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Sentinel Node Navigation Surgery with ^{99m}Tc-tin Colloid in Breast Cancer: Radiation Safety Considerations

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Abstract: *Purpose:* The incident at the Fukushima Daiichi nuclear power station in 2011 has again raised concerns with the public regarding radiation exposure, especially so in medical workers and patients undergoing treatment involving the use of radiation. Radioisotopes are currently used during sentinel node navigation surgery (SNNS) in operating rooms without radiation monitoring. To re-evaluate the safety issues, the potential effective dose (E_{poten}) from ^{99m}Tc-tin (-Sn) colloid in breast cancer surgery was estimated and personal dose equivalents, $H_p(10)$ and $H_p(0.07)$, were measured during SNNS.

Materials and methods: Seventeen breast cancer patients were enrolled. One day before SNNS, ^{99m}Tc-Sn colloid was injected around the tumor and radiation exposure rates were measured using survey meters. Personal dose equivalents for the surgical workers were measured. $H_p(10)$ and $H_p(0.07)$ for the body and $H_p(0.07)$ for the hands were recorded using semiconductor detectors and ring-type glass dosimeters.

Results: The maximum E_{poten} was 29 μSv per 74 MBq injection. The maximum $H_p(10)$ for the primary and assisting surgeons, nurse, and anesthetist was 3.7, 1.4, 0.3 and 0.6 μSv per SNNS, respectively. The maximum $H_p(0.07)$ for the hands was 100 μSv. Maximum radiocontamination 20 times higher than background (0.05 μSv/h) was detected in bloody gauze.

Conclusion: The workers' radiation dose exposure from SNNS was not high, although radiation management such as a temporary cooling off period may be required.

Keywords: Sentinel node, breast cancer, radiation exposure, radioactive contamination, ^{99m}Tc-tin colloid.

INTRODUCTION

Sentinel node navigation surgery (SNNS) has become a standard therapy for early stage breast cancer, and facilitates minimally invasive treatment [1]. The radionuclide (RN) method is very useful in surveying sentinel lymph nodes due to its superior localization and detectability [2-6]. Using the RN method, sentinel lymph nodes can be easily detected by means of a gamma camera or a gamma probe, even if they are located in remote or unexpected sites. Therefore, SNNS using the RN method has become a popular surgical treatment method for early stage breast cancer. However, radiation safety issues such as radiation exposure and radioactive contamination due to the use of this method are important concerns for medical workers and patients. People have renewed serious concerns regarding radiation exposure since the incident at Fukushima Daiichi nuclear power plant on March 11, 2011.

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Table 1. SNNS Patient Characteristics and Radiation Dose

Sex (M / F)	0 / 17	(Rt : 10, Lt : 7)
Age (y)	35 - 78	(58.9 ± 12.3)
Weight (kg)	40.5 - 63.8	(51.2 ± 6.7)
Hight (cm)	141.5 - 165.0	(142.3 ± 5.9)
Dose (MBq)	49.7 - 232.5	(99.4 ± 51.0)

The medical staff present in the operating room where SNNS for breast cancer is performed are not train radiation workers and thus they may be misinformed and unnecessarily alarmed by incorrect information. In the present study, in order to reconfirm the safety of SNNS in the light of the radiation exposure issue, we re-evaluated medical worker radiation exposure doses, potential contamination of the equipment used in SNNS, and the radioactive contamination on the operating room floor utilizing the revised International Commission on Radiological Protection (ICRP) 2007 recommendation [7].

MATERIALS AND METHOD

Seventeen patients with breast cancer who had surgery just after the approval of SNNS for clinical use in Japan in 2001 were enrolled in this study (Table **1**). The approval for the use of SNNS was obtained from the Fujita Health University Hospital Medical Department Ethics Committee and SNNS using the RN method was performed according to the guidelines of the Japanese Society of Nuclear Medicine. On the day before SNNS, at 23.6 ± 2.4 h before the initiation of surgery, 49.7 to 232.5 MBq (99.4 ± 51.0 MBq) of ^{99m}Tc-Sn colloid was injected subcutaneously around the primary breast tumor. Three to 4 h after injection, lymphoscintigraphy was performed using a dual headed gamma camera (GCA-7200A/UI, Toshiba, Tokyo, Japan). On the following day, SNNS was performed in an operating room using a gamma probe (NAVIGATOR, Radiation Monitoring Devices Inc., Watertown, MA, USA) for detection followed by sentinel lymph node biopsy. The mean SNNS operation time was 2.6 ± 0.6 h. Radioactive contamination due to using the RN method in SNNS, as well as radiation doses received by medical workers from exposure to the patients, were measured as follows.

MEASUREMENTS OF INITIAL RADIATION EXPOSURE

In order to estimate the amount of radiation exposure, from ^{99m}Tc-Sn colloid, around a patient just after completion of the injections, the initial radiation exposure rates were measured using three ionization survey meters (ICS-301, Aloka, Tokyo, Japan) calibrated against ^{137}Cs, as shown in Fig. (**1**). Survey meters specifications were as follows: the minimum range in full scale display was 1 mR/h, the available energy range was from 25 keV to 2 MeV, and the measurement error was within ± 10%. The radiation exposure rates from 17 patients injected with ^{99m}Tc-Sn colloid were measured in four directions, namely the front and rear of the patient along with the patient's right and left. The distance between the body surface and detector centers was varied at 0.05, 0.5, 1.0 and 1.5 m. The recorded exposure rates in the four directions were then averaged. From these averaged rates, the potential effective dose rates, $\dot{E}_{\mathrm{poten}}$, to a medical worker in contact with a patient that had received ^{99m}Tc-Sn colloid was estimated by means of a simple effective dose calculation method described below.

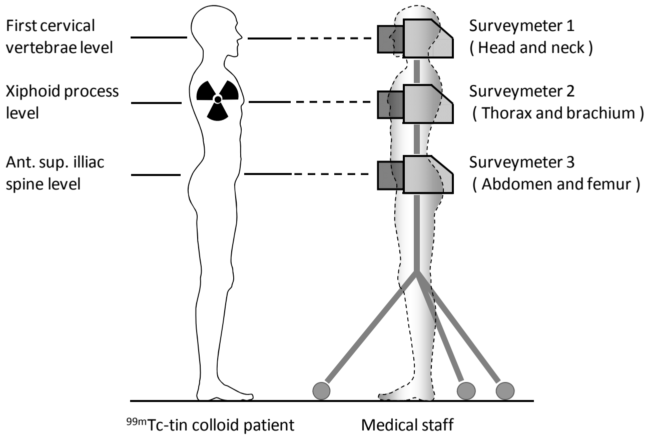

Fig. (1). Detector arrangement used for radiation dose measurement of the circumference of a patient injected with ^{99m}Tc; ^{99m}Tc-tin colloid. Each ionization survey meter (ICS-301, Aloka Co., Tokyo, Japan) measures the dose in each part the medical worker's body.

EFFECTIVE DOSE ESTIMATION AROUND A PATIENT WITH SN COLLOID

Radiation exposure rates, $\dot{X}$ [mR/h], measured with the ionization survey meters were normalized to an injection activity of 74 MBq and were converted into personal dose equivalent rates, $\dot{H}_{\mathrm{p}}(10)$ [μSv/h], using a conversion factor of:

$$8.76\ \mu\mathrm{Gy/mR} \times 1.903\ \mathrm{Sv/Gy} = 16.7\ \mu\mathrm{Sv/mR} \tag{1}$$

where, 8.76 μGy/mR was the conversion factor of D_{air}/X [μGy/mR] from an exposure, X [mR], to an air absorbed dose, D_{air} [μGy], obtained using the following equation:

$$2.58 \times 10^{-4}\ \mathrm{C\ kg^{-1}\ R^{-1}} \times 33.97\ \mathrm{J/C} = 0.00876\ \mathrm{J\ kg^{-1}\ R^{-1}}\ \text{or Gy/R}$$

$$= 8.76\ \mu\mathrm{Gy/mR} \tag{2}$$

where 2.58×10^{-4} C kg^{-1} R^{-1} is a conversion factor from Roentgen [R] units to [C/kg] units and 33.97 J/C is the energy required to make a 1C ion pair in dry air [8]. 1.903 Sv/Gy was the maximum value of the conversion coefficient, $H_{\mathrm{p}}(10)/K_{\mathrm{air}}$ [Sv/Gy], from air kerma (K_{air}) in air to the personal dose equivalent, $H_{\mathrm{p}}(10)$, which was obtained in a photon field with an energy of 0.08 MeV [9]. In this dose conversion, the use of 16.7 μSv/mR gave a slight overestimate of $_{\mathrm{p}}(10)$ which meant that underestimation of $_{\mathrm{p}}(10)$ in any photon energy field could be avoided. Since the K_{air} was also exactly equal to D_{air} under the conditions of secondary electron equilibrium, D_{air} was used instead of K_{air}. Potential effective dose rates ($\dot{E}_{\mathrm{poten}}$), measured in μSv/h around a patient injected with ^{99m}Tc-Sn colloid, were obtained as the received radiation dose rates of a model imaginary person, as depicted in Fig. (**1**), using the following equation enabling a simple calculation of E_{poten}:

$$E_{\mathrm{poten}} = 0.10\dot{H}_{\mathrm{a}} + 0.50\dot{H}_{\mathrm{b}} + 0.33\dot{H}_{\mathrm{c}} + 0.07\dot{H}_{\mathrm{MAX}} \tag{3}$$

Table 2. Tissue Weighting Factors given in the 2007 ICRP Recommendations

	Head and Neck		**Thorax and Brachium**		**Abdomen and Femur**	
	0.04	(Thyroid)	0.12	(Lung)	0.08	(Gonads)
	0.01	(Brain)	0.04	(Oesophagus)		
	0.01	(Salivary glands)	0.12	(Breast)		
			0.12	(Stomach)	0.04	(Bladder)
			0.04	(Liver)	0.12	(Colon)
	0.013	(Bone-marrow)	0.04	(Bone-marrow)	0.07	(Bone-marrow)
	0.002	(Bone surface)	0.002	(Bone surface)	0.003	(Bone surface)
	0.03	(Skin & Remainder)	0.02	(Skin & Remainder)	0.02	(Skin & Remainder)
Sum	0.10		0.50		0.33	

where $\dot{H}_a$, $\dot{H}_b$ and $\dot{H}_c$ are the equivalent dose rates ($\dot{H}_T$) to the head and neck, thorax and brachium, and abdomen and femur of the medical worker, respectively. $\dot{H}_{MAX}$ is the $\dot{H}_T$ to the remaining tissue. In this calculation, the maximum of $\dot{H}_a$, $\dot{H}_b$ and $\dot{H}_c$ was substituted for $\dot{H}_{MAX}$ to avoid the underestimation of $\dot{H}_T$ of the remaining tissue. Each coefficient of 0.10, 0.50, 0.33 and 0.07 was a partial sum of tissue weighting factors recommended by ICRP Publication 103, as shown in Table **2**.

In this study, we substituted $\dot{H}_p(10)$ for the $\dot{H}_a$, $\dot{H}_b$, and $\dot{H}_c$, which was converted from $\dot{X}$ that was recorded with survey meters 1, 2 and 3, respectively. Potential effective dose ($E_{\text{poten}\,(t_1,\,t_2)}$) for a time period from t_1 to t_1+t_2 after the injections of Sn colloids is given by the following equation:

$$E_{\mathrm{poten}(t_1,t_2)} = \int \dot{E}_{\mathrm{poten},0}\, e^{-\lambda t}\, dt \qquad (4)$$

where, $_{\mathrm{poten},0}$ is the initial effective dose rate, λ is the decay constant of 0.115 h^{-1} of ^{99m}Tc and t is the lapsed time after the injections of Sn colloids.

MEASUREMENTS OF RADIATION EXPOSURE TO SURGICAL WORKERS DURING SNNS

In order to assess the body and skin radiation doses of the surgical workers who performed SNNS, in 7 cases their $H_p(10)$ and $H_p(0.07)$ during SNNS were monitored using high sensitivity semiconductor detectors (DOSE^3, Chiyoda Technol Co., Tokyo, Japan). The detectors gave a minimum reading of 0.1 μSv, had an available energy range of 17 keV to 1.5 MeV for $H_p(10)$ and 20 keV to 6 MeV for $H_p(0.07)$, and a measurement error of ± 10% for $H_p(10)$ and ± 20% for $H_p(0.07)$. These detectors were attached to the trunk region (male, chest; and female, lower abdomen) of the surgical workers. Moreover, ring-type glass dosimeters (Glass Ring JP, Chiyoda Technol Co., Tokyo, Japan) were attached to the middle or third finger of the non-dominant hand to determine the $H_p(0.07)$ finger doses. The detection limit was 100 μSv.

INVESTIGATION OF RADIOACTIVE CONTAMINATION GENERATED DURING SNNS

The radioactive contamination originating from SNNS, such as excised specimens and surgical equipment that included gowns, gloves, gauze, cloth, surgical tools, waste and patient blood, were measured using a pocket scintillation survey meter (PDR-101, Aloka Co., Tokyo, Japan) in 7 cases. This survey meter had a minimum reading of 0.001 μSv/h for *(10) and an available energy range from 60 keV to 1.24 MeV that was within a ± 15% measurement error. The radiation dose rates were compared with the background (BG) counts averaged in the operating room free from radioactive materials. In 7 cases, floor contamination in the operating room used for SNNS was investigated using a wiping method, which involved rubbing the floor surface with coin-type filter papers (TH-E8304, Chiyoda Technol Co., Tokyo, Japan). Wiping was carried out in 15 areas (10 × 10 cm^2 each) per operating room. These filter papers were put into the bottoms of plastic test tubes and their counts were measured using a well-type scintillation counter (JDC-725, Aloka Co., Tokyo, Japan). The detection limit was 0.002 Bq/cm^2 of ^{99m}Tc.

RESULTS

EFFECTIVE DOSE ESTIMATION AROUND A PATIENT INJECTED WITH SN COLLOID

The initial personal dose equivalent rates, $\dot{H}_p(10)_{,0}$, of a medical worker in contact with a ^{99m}Tc-Sn colloid injected patient are shown in Table **3**. A maximum dose rate of 107.1 ± 66.0 μSv/h per 74 MBq injected radiation dose was recorded at a distance of 0.05 m ahead of the patient by an ionization survey meter. The meter was attached to the body surface of the medical worker and was positioned at the xiphoid process. This dose rate was quite high as compared with the dose rates in the other three directions. The initial effective dose rates, $\dot{E}_{\mathrm{poten},0}$, and total potential effective doses, $E_{\mathrm{poten}(0,\,\infty)}$, are shown in Tables **4** and **5**, respectively. The $\dot{E}_{\mathrm{poten},0}$ dose rates were 33.6, 5.2, 2.0 and 1.0 μSv/h per 74 MBq injected dose at 0.05, 0.50, 1.0 and 1.5 m from the patient, respectively. The $E_{\mathrm{poten}(0,\,\infty)}$ were estimated to be 292, 45, 17 and 9 μSv per 74 MBq injected dose at 0.05, 0.5, 1.0 and 1.5 m, respectively. The $\dot{E}_{\mathrm{poten},0}$ and $E_{\mathrm{poten}(0,\,\infty)}$ values decreased by about a factor of 7 or so at 0.5 m, 17 at 1.0 m, and 34 at 1.5 m, as compared with the respective values at 0.05 m. The maximum potential effective dose, $E_{\mathrm{poten}(0,8)}+E_{\mathrm{poten}(24,8)}$, of a medical worker in contact with a patient with ^{99m}Tc-Sn at a distance of 0.5 m, for the purpose of administering medical aid or nursing, was approximately 29 μSv per 74 MBq injected dose and was equivalent to about 64% of $E_{\mathrm{poten}(0,\,\infty)}$. In this study, the potential effective dose to surgical workers per SNNS session was $E_{\mathrm{poten}(23.6,\,2.6)}$ in a period from 23.6 ± 2.6 h after the ^{99m}Tc-Sn colloid injection. The $E_{\mathrm{poten}(23.6,\ 2.6)}$ was estimated to be 4.79, 0.76, 0.29 and 0.15 μSv per 74 MBq at 0.05, 0.5, 1.0 and 1.5 m, respectively; and 6.67, 1.02, 0.39 and 0.21 μSv per 99.4 MBq at 0.05, 0.5, 1.0 and 1.5 m, respectively.

SURGICAL WORKER EXTERNAL RADIATION EXPOSURE

The cumulative radiation doses monitored with semiconductor detectors placed on the bodies of surgical workers are shown in Table **6**. The mean (maximum values shown in parenthesis) $H_p(10)$ body doses per SNNS to the primary surgeon, assisting surgeon, nurse and anesthetist were 1.2 (3.7), 0.8 (1.4), 0.1 (0.3) and 0.2 (0.6) μSv, respectively. The mean (maximum values shown in parenthesis) $H_p(0.07)$ skin doses per SNNS to the primary surgeon, assisting surgeon, nurse, and anesthetist were 1.7 (3.4), 0.9 (2.8), 0.5 (0.9) and 0.1 (0.5) μSv, respectively. The maximum $H_p(0.07)$ hand dose during SNNS, measured using a glass ring dosimeter, was 100 μSv.

RADIOACTIVE CONTAMINATION IN SNNS

Dose rates from the radioactive contaminants on surgical equipment measured using a pocket scintillation survey meter, held at a distance of 1.5 cm from the equipment, are shown in Table **7**. The maximum dose rate was recorded in the measurements of bloody gauze and reached 20 times that of the BG dose rate of 0.05 μSv/h. Dose rates from radioactive contaminants on the other equipment did not exceed 12 times the BG rate. In many excised specimens, since the radiation intensity at a short distance of 1.5 cm exceeded the upper detection limit of 20 μSv/h, the survey meter could not provide an accurate reading. However, a maximum dose rate of 15.3 μSv/h was recorded by positioning the survey meter at a distance of 10 cm from the specimens. In the floor contamination check using the wiping method, the contamination levels at all check points in the operating rooms used for SNNS were below a lower detection limit of 0.002 Bq/cm$^{2.}$ This indicated that there was no evidence of superficial contamination on the operating room floor.

DISCUSSION

In the present study, the radiation doses received by surgeons and other medical workers from a patient that had been administered ^{99m}Tc-Sn colloid were very low and were at levels which can be safely ignored. Even if radioactive contaminants generated by SNNS were frequently detected in excised specimens or surgical equipment, the radiation risks were very slight; however, temporary management of these radiocontaminants and a simple contamination survey should be required to ensure the safety of the work environment.

Sentinel lymph node detection using an intra-operative RN gamma probe combined with the blue-dye technique has shown the highest sensitivity [5]. SNNS with the RN method has thus been quickly spreading to many institutions over the past decades [1]. However, most of the medical workers involved in SNNS may not have sufficient knowledge of the handling and management of radioactive materials as they are typically not trained as radiation workers. Therefore it is not surprising that some such workers have expressed grave concerns regarding potential radiation exposure risks during SNNS.

The incident at the Fukushima Daiichi nuclear power station has again sensitized the public to radiation exposure issues. Therefore, radiation exposure measurements from patients receiving RN injections should play a significant role in achieving a consensus on the safe use of radioactive materials. Our measurements could potentially play an important role in adding supplemental data to the data available in previous papers [10-13], guidelines [14] and recommendations [15] regarding the radiation safety of SNNS.

The $\dot{H}_p(10)_{,0}$ data shown in Table **3** clarifies the size and level of the radiation area temporarily generated around a patient administered with ^{99m}Tc-Sn colloid. The dose rates fell off rapidly and continuously with increasing distance from the patient. We are thus quite certain that only a small area around the patient delivers a radiation dose to the medical workers, but we could not determine a clear perimeter for the area of radioactive contamination. The medical workers do not always stay in the area of contamination, thus reducing the amount of radiation exposure; which also decreases with time due to radioactive decay. However, a certain radiation safety standard is required. For example, if we set a dose rate of 1 μSv/h as a boundary line demarking the radiation area, then the inside of a circle with 1.5 m radius centered on the front of the patient would be regarded as the radiation area; and if we adopt 5 μSv/h as the boundary line, then the inside of a circle with a 0.5 m radius would be regarded as the radiation area. An area around the patient which exceeds 5 μSv/h should be more suitable as the substantial radiation area, because a medical worker's contact time with a specific SNNS patient is be considerably shorter than the total nursing or care time required for several patients.

Potential health damage due to the radiation dose received from the patient should be examined only in terms of stochastic effects. Such a radiation dose is very low and thus would not have any deterministic detrimental health effects on the medical or surgical worker's body. We estimated the effective dose directly linked to the stochastic effect. As shown in Table **4**, the $\dot{E}_{\mathrm{poten},0}$ which the medical workers may received from a patient immediately after the injection of ^{99m}Tc-Sn colloid was estimated using dose rates of 33.6, 5.2, 2.0 and 1.0 μSv/h per 74 MBq at distances of 0.05, 0.50, 1.0 and 1.5 m from the patient, respectively. These dose rates are the averaged radiation intensity, per unit time, within the circumference of a patient injected with ^{99m}Tc-Sn colloid and illustrate the progressive decrease in dose rate with increasing distance from the patient. For radiation management, a radiation dose rate of 33.6 μSv/h may be used for effective radiation protection. If medical workers were continuously exposed to radiation during their working time, for example 40 h per week, then their effective dose would exceed the occupational effective dose limit of 50 mSv/y. However, such a radiation dose estimate is not be correct, as the medical workers are present in the substantial radiation area around the patient for only a fraction of the total operating time and the dose rate also decreases with time in line with the effective half life of the ^{99m}Tc-Sn colloid. The initial effective dose rates are important

Table 3. Initial Personal Dose Equivalent Rate $\dot{H}_p(10)_{,0}$ Around a Patient Injected with ^{99m}Tc-tin Colloid

Detector No.	Patient Position	Personal Dose Equivalent Rates $H_p(10)$ [μSv/h] per 74 MBq (n=17) Distance from Patients with ^{99m}Tc-tin Colloids 0.05 m	0.5 m	1.0 m	1.5 m
1	Anterior	24.6 ± 10.3	7.0 ± 2.4	2.6 ± 1.0	1.4 ± 0.6
	R-lateral	11.4 ± 9.6	4.0 ± 2.7	1.6 ± 1.0	0.9 ± 0.6
	Posterior	8.7 ± 15.3	2.7 ± 2.9	1.1 ± 1.1	0.7 ± 0.8
	L-lateral	11.7 ± 10.5	3.4 ± 2.8	1.4 ± 1.0	0.7 ± 0.5
	Average	14.1 ± 13.0	4.3 ± 3.1	1.7 ± 1.2	0.9 ± 0.7
2	Anterior	107.1 ± 66.0	9.3 ± 3.1	3.1 ± 1.2	1.6 ± 0.9
	R-lateral	29.1 ± 31.4	5.2 ± 3.9	1.9 ± 1.3	1.0 ± 0.8
	Posterior	23.4 ± 29.6	3.7 ± 4.0	1.4 ± 1.4	0.9 ± 0.9
	L-lateral	26.1 ± 32.7	4.5 ± 3.8	1.8 ± 1.2	0.9 ± 0.7
	Average	46.4 ± 54.7	5.7 ± 4.2	2.1 ± 1.4	1.1 ± 0.8
3	Anterior	29.6 ± 20.7	7.3 ± 3.1	2.8 ± 1.0	1.5 ± 0.7
	R-lateral	15.1 ± 17.9	4.1 ± 3.3	1.6 ± 1.0	1.0 ± 0.6
	Posterior	12.7 ± 25.0	3.1 ± 4.1	1.2 ± 1.3	0.7 ± 0.7
	L-lateral	12.8 ± 16.6	3.4 ± 3.1	1.5 ± 1.1	0.8 ± 0.6
	Average	17.5 ± 21.1	4.5 ± 3.7	1.8 ± 1.3	1.0 ± 0.7

Table 4. Initial Equivalent Dose Rates $\dot{H}_{a,0}$, $\dot{H}_{b,0}$ and $\dot{H}_{c,0}$ and Effective Dose Rate $\dot{E}_{poten,0}$ from a Patient Injected with ^{99m}Tc-tin Colloids

Dose Evaluation Tissue	Radiation Dose	[μSv/h] Per 74 MBq Injection (n=17) Distance from Patients with ^{99m}Tc-tin Colloids 0.05 m	0.5 m	1.0 m	1.5 m
Head and neck	$\dot{H}_{a,0}$	14.1	4.3	1.7	0.9
Thorax and brachium	$\dot{H}_{b,0}$	46.4	5.7	2.1	1.1
Abdomen and femur	$\dot{H}_{c,0}$	17.5	4.5	1.8	1.0
Whole body	$\dot{E}_{poten,0}$	33.6	5.2	2.0	1.0

$$\dot{E}_{poten,0} = 0.10\dot{H}_{a,0} + 0.50\dot{H}_{b,0} + 0.33\dot{H}_{c,0} + 0.07\dot{H}_{MAX}$$

factors to be taken into account when considering the medical worker's protection from exposure to radiation. The radiation dose received by a medical worker under various conditions involving exposure to the patient can be estimated based on a previously reported formula [4]. The $E_{poten(0,\infty)}$ was calculated to be 292, 45, 17 and 9 μSv per 74 MBq at distances of 0.05, 0.5, 1.0 and 1.5 m from the patient, respectively, giving the highest dose at each distance from the patient when the longest exposure to the patient occurred. A medical worker's dose should therefore not exceed these doses at the distances indicated. The $E_{poten(0,\infty)}$ doses should be useful in evaluating the maximum potential exposure risk near the patient. The cancer risk was estimated by multiplying the nominal probability coefficients of 5.5×10^{-2} Sv^{-1}, as detailed in ICRP Publication 103 [7], by the doses given above and were calculated to be 1.6×10^{-5}, 2.5×10^{-6}, 9.4×10^{-7} and 5.0×10^{-7} per patient at distances of 0.05, 0.5, 1.0 and 1.5 m, respectively. Assuming that a medical worker spends 8 h per day in the operating room, the maximum radiation dose exposure would be $E_{poten(0,8)} + E_{poten(24,8)}$ at 0.5 m from the patient. This dose was estimated to be 29 μSv per patient. In practice, general medical workers in the operating room, other than the surgeons, would spend a much shorter time in proximity with breast cancer patients undergoing SNNS, and the distance between the workers and the patient would not be 0.5 m over the duration of the operation. Therefore, the actual dose received by a worker should in fact be less than 29 μSv. In addition, a maximum radiation dose of 29 μSv is quite low, being equivalent to a cancer risk probability of 1.6×10^{-6}. A worker would thus have to be in contact with more than 1720 patients injected with ^{99m}Tc-Sn colloid for the radiation exposure to exceed the annual dose limit of 50 mSv. In reality, a medical worker would not be in contact with such a large number of patients over the period of a year, and the worker's radiation dose exposure per patient would be lower than the irrational assumption of 29 μSv; therefore, their anxiety concerning excessive radiation exposure should be allayed. In our study, we converted $\dot{X}$ into $\dot{H}_p(10)$ using a factor of 1.67 μSv/mR, and obtained $\dot{E}_{poten}$ from $\dot{H}_p(10)$ using an equation [3]. This method gives a

Table 5. Potential Effective Dose $E_{poten(0,\infty)}$ from a Patient Injected with ^{99m}Tc-tin Colloid

Dose Evaluation Tissue	Radiation Dose	[μSv/h] per 74 MBq Injection (n=17)			
		Distance from Patients with ^{99m}Tc-tin Colloids			
		0.05 m	0.5 m	1.0 m	1.5 m
Whole body	$E_{poten(0,\infty)}$	292	45	17	9

Table 6. Surgical Workers' Cumulative $H_p(10)$ and $H_p(0.07)$ Doses Without Background During SNNS Measured Using Semiconductor Detectors

$H_p(10)$					μSv/SNNS
Patient	**Primary Surgeon**	**Assisting Surgeon**	**Nurse**	**Assisting Nurse**	**Anesthetist**
1	0.9	1.2	0.1	***	0.2
2	3.7	0.8	0.1	0.2	0.6
3	0.2	1.4	0.1	0.1	0.0
4	1.4	1.1	0.0	0.1	0.0
5	1.3	0.4	0.3	0.0	0.1
6	0.4	0.3	0.1	0.0	0.1
7	0.5	0.1	0.0	0.0	0.1
Average	1.2	0.8	0.1	0.1	0.2
*** with no data					
$H_p(0.07)$					μSv/SNNS
Patient	**Primary Surgeon**	**Assisting Surgeon**	**Nurse**	**Assisting Nurse**	**Anesthetist**
1	2.6	2.8	0.6	***	0.0
2	3.4	0.0	0.7	0.4	***
3	0.4	***	0.9	0.0	0.0
4	0.5	1.3	0.3	0.0	0.0
5	3.3	0.1	0.0	0.8	0.0
6	0.6	0.9	0.0	0.0	0.5
7	1.1	0.4	0.8	1.0	0.0
Average	1.7	0.9	0.5	0.4	0.1
*** with no data					

larger radiation dose estimate in any photon field than the actual dose, so the actual risk would be lower still.

The surgical workers are in a different situation with regard to radiation exposure than the general medical workers, because they come into closest contact with the patients injected with ^{99m}Tc-Sn colloid due to their performance of SNNS. We measured the $H_p(10)$ and $H_p(0.07)$ of the workers using semiconductor detectors. $H_p(10)$ and $H_p(0.07)$ showed similar values across all measurements, so we only examined $H_p(10)$ which reflects the whole body dose well. Of all the surgical workers, the primary surgeon received the highest dose. The average dose of $H_p(10)$ for the primary surgeon was 1.2 μSv per SNNS, which was less than 1/5 of the mean dose exposure of 6.6 μSv per day [16] from natural radiation sources in the general environment. If we assume that $H_p(10)$ is approximately equal to the effective dose, a cancer risk probability of 6.6×10^{-8} per SNNS is predicted for the primary surgeon. This value shows that the primary surgeon's risk per SNNS is extremely low, so all surgeons involved should not be concerned about excessive radiation exposure, even if they perform SNNS without radiation protection. The surgical worker's dose was also in good agreement with $E_{poten(23.6,\,2.6)}$, calculated from $\dot{E}_{poten,0}$ and their exposure conditions using formula (4). For example, a surgeon's primary dose of 1.2 μSv was between 4.97 μSv at a distance of 0.05 m from the patient and 0.76 μSv at a distance of 0.5 m for $E_{poten(23.6,\,2.6)}$, when 74 MBq of ^{99m}Tc-Sn colloid was administered. The primary surgeon was almost always standing at less than 0.5 m from the patient during the SNNS operation. Average radiation doses received by the nurse and assisting nurse were 0.1 μSv, which were equal to $E_{poten(23.6,\,2.6)}$ estimated at a distance of 1.5 m from the patient corresponding to their positions during SNNS. In our study, we deduce that $E_{poten(t1,\,t2)}$ is very useful in the evaluation of the surgical worker's radiation dose exposure in various exposure situations during SNNS.

Table 7. Radioactive Contamination on Surgical Equipment Measured Using a Pocket Scintillation Survey Meter

							μSv/h
Materials	**Surgical Gown**	**Glove**	**Gauze**	**Cloth for Operation**	**Surgical Tool**	**Waste**	**Patient Blood**
Maximum	0.58	0.56	1.07	0.62	0.20	0.13	0.40
Minimum	0.00	0.00	0.01	0.00	0.00	0.00	0.03
Average	0.05	0.11	0.27	0.09	0.02	0.00	0.18
BG				0.05			
Max. / BG	10.9	10.5	20.0	11.6	3.8	2.3	7.5

Stratmann *et al.* [11] measured the mean radiation exposure rate to the surgeon's trunk in breast sentinel node biopsies. The dose rate was 1.33 mrem/h which was nearly equal to 13.3 μSv/h at an injection dose of 0.7~1.1 mCi, at a distance of 0.3 m from the breast injection site at 1.5~3 h after RN injection. If their conditions are applied to our data, the $\dot{H}_{b,1.5}$ radiation dose rate to the surgeon's trunk was 4.6 μSv/h (injection dose, 1.0 mCi; distance from the patient, 0.3 m; and time after RN injection, 1.5 h), which was estimated from the $\dot{H}_{b,0}$ shown in Table **4**, by applying a physical decay constant to ^{99m}Tc and an interpolation over distance. Our dose rate was averaged over four patient directions and was significantly lower than the dose rate reported by Stratmann *et al.* [11], the difference can probably attributed to methodology in that Stratmann *et al.* measured the radiation dose only in the direction directly towards the injection site. These authors also measured the dose rate to a scrub nurse trunk during breast sentinel node biopsy as 0.15 mrem (nearly equal to 1.5 μSv/h; injection dose, 0.7~1.1 mCi; distance from the breast injection site, 3.0 m; and time after RN injection, 1.5–3 h). Although a direct comparison cannot be performed because we did not measure the dose at a distance of 3 m, the dose is 0.5 μSv/h under the following conditions: injection dose, 1.0 mCi; distance from the patient, 1.5 m; and time after RN injection, 1.5 h. This dose rate was about one-third of the rate reported by Stratmann *et al.* [11], even if a patient was at a half distance by 1.5 mm of Stratmann's report by 3 mm even though the measurement was performed at half the distance to the patient, 1.5m, relative to the Stratmann *et al.* measurement at 3m. In the measurement of extremely low dose rates, we should expect a large uncertainty as was observed in the difference between these two dose rates.

Glass *et al.* [10] concluded that the radiation exposure to medical personnel from a submillicurie dose of ^{99m}Tc in a SNNS patient would be so low that radiation monitoring with personal dosimeters may not be required. Our results are consistent with this conclusion. However, monitoring could be considered important as a redundant safety check on radiation exposure and thus also serve to allay surgical worker's anxiety concerning overexposure.

A maximum skin dose of 100 μSv per SNNS session was recorded in measurements using glass ring dosimeters attached to the surgeon and assistant surgeons' hands. One hundred μSv is the minimum dose value that can be measured using a glass ring dosimeter with high reliability and is 1/5000th of the annual skin dose limit of 500 mSv for workers in a radiation environment. Hence, the radiation dose to the surgical worker's hands is irrelevant with regards to any concerns regarding radiation exposure. The mean dose to the hand of the surgeon in our measurements was probably lower than the maximum dose of 10.2 ± 5.8 mrem (range, 0–57 mrem; injection dose, 1 mCi; and time after injection, 3.5 h) per SNNS recommended in the guidelines published by Miner *et al.* [14]. Although accurately measuring radiation dose using the ring type glass dosimeter is difficult, which could be the main reason for this observed difference, the time interval of 23.6 h from tracer injection to SNNS initiation in our method was significantly longer than that of 3.5h in the guidelines [14]. If the initial injection activities were equal to each other, we would expect the Miner *et al.* dose to be five times our dose; indeed, their maximum dose of 57 mrem (nearly equal to 570 μSv) was equivalent to about five times our maximum radiation dose of 100 μSv.

In the investigations of radioactive contamination, the higher sensitivity of the pocket scintillation survey meter enabled us to measure radiation contamination on all of the surgical equipment used for SNNS. The maximum radiation dose rate from these radiocontaminants was 1.07 Sv/h from bloody gauze, and this dose rate corresponded to about 20 times that of the mean BG count of 0.05 Sv/h. The radiation dose intensity was quite low, far too low to be a serious safety concern for surgical workers. However, these contaminants should be regarded as unsealed radioactive materials and they must thus be appropriately processed as radioactive waste and stored in a designated secure location until the radioactivity falls below the regulatory safety limit. A suitable cooling-off period for the radioactive contaminations should be in excess of 2 days to reduce the ^{99m}Tc activity by at least a factor of 256.

Higher dose rates than those measured on surgical equipment were observed in extracted tissue specimens measured at a distance of 1.5 cm from these specimen. With some of the specimens the pocket scintillation survey meter displayed an overflow sign on the liquid crystal screen indicating a dose rate in excess of 20 μSv/h. At a distance of 10 cm from the specimens a maximum dose rate of 15.3 μSv/h was recorded. The extracted specimens consisted mainly of mammary glands invaded by tumor and the sentinel lymph nodes related to these glands. Most of these specimens contained a some detectable amount of radioactivity; therefore, for radiation protection and contamination control the careful handling of specimens extracted during SNNS should be required in conformance with established guidelines and regulations. The excised glands and nodes were immediately transported to an inspection room for pathological diagnosis. There the still radioactive tissue specimens are thin sliced and observed under an optical microscope. Pathologists who perform this procedure may be concerned about their radiation exposure and radioactive contamination. Recommendations for the safe handling of such tissues have already been published [15]. However, since the specimens which are removed from patients during SNNS have a certain amount of radioactivity, as is the case for the surgical equipment, they must be handled as radioactive materials in a similar manner to the radiocontaminated surgical equipment. Radiation management of the specimens including safe storage should be performed until the radioactive concentration falls below 74 Bq/g as specified in the guidelines or below 100 Bq/g in conformance with the Basic Safety Standards (BSS) international exemption level for ^{99m}Tc. If the initial radioactive concentration of the specimens is higher than 300 kBq/g, then more than three days are required for the radioactivity to decrease to the target activity level.

Although the wiping test had sufficient sensitivity to detect radioactive contamination on the floor of the operating room, in our study none was detected using this method. However, radioactive contamination on the floors of operating rooms used for SNNS should not be disregarded. It would be highly advisable to investigate contamination of the operation room using a high sensitivity gamma ray survey meter at the end of each SNNS session, to facilitate complete radiation management.

CONCLUSION

In SNNS, the radiation exposure doses to surgical workers were found to be very low. It is not possible that their radiation doses could exceed the occupational dose limits given in ICRP Publication 103. Therefore, it may not be necessary to take precautions such as the wearing of glass ring dosimeters with regards to radiation exposure from ^{99m}Tc. However, because radioactive contaminants are sometimes found in the materials used in SNNS the waste much be carefully handled and if hot materials are found, they should be stored separately until the radioactivity decreases to BG levels.

CONFLICT OF INTEREST

None declared.

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