALARA program, the opportunity to avoid close contact times between personnel immediately after radiopharmaceutical administration is exploited, provided that patient care is not compromised. Our study shows that an occasional patient interaction immediately after injection would not result in radiation doses of concern.

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APPENDIX A

Calculation Example: Exposures from a Gallium-67-Citrate Patient

Equations 1 and 2, used in these calculations, are discussed in the Results section above. An adult lymphoma patient, who was driven to the hospital by his daughter, arrives in nuclear medicine at 7:45 AM. He is administered 384 MBq (10.4 mCi) of ^{67}Ga-citrate at 8:00 AM and is told to return for his scan in 3 d. He then sits in the nuclear medicine waiting area for his daughter to pick him up. She arrives 1 h later.

1. Calculate the dose equivalent to another patient who is sitting on the patient's right at a distance of 100 cm.
   a. Exposure results are shown in Table 1 for 384.8 MBq (10.4 mCi) ^{67}Ga. The radiation dose rate at 100 cm from the subject's right lateral projection is 3.0 μSv/h immediately after injection. Equation 1 is not used to calculate E_{t1} because the beginning of the exposure period is immediately after injection.
   b. Equation 2 is used to calculate the cumulative exposure for 0.083 h (injection time) to 1.083 h, for a total exposure period of 1 h. At 0.083 h the radiation dose rate at 100 cm (right lateral) is 3.0 μSv/h (from 1a. above). The 1-h exposure, E_T, is determined as follows:

$$E_T = 3.0[5.31(1 - e^{-(0.032)(1)}) + 90.1(1 - e^{-(0.00921)(1)})]$$

$$E_T = 3.0[5.31(1 - 0.9685) + 90.1(1 - 0.9908)]$$

$$E_T = 3.0(0.1673 + 0.8289) = 3.0(0.9908)$$

$$E_T = 2.97\ \mu Sv.$$

2. The patient and his daughter have brunch together from 1.25–4.25 h postinjection. She sits 100 cm away from her father's anterior. Calculate the daughter's dose equivalent.
   a. Dose rate 1.25 h postinjection (Equation 1):

$$E_0 = 4.2\ \mu Sv/hr \text{ (anterior projection at 100 cm (Table 1))}$$

$$E_{1.25hr} = 4.2(0.17e^{-(0.032)(1.25)} + 0.83e^{-0.00921)(1.25)})\ \mu Sv/hr$$

$$E_{1.25\ hr} = 4.2(0.16 + 0.821) = 4.2(0.991) = 4.1\ \mu Sv/hr$$

   b. Cumulative dose equivalent, E_T, 1.25–4.25 h postinjection (Equation 2):

$$E_T = 4.1[5.31(1 - e^{-(0.032)(3)}) + 90.1(1 - e^{-(0.00921)(3)})]$$

$$E_T = 4.1(0.486 + 2.46) = 4.1(2.94) = 12.3\ \mu Sv$$

Table 4 lists additional situations.

REFERENCES

1. Castronovo FP, Beh RA, Veilleux NM. Dosimetric considerations while attending hospitalized I-131 therapy patients. *J Nuc Med Tech.* 1982;10:157–160.
2. St. Germain J. The radioactive patient. *Sem Nucl Med.* 1986;16:179–183.
3. Harding LK, Mostafa AB, Roden L,et al. Dose rates from patients having nuclear medicine investigations. *Nucl Med Commun.* 1985;6:191–194.
4. Mountford PJ, O'Doherty MJ, Forge NI, et al. Radiation dose rates from adult patients undergoing nuclear medicine investigations. *Nuc Med Commun.* 1991;12:767–777.
5. Castronovo FP. Time-dependent radiation exposures surrounding technetium-99m MDP patients. *J Nuc Med Tech.* 1991;19:182–184.
6. Castronovo FP Jr, Veilleux NM. Radiopharmaceutical exposures of nurses in health care units at a large research hospital. *J Nuc Med Tech.* 1996;24:45–48.
7. Harding LK, Harding NJ, Warren H, et al. The radiation dose to accompanying nurses, relatives, and other patients in a nuclear medicine department waiting room. *Nucl Med Commun.* 1990;11:17–22.
8. Harding LK, Bossuyt A, Pellet S, et al. Radiation doses to those accompanying nuclear medicine department patients: a waiting room survey. *Eur J Nucl Med.* 1994;21:1223–1226.
9. Gandsman E, North D, Tyson I. Update on radiation safety in a nuclear medicine department. *Health Physics.* 1984;46:1293–1295.
10. Hussain R, Christie DR, Gebski V, et al. The role of the gallium scan in primary extranodal lymphoma. *J Nuc Med Tech.* 1998;39:95–98.
11. Parkhurst JB, Foster P, Johnson SF et al. Upstaging of non- Hodgkin's lymphoma in a child based on ^{67}Gallium scintigraphy. *J Pediatr Hematol Oncol.* 1998;20:174–176.
12. Lederer C, Hollander J, Perlman I. Section 4: Appendix; Table C, Radiation dose from commonly performed imaging procedures. *Physicians Desk Reference for Radiology and Nuclear Medicine.* Blaufox MD, Freeman LM, eds. Orandell, NJ: Medical Economics Co.;1978/79:100.
13. MIRD Dose Estimate Report No. 2. Summary of current radiation dose estimates to humans from ^{66}Ga-, ^{67}Ga-, ^{68}Ga-, and ^{72}Ga- citrate. *J Nuc Med.* 1973;14:755–756.
14. Nelson B, Hayes RL, Edwards CL, et al. Distribution of gallium in human tissues after intravenous administration. *J Nuc Med.* 1972;13:92–100.
15. Cormack J, Shearer J. Calculation of radiation exposures from patients to whom radioactive materials have been administered. *Phys Med Biol.* 1998;43:501–516.
16. *Sources and Magnitude of Occupational and Public Exposures from Nuclear Medicine Procedures.* NCRP publication 124. Bethesda, MD: NRCP;1996.
17. Bloe F, Williams A. Personnel monitoring observations. *J Nuc Med Tech.* 1995;23:82–86.
18. Weber PJ, Castronovo FP. A software application to estimate exposure around ^{131}I cancer and hyperthyroid patients. *Nuc Med Commun.* 1996;17:8–14.
19. Castronovo FP. A mathematical method for determining radiation exposures surrounding technetium-99m-MDP patients. *J Nuc Med Tech.* 1993;21:224–230.
20. NRC Office of Regulatory Research. *Quality Managment Program.* NRC Regulatory Guide 8.33. Washington, DC; NRC: October 1991.
21. NRC Office of Regulatory Research. *Monitoring Criteria and Methods to Calculate Occupational Radiation Doses.* NRC Regulatory Guide 8.34. Washington, DC; NRC: July 1992.
22. Clarke EA, Notghi A, Harding LK. Are MIBI/tetrofosmin heart studies a potential radiation hazard to technologists? *J Nuc Med Tech.* 1997;18: 574–577.
23. Owens TP, Hung JC. The effect of job duties in contributing to radiation exposure of the nuclear medicine technologist. *J Nuc Med Tech.* 1995;23: 87–90.
24. Flores C, Ponto JA, Rezai K et al. Radiation exposure sustained by sonographers after renal scintigraphy. *J Nuc Med Tech.* 1992;20:36–39.
25. NRC Office of Regulatory Research. *Regulatory Analysis on Criteria for the Release of Patients Administered Radioactive Material.* NUREG-1492. Washington, DC: NRC; Feb. 1997.