

ARTICLE

Exposure for medical staff from patients during/after ^{89}Sr therapySumi Yokoyama^{a*}, Hiroshi Toyama^a, Kaoru Kikukawa^a, Seiichiro Ota^a, Kazuhiro Katada^a,
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Personal dose equivalent, $H_p(10)$ and $H_p(0.07)$ doses were measured using an ionization chamber and personal electric dosimeters to estimate the exposure dose for medical staff members and carers as received from ^{89}Sr therapy patients. The $H_p(10)$ for medical workers was measured using personal dosimeters and was found to be $<1 \mu\text{Sv}$ during the measurement period. $H_p(0.07)$ for medical workers did not exceed $5 \mu\text{Sv}$ per case during routine work, although the dose on the patient's skin surface was about 20 times that on the medical staff. To investigate the contribution of electrons to the measured dose, the dose on the patient's skin surface as obtained from uniformly distributed ^{89}Sr in a similar MIRD phantom was calculated using EGS5 code. The peak energy of the incident photons was approximately 0.6 MeV. The estimated $H_p(10)$ and $H_p(0.07)$ doses for the medical staff were 0.43 and $91 \mu\text{Sv/h}$, respectively. The contribution of electrons to the calculated $H_p(0.07)$ was approximately 200 times that of photons. Thus, the high $H_p(0.07)$ for medical staff is attributed to the strong contribution of electrons.

Keywords: ^{89}Sr for bone metastases; medical staff; $H_p(0.07)$; EGS5; dose distribution

1. Introduction

^{89}Sr is administered to patients with painful bony metastases [1]. The injected amount is 2 MBq/kg for an adult. This activity is sufficiently low to meet Japanese guidelines for releasing ^{89}Sr therapy patients from the hospital [2]. Thus, patients can return home soon enough.

^{89}Sr is a beta-emitter with energies of <1.5 MeV and half-life of 50.5 days [3]. ^{89}Sr injected in the blood is distributed not only in the bone but also throughout the body after several days, as estimated by calculations using Dose and Risk Calculation (DCAL) software (see **Figure 1**) [4]. The effective dose for a male adult in ^{89}Sr therapy is estimated to be about 3 mSv/MBq [5,6]. However, the dose for the public is negligible because most electrons emitted from ^{89}Sr are absorbed in the patient's body and low-energy bremsstrahlung radiation is emitted outside the body, as observed by SPECT [7].

The effective dose and skin dose received by the medical staff and carers from ^{89}Sr in a patient's body are also very low. However, the actual levels of $H_p(10)$ and $H_p(0.07)$ for medical staff and carers who approach these patients are not clear. These doses may be raised because of the influence of electrons and bremsstrahlung radiation emitted from a patient's skin surface.

In this study, the exposure dose of electrons to

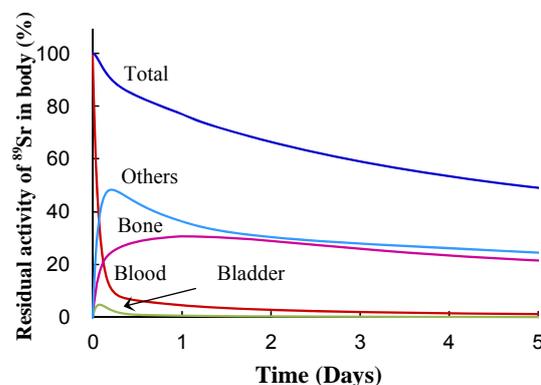


Figure 1. Distribution of ^{89}Sr in the body of an adult for direct uptake to blood as calculated by DCAL.

medical staff such as doctors, nurses, and radiological technologists from an ^{89}Sr therapy patient was measured using an ionization chamber (IC) or personal electrical dosimeter. The effects of the measurement height, measurement detection, and elapsed time on the dose for medical staff were examined in the measurement results.

To estimate the contributions of electrons and photons to the skin dose of the medical staff as received from an ^{89}Sr source inside a patient, the energy fluences of incident electrons and photons in the region of interest on the body surface of a similar MIRD phantom

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were also calculated by the Monte Carlo simulation code EGS5. These calculation results were compared with the measured dose on a surface of a patient's body.

2. Measurement and calculation methods

2.1. Measurement methods for medical staff's dose

Figure 2 shows a flowchart for administration of ⁸⁹Sr-labeled strontium chloride to a patient.

The doses for a doctor, nurse, and radiological technologist involved in the administration of ⁸⁹Sr were measured using personal dosimeters (DOSE³, Chiyoda Technol Co.) during the treatment. After 1 h of bed rest by the patient and 4 days after discharge when the patient visits the hospital to get checked for the accumulation of ⁸⁹Sr, the radiological technologist usually measures H_p(10) at the height of the xiphoid process (level 1) using an IC (ICS-315, ALOKA). In this study, the doses at the heights of the xiphoid process (level 1), abdomen (level 2), and bladder (level 3) of the patients were measured using the IC at that time to investigate the effects of the accumulation spots of the dose on a surrounding medical staff. The dose was also measured at the front, back, and right and left sides of the patients at these heights, as shown in **Figure 3**. These objectives are to investigate the dose of the medical staff when they are close to medical staff.

The measurements were performed for seven patients aged between 39 and 77 years. **Table 1** presents a representative body mass index (BMI), administration activity, and dose accumulation place for patients.

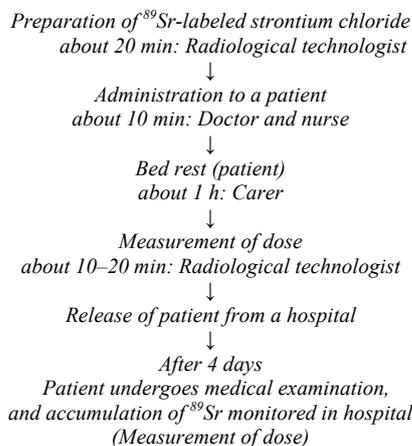


Figure 2. Flowchart of examination for administration of ⁸⁹Sr-labeled strontium chloride to a patient at a hospital.

2.2. Development of mathematical model

A similar simplified MIRD phantom used as a radiation source was developed to estimate the dose for the medical staff as received from the patient's entire body by the Monte Carlo simulation code EGS5. This phantom comprised a head, a trunk, arms, a skull, a spine, legs, ribs, a clavicle, arm bones, and leg bones. The body and tissues had the same size and density as

the MIRD phantom [8]. However, lungs were not included in this phantom as a preliminary study because it was considered that only existing ⁸⁹Sr in an extremely surface soft tissue contributes to the energy spectra. The thickness of the skin, which had the same density as the soft tissue, was set as 0.02 cm.

In this calculation, 100 MBq of ⁸⁹Sr was distributed uniformly over the entire body under the skin of the phantom. The region of interest (ROI), which had dimensions of 10 cm Φ \times 1 cm thickness, lay at the center of the front trunk surface of the phantom. The dose on the phantom's surface was calculated using the dose conversion coefficients in ICRP Publication 74 and the energy spectrum per particle fluence in the ROI. **Figure 4** shows the geometry for the similar simplified MIRD phantom. The calculated results were compared with the measured results converted to the value when 100 MBq of ⁸⁹Sr is absorbed in the body.

Table 1. Representative information of patients.

Sex	BMI	Activity	Accumulation spots
M	16.9	94.5 Bq	right femoral fracture, costa, xiphoid process, etc.
F	21.1	112 Bq	left acetabulum, lumbar spine, sacral spine
F	18.8	88 Bq	sacral spine, pubis, right ischium, lumbar spine
F	19.5	74 Bq	spine, pelvis, scapula

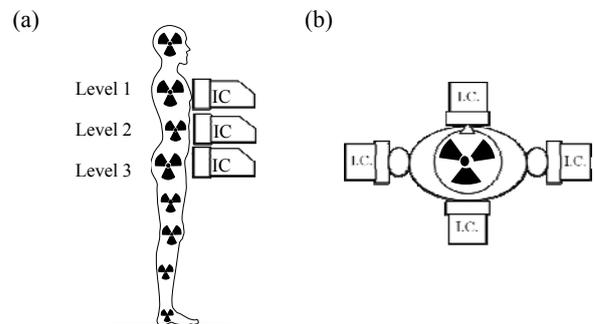


Figure 3. Setting the position of the ionization chamber (IC): (a) vertical measurement position of IC; (b) horizontal measurement position of IC.

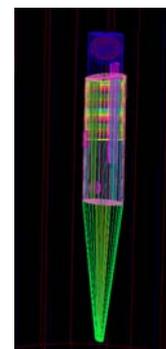


Figure 4. Geometry of a similar simplified MIRD phantom.

3. Results and discussion

3.1. Dose measured on patient surface

Figures 5 and 6 show the average $H_p(10)/h$ measured using the IC 1 h and 4 days after administration of ^{89}Sr -labeled strontium chloride to blood at each height of the patient body surface. All measured $H_p(10)/h$ on a patient's body surface were less than $1 \mu\text{Sv}/h$. The relative standard deviations (RSDs) were $<70\%$ of the mean value at the bladder height on the front side, because of the large difference in the accumulation rates of ^{89}Sr among individuals.

One hour after the injection of ^{89}Sr , the highest dose was measured at the height of the abdomen. The mean value of the front, left, right, and back was $0.79 \mu\text{Sv}/h$. The measured dose at the xiphoid process height was not very different from that measured at the abdomen height. The doses of the front and back sides were high. The RSD was about 20% of the mean value.

Four days after injection, the dose rates measured at most points were lower than those measured after 1 h. The dose rate on the front side of the abdomen height after 4 days was about 70% that after 1 h. This is because half of ^{89}Sr still remained in not only the bone but also the entire body, as shown in Figure 1.

Table 2 lists the ratio of decrease in $H_p(10)/h$ for patients with different accumulation points 4 days after the injection of ^{89}Sr to that after 1 h; these values were taken from the front of a patient's body surface at the xiphoid process height. The ratios of decrease in the dose measured at the front and left sides of the body were slower than those measured on the right and back sides. No clear difference was observed in the dose at a particular accumulation point in the case of differences in the uptake of radionuclides from the body sizes among individuals; this is discussed below.

Figure 7 shows the relationship between the dose rate ($H_p(10)/h$), the patient's injected amount and the BMI value. The dose rate decreased with increasing BMI. The correlation factor between $H_p(10)$ and the BMI was 0.58. This indicates that the injected ^{89}Sr spreads out and that individuals with higher BMI have higher absorption rates for the radiation. The dose for the individual with the highest BMI was twice that of the individual with the lowest BMI.

3.2. Measured dose for medical staff during ^{89}Sr therapy operation

Table 3 presents the dose equivalent for medical staff such as a doctor, nurse, and radiological technologist ($H_p(10)$ and $H_p(0.07)$) as measured using personal dosimeters. $H_p(10)$ for the medical staff was lower than $1 \mu\text{Sv}$ during treatment. $H_p(0.07)$ measured on the body surfaces of the doctors and nurses was lower than $5 \mu\text{Sv}/\text{episode}$, although the dose measured on the patient's skin surface was 32–267 $\mu\text{Sv}/\text{case}$. The dose for radiological technologists was 3 μSv during the ^{89}Sr injection preparation period and 10 μSv during the dose

measurement period. The measurement period was kept longer than usual in this study because the dose was measured in detail to examine its distribution in patients. Thus, the dose for the radiological technologist would be smaller and similar to that of the doctor and nurse in routine work.

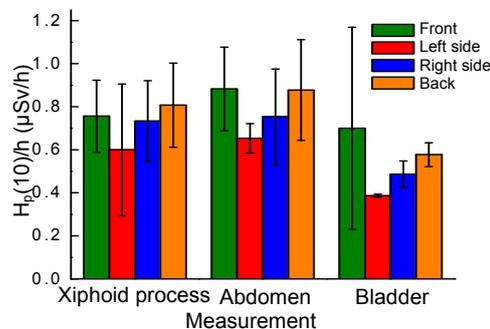


Figure 5. Effective dose equivalent rate $H_p(10)$ as measured using the IC at each height of a patient's body surface 1 h after administration of ^{89}Sr .

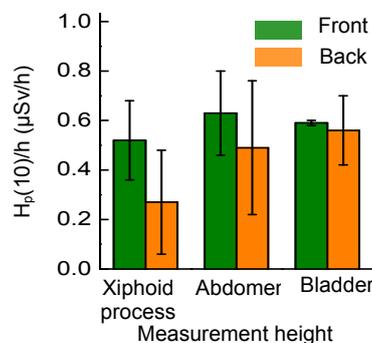


Figure 6. Effective dose equivalent rate $H_p(10)/h$ on the patient body surface as measured by the IC 4 days after administration of ^{89}Sr .

Table 2. Ratio of decrease in $H_p(10)$ 4 days after the injection of ^{89}Sr to that after 1 h and the accumulation points.

No.	Rate of decrease in dose after 4 d/after 1 h				Main accumulation place
	Front	Left	Right	Back	
1	0.63	0.6	0.20	0.33	lumbar spine, ischium
2	0.49	0.73	0.33	0.23	spine, pelvis, scapula

Measurement point: front side of patient's body at the xiphoid process height

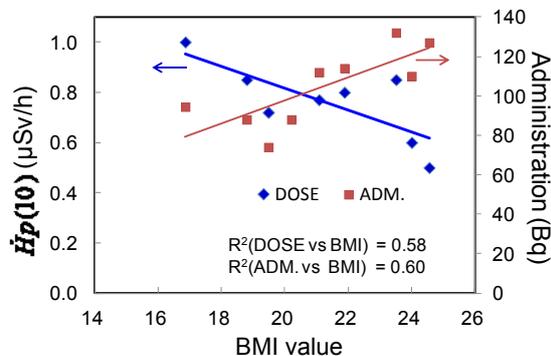


Figure 7. Relationship between dose rate $H_p(10)/h$, the injected amount and body mass index (BMI) value.

3.3. Calculation of dose for similar MIRD phantom

The energy spectrum of particles deposited in the ROI set at the front of the phantom's body surface was calculated by EGS5 when the injected ⁸⁹Sr was uniformly distributed over the entire body. The contribution of particles emitted from ⁸⁹Sr in the head and leg to the deposition energy in the ROI located at the center of phantom's trunk was negligible. The incident electrons per occurring electron fluence had a broad peak, as shown in **Figure 8**. The energy spectrum of photons had a peak at 0.06 MeV. This distribution was similar to the experimental results of Ota et al. [7].

Table 4 presents H_p(10)/h and H_p(0.07)/h calculated from the energy spectrum shown in Figure 8. H_p(10)/h was derived from only photons. The contribution of photons to H_p(0.07)/h was small even though the number of incident photons in the ROI was an order of magnitude higher than that of electrons.

The calculated and measured dose rates are listed in Table 4. The calculated results were within the SD of the measured results. Thus, the calculated results corresponded to the measured ones relatively well, although the differences among individuals were large in the measured results, as mentioned above. The calculated H_p(0.07) was reduced to one-sixth when the phantom was covered by a 1 mm thick cellulose cloth.

Table 3. H_p(10) and H_p(0.07) measured using the personal semiconductor dosimeter.

	H _p (10) [μSv]	H _p (0.07) [μSv]
Doctor	n/d*	4
Nurse	n/d*	2
Radiological technologist	n/d*	13
		preparation (20 min): 3 measurement (20 min): 10
Patients	1-3	(1 h-1 h 30 min): 32-267

* n/d: Not detectable (<1 μSv)

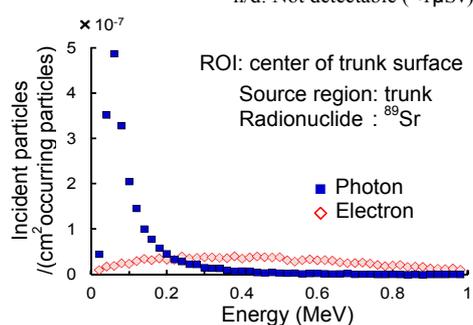


Figure 8. Energy fluence of incident particles in the ROI.

4. Conclusion

The doses H_p(10) and H_p(0.07) were measured 1 h and 4 days after the injection of ⁸⁹Sr to estimate the dose for medical staff involved in ⁸⁹Sr-therapy-related-work, such as a doctor, nurse, radiological technologist and carers.

The doses for the medical staff as received from the ⁸⁹Sr therapy patients and the contributions of electrons

and photons to the dose were calculated by EGS5 using a similar MIRD phantom.

The doses measured on the front sides of the abdomen and xiphoid process heights of the patient did not show much difference and were higher than that measured at the bladder height. Among the doses measured at the front, left, right, and back sides of the patient, the doses at the front tended to be high. Thus, the dose could be measured on the patient's front surface of the abdomen or xiphoid process height for obtaining a reasonable and conservative estimate of the dose for medical staff and carers. H_p(10) measured at the patient's body surface and for the medical staff was lower than 10 μSv during treatment, although H_p(0.07) at the patient's skin surface was a few orders of magnitude higher.

The calculated H_p(10) and H_p(0.07) at the phantom surface agreed with the measured results when the source of ⁸⁹Sr existed in the similar MIRD phantom. The calculated and measured H_p(0.07) were higher than calculated and measured H_p(10). The calculated energy fluence of the electrons was not as high as that of the photons. However, the dose calculated from these fluences suggests that the contribution of electrons to H_p(0.07) at the patient's surface is 200 times that of photons.

Table 4. Calculated and measured $\dot{H}_p(10)$ and $\dot{H}_p(0.07)$.

	$\dot{H}_p(10)$ [μSv/h]	$\dot{H}_p(0.07)$ [μSv/h]	Administrated activity [MBq]
Calculation			
Electron	0	91	100
Photon	0.43	0.46	
Measurement*	0.84 ± 0.52**	125 ± 55**	Convert into 100 MBq
	0.80 ± 0.69***	—	

* Measurement point is at the front of abdomen.

** The dose is measured by the semiconductor detector.

*** The dose is measured by the ionization chamber. This is shown as a reference value.

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