Evaluation of the Entrance Skin Dose in Overlapping Irradiation Fields Using an Area Dosimeter during Radiofrequency Catheter Ablation

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Abstract
Purpose: We aimed to evaluate the entrance skin dose (ESD) during radiofrequency catheter ablation (RFCA).
Methods: The X-ray fluoroscopic mode (70 kV, 7.5 p/s, 13.0 × 13.0 cm) was evaluated at C-arm angles of 45° left anterior oblique and 35° right anterior oblique. The bed height was raised by 4 to 8 cm from the bed base-point position (BP, 0 cm). Fluoroglass dosimeters were placed in three lines at 5-cm intervals on the surface of the phantom. The maximum skin dose conversion factors were calculated as the ratio of the calculated and the actual maximum skin doses.
Results: At heights of 6 and 8 cm, calculated ESDs had peak values of 93.0 ± 0.2 and 74.5 ± 2.7 mGy, respectively, whereas the actual maximum skin doses were in the range of 47.4 ± 0.2 to 59.5 ± 0.2 mGy. The maximum skin dose conversion factors were 0.79, 0.87, 0.53, 0.64, and 0.72 at bed heights of 0, 2, 4, 6, and 8 cm from the BP, respectively.
Conclusion: A maximum skin dose conversion factor should be taken into consideration when determining the maximum skin dose in overlapping irradiation fields.

Article Information

Key words:
radiofrequency catheter ablation, skin dose, overlapping irradiation field, interventional radiology

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1. Background

Arrhythmias require integrative treatment because the treatment varies depending on the patient and the long-term prognosis.¹ Radiofrequency catheter ablation (RFCA) has become a more popular method for the treatment of arrhythmias since 1990.² However, with the development of micro-catheters and the increase in treatable diseases, RFCA procedures have become complicated, and the time taken for examinations and fluoroscopy has increased. Thus, dermatopathy caused by interventional radiology (IR) becomes a concern as the exposure dose to the patient increases.

To avoid this complication, “Avoidance of Radiation Injuries from Medical Interventional Procedures” was published in the International Commission of Radiological Protection (ICRP) Publication 85.

Furthermore, there are some case reports of dermatopathy associated with IR.³–⁷ There are multiple reasons for the development of this condition, for example, increased exposure due to the convergence of the X-ray incidence plane as a result of performing the procedure with a fixed irradiation field and C-arm angles. Another reason may be the overlap of the two irradiation fields on the patient’s skin surface due to the bed height. A number of studies evaluating the
entrance skin dose (ESD) of overlapping irradiation fields using the area dosimeter have been conducted to date.8−10

Clinically, the ESD is roughly estimated using the area detector of an angiography system, even in the overlapping irradiation field. However, since the X-ray incidence is oblique and the dose distribution is biased, overestimation can be expected.

In this study, we reported a comparison between the ESD calculated from an area detector (calculated ESD) and the ESD measured by Fluoroglass dosimeters (FGD) (actual ESD) to evaluate the ESD in the overlapping irradiation field during RFCA. Conversion factors to easily estimate the actual maximum skin dose from the dose of an area detector and the bed height were calculated.

1. Materials and methods

2.1. Fluoroscopy

All procedures were performed using an AXIOM Artis dBA Twin (Siemens Healthcare Japan Corporation, Tokyo, Japan). The X-ray fluoroscopic conditions included a tube voltage of 70 kV, a fluoroscopic pulse rate of 7.5 p/s, and an irradiated area of 13.0 × 13.0 cm. The X-ray source to image intensifier distance was set at 104 cm, and the X-ray tube focal spot to dosimeter distance was 60 cm. The C-arm angles were set at 45° left anterior oblique (LAO) and 35° right anterior oblique (RAO) angles. The interventional reference point (IVRP) is the reference point for air kerma on an area dosimeter, as established by the International Electrotechnical Commission (IEC). A bed height of 1 cm below the IVRP was set as the base-point position (BP) and was defined as 0 cm. Each measurement was obtained three times at a dose rate of 3-min exposures.

2.2. Estimation of ESD from an area detector

The ESD was calculated as the air kerma indicated using the area dosimeter (Aa) multiplied by a correction factor (fa). This value was used for assessing the absorption by the bed and backscatter X-ray (Eq. 1).

\[
ESD = A_a \times f_a \quad \cdots (1)
\]

A 20-cm thick polymethylmethacrylate sheet (PMMA; length, 30 cm; width, 30 cm) and a thimble chamber (model 9010; detecting element, 10 × 5–6 cc) were used as the reference dosimeter. The bed height was raised by 2 cm increments (0, 2, 4, 6, and 8 cm) from the BP. The fa was calculated as the ratio of the actual value of the reference dosimeter to the measurements of the area dosimeter (Eq. 2).

\[
f_a = K \times \frac{(\mu_{en}/\rho)_{tissue}}{(\mu_{en}/\rho)_{air}} \cdot \frac{DAP}{A} \quad \cdots (2)
\]

*Readings on the reference dosimeter (mGy): K
Irradiation area (m²): A
Indicated value on the area dosimeter (µGy/m²): DAP
Tissue dose conversion factor (the ratio of mass energy absorption coefficient of the skin to air):

\[
(\mu_{en}/\rho)_{tissue}/(\mu_{en}/\rho)_{air}
\]

2.3. Measurement of overlapping irradiation fields

The measurement of overlapping irradiation fields was conducted using a photostimulable phosphor image plate (14 × 17 in) attached to the surface of the bed. The percentage of each overlapping irradiation field was evaluated at 1-cm increases in bed height from the BP. The percentage of the overlapping irradiation field at each bed height was determined by calculating the trapezoidal area (Ts) and the overlapped trapezoidal area (Ts0), under the assumption that the two irradiation fields had equal areas. The bed height and percentages of overlapping areas are shown (Eq. 3).

\[
\text{Percentage of overlapping areas (\%)} = \frac{(Ts_0/Ts)}{\times 100} \quad \cdots (3)
\]

2.4. Fluoroglass dosimetry for ESD with a water phantom

Fluoroglass dosimeters (FGD) (Dose Ace1000; Chiyoda Technol Corporation, Tokyo, Japan) were placed on three lines (8 dosimeters each on lines # 1, # 2, and # 3) at 5-cm intervals on the surface of a water

![Fig. 1](image-url) Arrangement of the FGD in the body (water) phantom.
(a) The FGD were placed on three lines at equal intervals on the body phantom surface.
(b) Left anterior view of the body phantom.
phantom (JIS Z4915–1974; Miwa Medical Care Electric Co., Ltd, Nagoya, Japan, Fig. 1, 2). The bed height was raised by 2 cm at a time (0, 2, 4, 6, and 8 cm) from the BP, and when overlapping fields were thought to exist, the dosimeter was calibrated beforehand to avoid counting scattered radiation.

2.5. Maximum skin dose conversion factor

With respect to the maximum skin dose in the overlapping irradiation field, the ESD obtained from the readings on the area dosimeter in the 35° RAO and 45° LAO were set as $A_{35\text{ RAO}}$ and $A_{45\text{ LAO}}$, and added. According to the overlapping percentage, this value was then multiplied by the maximum skin dose conversion factor ($f_i$) to determine the maximum skin dose in the overlapping irradiation field (Eq. 4).

$$\text{Maximum skin dose in the overlapping}$$
$$\text{irradiation field} = (A_{35\text{ RAO}} + A_{45\text{ LAO}}) \times f \times f_i \ldots (4)$$

3. Results

3.1. The distribution of calculated ESD

The ESD was obtained by an $A$, ratio of 1.23, as determined by the readings of the reference dosimeter (58.8 ± 0.3 mGy), the irradiation area (0.0156 m²), and indicated value on the area dosimeter (74.5 ± 0.4 μGy/m²). The backscatter phantom and the dose absorbed by the bed were also taken into account. When the bed was moved closer to the image intensifier, 4 cm from the BP, the fields started to overlap. The percentage of overlap at bed heights of 4, 5, 6, 7, and 8 cm were 13.0%, 19.5%, 25.2%, 43.5%, and 51.8%, respectively (Fig. 3).

The calculated ESD by the area detector peaked in the area center and had a calculated maximum skin dose of 105.1 ± 0.4 mGy at 4 cm from the BP. This value was almost twice higher than that at 0 and 2 cm, 60.3 ± 0.1 and 61.1 ± 0.5 mGy, respectively. At 6 and 8 cm heights, calculated ESDs had peaks of 93.0 ± 0.2 and 74.5 ± 2.7 mGy, respectively (Fig. 4 (a-d)).

3.2. Actual ESD from the FGD

The dose profiles at 45° LAO and 35° RAO showed a tendency for a higher dose on the X-ray tube side and a lower dose inside. In addition, the maximum dose measured by the FGD indicated a dose that was approximately 1.3 times higher for the 45° LAO than that for the 35° RAO. Furthermore, with bed heights with partial overlapping dose (bed height: 4–8 cm), the maximum doses did not overlap.

The actual ESDs, as determined by Eq. 1, were much lower than the calculated ESDs. The distributions of the actual ESDs were flat at the height of 4 cm, and the actual maximum skin doses were much lower than the calculated maximum skin doses at each bed height (52.6%–86.9%). The actual maximum skin doses were in the range of 47.4 ± 0.2 to 59.5 ± 0.2 mGy (Fig. 5 (a-c)).

3.3. Maximum skin dose conversion factor

The maximum skin dose conversion factors were calculated as the ratio of the calculated and the actual

<table>
<thead>
<tr>
<th>The height of the bed (cm)</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of overlapping area (%)</td>
<td>13.0</td>
<td>19.5</td>
<td>25.2</td>
<td>43.5</td>
<td>51.8</td>
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Fig. 3 Relationship between the height of the bed from BP and the overlapping irradiation fields.
Skin dose in overlapping irradiation

Fig. 4 Radiation dose from an area detector and calculated ESD profile by the height of the bed. The height is (a) 0 cm (BP), (b) 4 cm, (c) 6 cm, and (d) 8 cm.

Fig. 5 Comparison between actual ESD and calculated ESD in the bed position of radiation field. The height is (a) 4 cm, (b) 6 cm, and (c) 8 cm.
maximum skin doses (Table 1). In cases where the irradiation fields did not overlap, the higher value was selected as the calculated maximum skin dose. When the bed heights were between 0 and 2 cm, the calculated maximum skin doses were chosen from the ESD at 45° LAO. The maximum skin dose conversion factors were 0.79, 0.87, 0.53, 0.64, and 0.72 at bed heights of 0, 2, 4, 6, and 8 cm from the BP, respectively. These measurements indicated that the maximum skin dose at the overlapping percentages of 51.8%, 25.2%, and 13.0% were 28.2%, 36.0%, and 47.4%, respectively, which were lower than those obtained by the calculated method based on data obtained using the area detector.

4. Discussion

At bed heights of 4, 6, and 8 cm, the overlapping irradiation fields were 13.0%, 25.2%, and 51.8%, respectively. The comparison between the actual ESD and the calculated ESD revealed that the maximum skin doses measured using FGD were approximately 30%–50%, i.e., much lower than those using the calculated method based on an area detector. The calculation method was simply adding the ESD in the overlapping irradiation field to the correction factors represented in Eq. 1 and 2. However, since the overlapping field on the center of patient’s body was much bigger than that on the back surface of the body, the maximum skin dose could be overestimated using the area detector with PMMA and thimble chamber corrections.

In general, raising the bed decreases the skin dose and leads to a reduction in the exposure dose in angiographic examinations. However, performing an examination by raising the bed could cause an overlap of the irradiation fields due to the thickness of the patient’s body, and thus, the physician’s workability during RFCA could worsen. From our study, the maximum skin dose at each height was similar, ranging from 47.4 to 59.4 mGy. On the other hand, the calculated maximum skin dose ranged from 60.3 to 105.1 mGy. These results showed that a higher bed position could indicate a higher maximum skin dose in the overlapping irradiation field.11

We reviewed whether the ESD during RFCA exams could be estimated with an area dosimeter placed in the device.12 Conversion factors varied based on the bed height and enabled a calculation of maximum skin dose using information from the area detector. This estimation is useful in the clinical setting and allows physicians to quickly estimate the dose. However, the environment and the conditions of the angiographic room, such as the device, X-ray incidence angles, and size of the visual field can differ in each facility.13,14 Our conversion factors can be used only in our institution or in one with similar conditions. The percentages of the overlapping area and correction factors are also expected to vary; therefore, it is necessary to manage the appropriate exposure dose using different correction factors for each device.

5. Conclusion

The calculated ESD using area detectors showed was higher than the actual ESD under the experimental conditions, particularly using a biplane X-ray system for RFCA. A maximum skin dose conversion factor should be taken into consideration when determining the maximum skin dose in overlapping irradiation fields.

Acknowledgment

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Conflict of interest

The authors declare that they have no conflict of interest.

References

5. Rosenthal LS, Mahesh M, Beck TJ, et al. Predictors of