Evaluation of Staff Radiation Exposure during Transthoracic Echocardiography Close to Myocardial Perfusion Imaging

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Background: Transthoracic echocardiography (TTE) and myocardial perfusion imaging (MPI) are used in cardiac patients. In this study the radiation exposure of sonographers performing TTE following MPI was evaluated.

Methods: Of 40 study patients, 30 underwent same-day ^{99m}Tc sestamibi MPI and TTE, while another 10 underwent only TTE. Patients who underwent both studies were divided into three groups: right-handed TTE performed by an echocardiographer and right- and left-handed TTE performed by a cardiac sonographer. Seven thermoluminescent radiation dosimeter badges monitored the forehead, wrists, anterolateral right and left chest, sternal notch, and umbilical region of each examiner. Group characteristics were compared. Radiation exposures were deemed positive if >0.1 mSv.

Results: There were no statistical differences in patient weight and body mass index. The left-handed approach group had higher residual radioactivity (979 ± 73 vs 884 ± 73 MBq [P < .01] and 906 ± 81 MBq [P < .04]), but no statistical difference in duration of TTE, compared with the other two MPI groups. Radiation exposure was positive in the right anterolateral chest and hand (0.45 and 1 mSv, respectively) for the echocardiographer, the right anterolateral chest and wrist and umbilical region (0.59, 1.06, and 0.15 mSv, respectively) for the right-handed sonographer, and the left chest and hand (0.12 and 0.34 mSv, respectively) for the left-handed sonographer. Dosimeters indicated no radiation exposure in the TTE-only group.

Conclusions: Staff members performing TTE after MPI are exposed to radiation that might warrant monitoring. Altering study sequence, adopting a left-handed approach, and using other radiation-reducing techniques can minimize the degree of exposure. (J Am Soc Echocardiogr 2018;31:763-70.)

Keywords: Myocardial perfusion imaging, Echocardiography, Ionizing radiation exposure

Cardiac imaging has become a major contributor to population radiation exposure, accounting for approximately 40% of the cumulative dose from medical imaging procedures.[1] Myocardial perfusion imaging (MPI) using radioactive tracers is a well-established noninvasive test for the diagnosis, risk stratification, prognostic assessment, and management of coronary artery disease.[2-4] Approximately 15 million to 20 million procedures are performed annually in the United States, where the radiation exposure attributed to medical imaging has increased sixfold in the past 30 years,[5] of which MPI accounts for 10%.[6] The occupational risks among physicians and other personnel exposed to ionizing radiation while performing imaging have been the subject of study since the 1940s.[6]

Awareness of exposure to ionizing radiation among patients and medical personnel has led to advances in technology and imaging protocols and the development of appropriate use criteria to limit radiation exposure and also to meet the practice mandate of "as low as reasonably achievable."[7,8] These criteria are applied mainly to patients exposed to radiation during tests and to certain medical workers in departments such as radiology, interventional cardiology, and radiation therapy who may be required to be monitored for radiation exposure. The International Commission on Radiological Protection recommends individual monitoring and appropriate training for personnel with potential occupational radiation exposure to an effective annual dose of 1 to 20 mSv.[9,10]

On the basis of a recent meta-analysis of 12 epidemiologic studies, the cancer risk from occupational exposure with low– and moderate–dose rate exposure was not lower than among atomic bomb survivors with high–dose rate exposure.[11] Some studies have indicated that radiation workers had increased cancer mortality associated with low-dose radiation.[12,13] Despite the growing concern of the public and federal regulators, it remains unclear

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Abbreviations

MPI = Myocardial perfusion imaging

PPD = Personal protective device

RSO = Radiation safety officer

TLD = Thermoluminescent dosimeter badge

TTE = Transthoracic echocardiography

whether low-dose radiation causes an increased risk for cancer.[14,15] Other studies discuss the potential presence of a "hormesis" model that suggests that exposure to low-dose radiation might actually be beneficial by stimulating deoxyribonucleic acid damage prevention and repair in addition to stimulating the immune system.[16,17] Regardless of the uncertainty, a linear-no-threshold model is currently used in the health physics community as a comparatively conservative model to extrapolate risk from low-dose radiation, an approach that is endorsed by the BEIR report of the US National Academy of Sciences and the International Commission on Radiological Protection.

Cardiac ultrasound has a paramount role in daily practice, essential for the diagnosis and management of cardiac conditions with no additional radiation burden to the patient. Echocardiography has high sensitivity, is easily portable, and has lower cost compared with other imaging modalities. Echocardiography does not use ionizing radiation and therefore does not carry the associated assigned risk. Cardiac sonographers and echocardiographers increasingly perform studies on patients shortly after MPI as part of a comprehensive cardiac investigation. During such studies, the examiners sit very close to and frequently wrap their arms and bodies over patients who may have been recently administered radioactive agents, which make them transiently radioactive.[18] Standard estimates show that patients released after performing MPI do not significantly increase radiation exposure to the general public, but such estimates assume that there is no prolonged close contact shortly after release.[13] Proximity to the radioactive source, the relatively long duration of the exposure, and the short period of time after MPI are important determinants of potential radiation dose absorption by cardiac sonographers. Whereas the occupational exposure to ionizing radiation of medical staff members with known planned exposures, such as workers in radiology, nuclear medicine, and interventional departments, has been addressed,[19,20] the possible occupational exposure of cardiac sonographers has not been comprehensively studied.[18] The radiation dose and possible associated risks for sonographers performing transthoracic echocardiography (TTE) on post-MPI patients are not known.

The objective of the present study was to evaluate the effective dose of ionizing radiation to cardiac sonographers and/or echocardiographers performing echocardiography on patients who recently underwent MPI. An additional goal was to provide recommendations based on the degree of staff radiation exposure in the echocardiography laboratory.

METHODS

We studied 30 patients who were scheduled for both MPI and TTE as part of their routine clinical cardiac workup and 10 patients scheduled for TTE only. Patients scheduled for both studies underwent MPI first, followed by TTE. Patients were divided into four groups of 10 patients each. Group 1 consisted of 10 transthoracic echocardiographic studies performed right-handed by an echocardiographer. The remaining studies were performed by a cardiac sonographer. Group 2 underwent right-handed TTE, and group 3 underwent left-handed TTE. Group 4 was a control group consisting of right-handed TTE but no MPI. Comparison of groups included population characteristics, acquisition parameters, and the resultant thermoluminescent dosimeter badge (TLD) readings to the echocardiographer or cardiac sonographer. With respect to group comparisons, parameters relevant to potential exposure from radiation fields due to MPI included patient weight, body mass index, radiopharmaceutical activity, radiopharmaceutical decay times, and duration of TTE ($P < .05$, t test). The first two groups were compared to investigate operator-related differences, as TTE is an operator-dependent study in terms of length and proximity of the operator to the patient. Examiners in groups 1 and 2 performed right-hand studies, approaching the patient from his or her right side (Figure 1A). Echocardiography is operator dependent such that study duration may be shorter when the performing imager is experienced, resolving the clinical question without the need to repeat or take extra views. We sought to examine the distinction between physicians and sonographers by group 1, in which the physician was the more experienced imager. Group 3 provided a comparison for an alternative transthoracic echocardiographic method (left-handed) and was performed left-handed while the examiner sat facing the patient with the latter lying on his or her left side (Figure 1B).

Both examiners had seven TLDs placed on the forehead, wrists, and anterolateral right and left chest, at the sternal notch, and at the umbilical region (Figure 2). Because the orientation between the examiner and patient is typically oblique and changes during ultrasound imaging, this placement of the TLDs was chosen to accommodate differential exposure along an examiner's axial and lateral axes, as well as possible differences in hand exposure. TLDs are devices used for the monitoring beta, x-ray, and gamma radiation exposure. They were supplied by the Soreq Research Center, a national laboratory, and have an accuracy of ±20% for exposures above a threshold of 0.1 mSv. Cumulative energy absorbed from the incident radiation remains trapped in lithium fluoride crystals until heating releases a proportional amount of light energy that can then be scaled to units of radiation exposure (millisieverts). After each use, the TLDs were kept well isolated from external radiation fields. For each group, TLDs were read by employees of the research center blinded to the study. TLDs were read at the completion of each group so that each radiation exposure reading represented 10 ultrasound imaging studies. TLD estimates of radiation exposure were deemed positive if above threshold, indicating that the exposure of the examiner was at a level measurable by standard personal monitoring methods.

MPI was performed using a same-day rest/stress study using a nominal dose of 296 MBq (8 mCi) ^{99m}Tc sestamibi for rest and 925 MBq (25 mCi) for stress. MPI injection was completed before TTE in a time range of 2.30 to 5.75 hours for rest (mean, 3.61 ± 0.69 hours) and 0.40 to 2.33 hours for stress (mean, 1.45 ± 0.48 hours). After the end of the stress scan, TTE was performed in an echocardiography laboratory physically isolated from radiation fields potentially arising from other nuclear or x-ray imaging studies. The starting time of the transthoracic study was immediately after MPI but dependent on the availability of a study room and the cardiac sonographer or echocardiographer, similar to the timing of the standard clinical work flow for post-MPI TTE.

A simple model of exposure was developed primarily to model the effects of delaying TTE and also to double-check if the TLD

HIGHLIGHTS

- The amount of radiation exposure of cardiac ultrasound personnel was evaluated.
- Post-MPI patients act as a measurable "radiation source" for echocardiographers.
- Radiation exposure depends on study duration and TTE method used.
- Results were similar regardless of the degree of experience of the operator.
- Cardiac sonographers who might be exposed to >1 mSv/y should be personally monitored.

measurements were reasonable. The exposure h to the sonographer's TLD for n patients with a nominal TTE duration of t_{TTE} was estimated as

$$h = f \bullet n \left(A_R \left(\frac{1}{2}\right)^{\frac{t_R + t_D}{\tau}} + A_S \left(\frac{1}{2}\right)^{\frac{t_S + t_D}{\tau}} \right) \frac{\Gamma \exp(-\mu R)}{(R+d)^2} \bullet \frac{\tau}{\ln(2)} \left(1 - \left(\frac{1}{2}\right)^{t_{TTE}/\tau}\right),$$

where f is the occupancy factor (set to 1 for TTE duration), A_R is the nominal activity injected for rest (296 MBq), A_S is the nominal injected activity for stress (925 MBq), t_R is the nominal time from rest injection to TTE (3.5 hours), t_S is the nominal time from stress injection to TTE (1.5 hours), τ is the effective half-life of ^{99m}Tc sestamibi, and Γ is the radiation field constant for ^{99m}Tc (2.24×10^{-5} mSv/h/MBq at 1 m).[21] For simplicity, a point source with an attenuator of length R and an attenuation coefficient of μ (0.12 cm^{-1} effective for water/tissue)[22] in all directions was assumed. The distance d is the distance from the surface of the attenuator to the point of measurement (the estimated location of the TLD tag). The effective half-life was, conservatively, set to the physical half-life of ^{99m}Tc (6.01 hours), because the biological elimination of sestamibi is relatively slow by comparison (27% eliminated by renal and 33% by fecal paths at 48 hours after injection).[23] During ultrasound imaging, the sonographer is frequently in motion during the study, causing his or her distance and orientation with respect to the patient to change. Consequently, an average distance d for the closest TLDs and average distance R were adjusted to maximize the number of measured results that fit the model, because the purpose of the model was primarily to estimate the effects of introducing an additional delay time (t_D) before TTE. The study was approved by the ethics committee of Rambam Health Care Campus.

RESULTS

Tables 1 through 4 describe the characteristics of the four respective study groups. There were no significant differences among the four groups in patient weight (80.6 ± 14.7, 78.1 ± 16.2, 79.2 ± 20.7, and 85.4 ± 17.6 kg; P = .52) and body mass index (28.5 ± 6.2, 28.8 ± 4.2, 31.2 ± 7.6, and 29.8 ± 5.7 kg/m^2; P = .41). Group 3 had moderately higher estimated residual radioactivity at the start of TTE (979 ± 73 MBq) than either of the first two groups (884 ± 73 MBq [P = .01] and 906 ± 81 MBq [P = .04], respectively). Group 4 (control) had a moderately longer duration of TTE (51.1 ± 6.4 min) compared with the first two groups (39.0 ± 8.2 min [P = .03] and 45.4 ± 5.3 min [P = .01]).

All studies were performed during a 1-month period. None of the assigned patients had complicated congenital heart disease, valvular heart disease, stenosis or regurgitations, or periprocedural valvular assessment. Consequently, the longest duration of TTE was no more than 61 min.

Table 5 and Figure 3 show the radiation exposure measured by each of the seven TLDs for all four groups. In right-handed transthoracic echocardiographic studies (groups 1 and 2) the right wrist (TLD 6) and the right chest (TLD 3) had positive readings (>0.1 mSv) for both the echocardiographer and cardiac sonographer. The cardiac sonographer had a positive reading on the TLD placed at the umbilical area (TLD 5). For right-handed TTE, with adjustment (d_{TLD3} = 10 cm, d_{TLD6} = 2 cm, R = 15 cm), the model agreed with four of five of the positive readings and six of nine of the readings below threshold.

For left-handed TTE (group 3), the left wrist (TLD 7) and left chest (TLD 4) had positive readings but with values considerably less than the right-handed studies. This was consistent with the results of an adjusted model in which the distance parameters were fitted to the left-hand side (d_{TLD4} = 30 cm, d_{TLD7} = 12 cm), with the assumed attenuation remaining the same as for right-handed TTE (R = 15 cm). The control group consisting of right-handed TTE, but no MPI, gave no positive TLD readings, consistent with the model estimate of zero exposure (Table 5).

DISCUSSION

Results for the region closer to the patient (TLD 3) indicate a breast-tag reading of about 0.05 mSv per patient for exposure to staff performing right-handed TTE immediately following ^{99m}Tc sestamibi MPI. This suggests that if such scenarios cannot be avoided, a work flow of 20 patients per year would warrant personal monitoring and instruction as per International Commission on Radiological Protection recommendations. A workf low of 20 such patients per week may lead to exposures exceeding standard annual occupational dose limits, such as those defined by the US Nuclear Regulatory Commission (50 mSv). Results also indicate that given a 20-fold increase in the exposure of the wrist tag (TLD 6) compared with the breast tag (TLD 3), the hand closest to the patient should be monitored with a ring tag for such a work flow. The umbilical region (TLD 5) had a positive reading for right-handed TTE, but not for the left-handed TTE, consistent with an increased average distance between the thorax of the sonographer and the patient for left-handed TTE. Unlike with right-handed TTE, with left-handed TTE, the sonographer does not have to frequently lean over the patient, bringing the core of his or her body closer to the patient (Figure 1). Because of an increased distance between patient and examiner with left-handed TTE, estimated exposures were about one fourth to one third of the exposure for right-handed TTE, indicating that left-handed TTE is the preferred method for post-MPI patients in terms of occupational exposure reduction. Even so, given a proportional increase in the number of procedures done per year, similar personal monitoring would also be warranted for left-handed TTE.

We believe that in real practice and with the existence of complicated studies that are normally performed in daily clinical routine in the echocardiography laboratory, there is a need for reconsideration of the possible radiation exposure to sonographers according to the

Figure 1 Simulation showing the proximity of the cardiac sonographer to a patient during **(A)** right-handed TTE and **(B)** left-handed TTE.

Figure 2 Placement of TLDs on the upper body of the sonographer/echocardiographer.

principle of "as low as reasonably achievable." Standard methods of reducing occupational exposure include reducing the injected amount of the radiotracer used for MPI, reducing the duration of the exposure, increasing the distance from the radiating object or source of radiation, the use of shielding, and educating staff members about radiation safety.[18]

Application of these principles and methods of protection is not completely feasible during an echocardiographic study. For example, a shorter study would reduce exposure time but likely affect the quality of the study and its diagnostic accuracy. Increasing the distance from a radiation source is also not fully applicable during TTE, even if it is performed left-handed (Figure 1B), because the thorax and the hand holding the ultrasound probe would still be in a range of few centimeters from the source of radiation (the patient). Group 3 indicates that given sufficient throughput, occupational exposure remains a concern also with left-handed TTE.

For commonly used radiotracers for MPI, such as ^{99m}Tc sestamibi, it is inappropriate to use personal protective devices (PPDs) such as radiation protective garments including thyroid collars and protective eyewear. Designed for x-ray photon energies, such PPDs do not provide substantial protection for the higher photon energies found with nuclear medicine radiotracers. In addition, these PPDs are usually heavy and not easy to use by a cardiac sonographer. Although not studied here, draping a lead PPD on the back of the patient during right-handed TTE would likely reduce the exposure of the sonographer by providing additional gamma-ray attenuation between the sonographer and patient. However, it remains to be studied if such draping inhibits the motion of the sonographer, possibly prolonging the ultrasound imaging and exposure time, rendering the practice less effective.

Performing TTE before MPI would be optimal in a clinical setting. However, this is not always feasible, because in many cases the need for TTE might follow from the results of MPI. An effective method for reducing radiation exposure to echocardiography staff members performing TTE after MPI is to delay the study, allowing radioactive decay. Figure 4 plots the model-based estimates for radiation exposure per patient due to right-handed TTE after MPI performed with ^{99m}Tc sestamibi as a function of additional time delay. The fitted parameters of the model for depth of the attenuator ($R = 15$ cm), distances for right- and left-handed TTE to the wrist holding the ultrasound probe ($d_{TLD6} = 2$ cm and $d_{TLD7} = 12$ cm, respectively), and to the chest ($d_{TLD3} = 10$ cm and $d_{TLD4} = 30$ cm, respectively) are reasonable given sonographer and patient arrangement. A time delay of only 1 or 2 hours reduces the field by about 10% or 20%, insufficient for a substantial decrease in exposure. In contrast, a delay of 24 hours reduces possible exposure to $<$7% compared with the scenario in which TTE follows MPI immediately. If TTE cannot be scheduled before MPI, TTE should then be delayed to the following day. This recommendation is conservative. All radiotracers commonly

Table 1 Characteristics of group 1

Patient	1	2	3	4	5	6	7	8	9	10
Gender	M	M	M	M	F	M	F	F	F	M
Weight (kg)	78	86	70	79	95	93	52	94	65	94
Height (cm)	178	178	170	180	160	178	158	154	165	170
BMI (kg/m^2)	24.6	27.1	24.2	24.4	37.1	29.4	20.8	39.6	23.7	32.5
Rest activity at injection (MBq)	289	270	257	279	282	286	289	282	249	304
Rest injection to TTE scan time (hh:mm)	03:00	02:55	03:20	03:30	04:22	03:19	03:53	04:16	03:27	04:24
Stress activity at injection (MBq)	925	875	875	712	763	875	894	776	812	855
Stress injection to TTE scan time (hh:mm)	01:54	00:24	01:50	01:40	01:42	01:26	02:20	01:06	01:15	01:46
TTE duration (min)	25	33	50	48	44	32	37	45	33	43
Activity at TTE (MBq)	948	1,029	884	774	798	937	868	856	870	880

BMI, Body mass index; *F*, female; *M*, male.

Table 2 Characteristics of group 2

Patient	1	2	3	4	5	6	7	8	9	10
Gender	F	F	F	F	M	F	F	M	M	M
Weight (kg)	64	90	78	83	62	47	78	101	86	92
Height (cm)	160	162	158	163	162	150	162	184	165	175
BMI (kg/m^2)	25.0	34.3	31.2	31.2	23.6	20.9	29.7	29.8	31.6	30.0
Rest activity at injection (MBq)	228	273	294	289	334	286	240	307	254	283
Rest injection to TTE scan time (hh:mm)	02:41	03:37	03:10	04:11	05:45	04:21	03:55	03:54	03:28	03:01
Stress activity at injection (MBq)	802	804	985	912	782	869	783	870	934	847
Stress injection to TTE scan time (hh:mm)	01:20	01:32	01:15	01:35	01:45	01:41	01:35	01:22	02:01	00:28
TTE duration (min)	43	47	57	43	43	41	49	40	50	41
Activity at TTE (MBq)	855	853	1,057	940	811	889	806	939	911	1,002

BMI, Body mass index; *F*, female; *M*, male.

Table 3 Characteristics of group 3

Patient	1	2	3	4	5	6	7	8	9	10
Gender	M	F	F	F	F	M	M	F	M	M
Weight (kg)	71	77	96	87	48	62	60	90	81	120
Height (cm)	160	159	150	145	152	160	161	160	166	181
BMI (kg/m^2)	27.7	30.5	42.7	41.4	20.8	24.2	23.2	35.2	29.4	36.6
Rest activity at injection (MBq)	264	299	288	282	291	293	296	293	296	293
Rest injection to TTE scan time (hh:mm)	03:18	02:31	03:33	03:14	03:32	03:57	03:37	04:27	02:18	03:32
Stress activity at injection (MBq)	873	921	925	930	907	857	925	920	947	925
Stress injection to TTE scan time (hh:mm)	01:18	00:24	01:48	01:42	01:30	01:22	01:37	01:59	00:30	01:21
TTE duration (min)	57	46	47	38	43	39	53	38	47	45
Activity at TTE (MBq)	932	1,103	943	959	957	918	963	907	1,121	993

BMI, Body mass index; *F*, female; *M*, male.

used for MPI other than ^{201}Tl have short half-lives, thereby presenting even smaller fields after a 1-day delay. Despite the longer half-life, because of lower injected activities (<150 MBq)[24] and a lower external field per megabecquerel (1.85×10^{-5} mSv/h/MBq at 1 m),[24] ^{201}Tl-injected patients would also produce fields of comparable magnitude for those presented by ^{99m}Tc sestamibi, given a similar 1-day delay. If a delay of 1 day before TTE is not possible, rotation among staff members might be another approach to reduce repetitive exposures of the same sonographer.

In the present study, the MPI protocol included a rest/stress acquisition, which typically uses 3 times the injected dose of a stress-only protocol. A stress-only protocol would reduce radiation exposure to both patients and staff members for cases in which a subsequent rest study is not needed.

Because breast tissue is considered to be more vulnerable to ionizing radiation,[25] the relative position between the sonographer and the post-MPI patient is likely of greater concern for female examiners because of the close proximity of the breast to

Table 4 Characteristics of group 4 (control group)

Patient	1	2	3	4	5	6	7	8	9	10
Gender	M	M	M	F	M	M	M	M	F	F
Weight (kg)	64	14	77	75	100	97	112	75	70	70
Height (cm)	166	172	176	170	178	176	165	173	156	160
BMI (kg/m^2)	23.2	38.5	24.9	26.0	31.6	31.3	41.1	25.1	28.8	27.3
TTE duration (min)	44	44	44	50	47	48	60	57	56	61

BMI, Body mass index; *F*, female; *M*, male.

Table 5 TLD readings

	Right-handed radiation exposure (mSv)			Left-handed radiation exposure (mSv)		Control radiation exposure (mSv)	
	Measured*						
TLD no.	Echocardiographer	Cardiac sonographer	Modeled estimate	Measured* cardiac sonographer	Modeled estimate	Measured* cardiac sonographer	Modeled estimate
1			0.05		0.04		0
2			0.16		0.07		0
3	0.45 ± 0.09	0.59 ± 0.12	0.42		0.05		0
4			0.09	0.12 ± 0.02	0.13		0
5		0.15 ± 0.03	0.16		0.07		0
6	1.02 ± 0.20	1.06 ± 0.21	0.90		0.01		0
7			0.01	0.34 ± 0.07	0.36		0

TLD positions: TLD 1, head; TLD 2, sternum; TLD 3, right anterolateral chest wall; TLD 4, left anterolateral chest wall; TLD 5, umbilical region; TLD 6, right wrist; TLD 7, left wrist.
*No reading implies measurement <0.1 mSv.

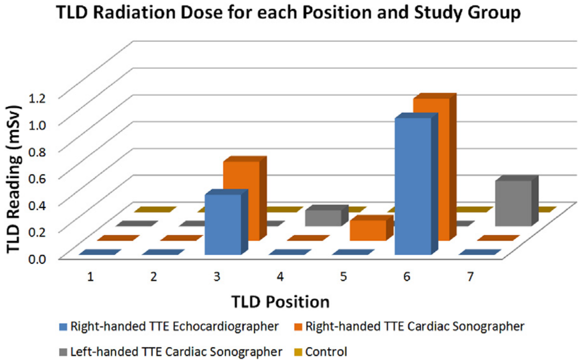

Figure 3 Visual comparison of TLD radiation dose reading for each position in all study groups. TLD positions: TLD 1, head; TLD 2, sternum; TLD 3, right anterolateral chest wall; TLD 4, left anterolateral chest wall; TLD 5, umbilical region; TLD 6, right wrist; TLD 7, left wrist.

the patient, especially for right-handed TTE (Figure 1A). In all cases, except for the control, the TLD closest to the breast that was proximal to the patient gave a positive reading for radiation exposure.

A special concern is the exposure of fetuses to ionizing radiation. The working conditions for pregnant women performing TTE immediately after MPI should be individually evaluated by an institutional radiation safety officer (RSO) to ensure that

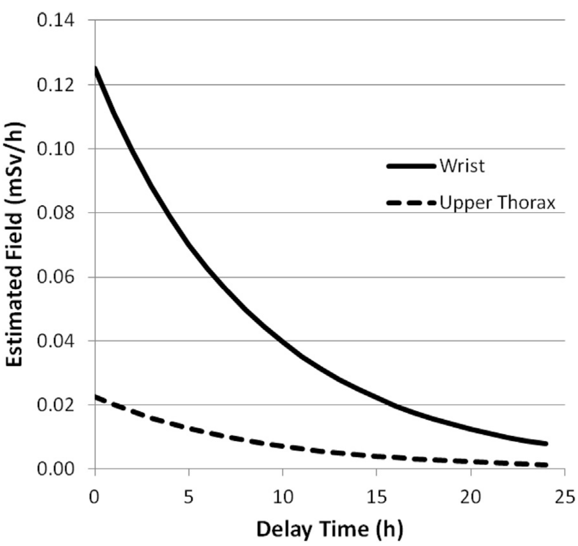

Figure 4 Radioactive decay. A delay of three or four half-lives is necessary to reduce fields from radioactive source by an order of magnitude. A delay of 24 hours reduces the estimated radiation field by 94%, whereas a delay of only 1 or 2 hours reduces the field by about 10% or 20%. These conservative estimates account for physical decay, not biological elimination, and are based on the model for occupational exposure from right-handed TTE per patient.

recommended limits of radiation exposure to the fetus are not exceeded. These limits (typically 1 mSv to the fetus, often estimated by a 2-mSv exposure to the pregnant woman) are substantially lower than regular limits for occupational exposure. Women performing TTE immediately after MPI should inform the RSO if they become pregnant.

This study supports the call of McIlwain *et al.*[18] to consider radiation exposure to echocardiographers and cardiac sonographers performing TTE immediately after MPI in order to optimize methods and work flow according to the principle of "as low as reasonably achievable." At a minimum, given current practice, such staff members should receive personal instruction and monitoring if any of them performs >20 of these studies per year.

These observations and recommendations can be summarized as follows: (1) Exposure to ionizing radiation for ultrasound personnel performing TTE on post-MPI patients was measurable using standard personal monitoring devices for two different methods of TTE and for two different examiners. (2) At a dose rate to the examiner of up to 0.05 mSv per patient, performing just 20 transthoracic studies after MPI per year may warrant personal instruction and monitoring for ionizing radiation exposure. (3) Examiners consistently performing >20 transthoracic studies after MPI per week are at risk for exceeding legally mandated annual occupational exposure limits. (4) Pregnant examiners should have their working conditions personally evaluated by an institutional RSO before performing TTE after MPI studies. (5) Dose-sharing strategies among examiners and stress-only MPI protocols should be considered. (6) When practical, TTE after MPI should be performed left-handed. (7) When practical, MPI should be performed after TTE or ≥1 day before TTE.

CONCLUSIONS

Patients injected with radiopharmaceuticals should be considered temporary sources of radiation. Because echocardiography laboratories do not have fixed radiation sources, occupational exposure of the staff has not typically been addressed. Current results indicated that examiners performing TTE in patients who underwent recent same-day ^{99m}Tc sestamibi MPI can show positive levels of ionizing radiation exposure as measured by standard personal monitoring devices. In institutions in which a relatively large number of patients may undergo both types of examinations, the sequence of performing TTE and MPI should be scheduled to reduce exposure. If planned exposures for medical staff members performing echocardiography could possibly fall in the range of 1 to 20 mSv/year, they should be personally instructed and monitored. Workers who might perform TTE on post-MPI patients should inform the institutional RSO if they become pregnant.

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