Radiation Exposure of Interventional Radiologists during Computed Tomography Fluoroscopy-Guided Percutaneous Cryoablation

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Abstract

Purpose: The principal aim of this study was to evaluate radiation exposure of interventionalists during computed tomography (CT) fluoroscopy-guided percutaneous cryoablation (PCA) using radiophotoluminescent glass dosimeters (RPLDs). The radioprotective effects of safety glasses and lead apron were also evaluated.

Materials and Methods: Radiation exposure of interventionalists during 46 CT fluoroscopy-guided PCA procedures was evaluated. Entrance surface dose (ESD) was measured using RPLDs on multiple sites: five sites, representing eye lens exposure; five sites, representing body exposure; and four sites, representing skin exposure. The ESD values on multiple sites were compared between different PCA procedures (renal, liver, and bone).

Results: The mean ESD on the X-ray-side hand exhibited the highest value (358.8 μGy). Regarding evaluation sites representing exposure to the eye lens, the highest ESD inside the radiation protective glasses was detected on the X-ray-side cheek (167.1 μGy). Most ESD values among multiple sites (10/14) were linearly correlated with CT fluoroscopy time. Among them, the ESD values measured during renal and liver PCA were relatively higher than those measured during bone PCA, especially on the chest area outside the lead apron, and on the X-ray tube-side elbow and hand during renal and bone PCA. Radioprotective effects of safety glasses and lead apron ranged from 44.6 to 50.6% and from 30.2 to 79.6%, respectively, on each evaluation site.

Conclusion: The site with the highest radiation exposure on interventionalists during CT fluoroscopy-guided PCA was the X-ray tube-side hand. Radiation exposure of interventionalists was at acceptable levels and consistent with the recommended dose limits.

Key words: Cryoablation, Radiation exposure, Computed tomography fluoroscopy

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Introduction

Radiofrequency ablation (RFA) and percutaneous cryoablation (PCA) use thermal energy to destroy tumors, including liver, lung, kidney, and musculoskeletal neoplasms [1-6]. Computed tomography (CT) fluoroscopy is frequently used to guide thermal ablation procedures. CT fluoroscopy enables nearly real-time image guidance with geometric accuracy without significant interfering artifacts, resulting in
safe, effective, and rapid interventional radiology (IR) procedures. Although there are reports of high radiation exposure of interventional radiologists (interventionalists), when CT fluoroscopy guidance is used [7-10], they specifically refer to CT-guided biopsy or drainage procedures. To our knowledge, there are only two articles investigating radiation exposure of interventionalists due to CT fluoroscopy-guided PCA [11-12]. Stewart et al. reported that the estimated interventionalists’ radiation exposure was 0.0503 mGy/min during CT fluoroscopy-guided renal PCA [11]. Matsui et al. compared the direct interventionalists’ radiation dose between CT fluoroscopy-guided renal PCA and lung RFA measured by electric dosimeters (for the effective dose) and thermoluminescent dosimeter rings (for the equivalent dose on the finger skin) [12]. However, there is no published study directly measuring radiation dose on multiple sites (such as the eye, hand, neck, chest and abdomen) to evaluate interventionalists’ radiation exposure during CT fluoroscopy-guided PCA.

The aims of this study were to evaluate radiation exposure of interventionalists at multiple sites during CT fluoroscopy-guided PCA using radiophotoluminescent glass dosimeters (RPLDs), and to estimate potential differences in exposure among different therapeutic PCA applications. The radioprotective effects of safety glasses and lead apron were also evaluated.

Materials and Methods

This study was approved by our institutional review board. Informed consent was obtained from all interventionalists who participated in this study, but was not required for patients.

PCA procedures and interventionalists

From September 2014 to March 2016, radiation exposure of interventionalists was evaluated during 46 consecutive CT fluoroscopy-guided PCA procedures (32 renal lesions, 8 liver lesions, 6 bone lesions). Two interventionalists who performed the CT fluoroscopy-guided procedures were board-certified with 11-16 years of experience.

Procedure of CT fluoroscopy-guided PCA

The CT fluoroscopy system used in all procedures was SOMATOM Sensation Open ICT (Siemens Healthineers; Munich, Germany) (120 kV and 20 mAs). The rotation time was 0.5 s, during which three consecutive images of 4.8 mm slice thickness were obtained. For the treatment of osteoid osteoma, three consecutive images of 2.4 mm slice thickness were obtained, as the tumor size of an osteoid osteoma is usually less than 10 mm. Tube voltage of the CT helical scan was always at 120 kV with 100 quality reference mAs. The pitch factor was 0.7 and the Kernel was B41f. The cryoablation equipment used was CryoHit (Galil Medical, MN, USA /Hitachi, Tokyo, Japan).

After CT positioning and local anesthesia, a cryoneedle (IceRod and/or IceSeed; Galil Medical) was inserted in the target lesion under intermittent CT fluoroscopy guidance. CT fluoroscopy was activated by interventionalists with a foot switch and was used intermittently by brief activation. When CT fluoroscopy was off, the needle was advanced, and then its position was checked again with CT fluoroscopy; this was repeated until the needle penetrated the target lesion. After the procedure, a CT helical scan was performed for final confirmation of the needle position with interventionalists outside the IR room.

Depending on the lesion size, multiple cryoneedles were used. If a critical organ was near the tumor, artificial ascites or carbon dioxide were injected through a needle inserted between the organ and the tumor (hydro- or pneumo-dissection method) [13]. The needle used for hydro- or pneumo-dissection was also positioned under CT fluoroscopy. In bone lesions, a bone biopsy needle or a Kirschner wire was used to create a hole in the bone, and then the needle was changed for a cryo-needle. During the puncture, interventionalists usually hold the needle using forceps (length: 23 cm), however they sometimes hold the proximal bent part of the needle by their hand to prevent direct radiation exposure on the hand.

The basic ablation protocol used for most diseases was two 10- to 15-min freeze cycles separated by 5- to 10-min thaw cycles. For osteoid osteoma, two 3-min freeze cycles separated by 10-min thaw cycles were applied. The number of freeze-thaw cycles also depended on the lesion size and location. During the freezing time, the size of the ice ball was evaluated routinely by conventional CT, and sometimes by CT fluoroscopy if necessary, to prevent injury to critical organs.

Radiation protection

Interventionalists wore a lead apron with a lead equivalent value of 0.25 mm Pb in the front part (Maeda, Tokyo, Japan) during the procedure. They also wore radiation protective glasses with a lead equivalent value of 0.07 mm Pb (Toray Medical, Tokyo, Japan) and radiation protective gloves (FLAIR, Tokyo, Japan) on both hands. The CT fluoroscopy system used in this study had a system for radiation dose reduction called angular beam modulation (ABM). This system turns off the X-ray tube at 12 o’clock, 10 o’clock, and 2 o’clock positions during CT fluoroscopy for a total sector of 100°. Hohl et al. reported that the dose on interventionalists’ hands could be reduced by 72% using ABM [14]. In this study, ABM was used according to the direction of the puncture route in each PCA procedure.

Radiation dose measurement on interventionalists

Entrance surface dose (ESD) was measured using RPLDs on multiple sites: inside and outside the radioprotective glasses (four sites inside the glasses: on both cheeks and temples, one site outside the glasses; on the X-ray tube-side temple), representing eye lens exposure; on the neck, chest (two sites: on and underneath the lead apron), and abdomen
Statistical analysis

All statistical analyses were performed with SPSS version 25.0 software (IBM, Armonk, NY). Continuous variables were expressed by mean value +/- standard deviation (SD), and were compared using the Mann-Whitney U test with Bonferroni correction. Categorical variables were analyzed using Chi-square or Fisher’s exact test. Spearman correlation coefficient was used to estimate the correlation between ESD and CT fluoroscopy time. Correlation coefficient > 0.7 was considered strong, 0.4-0.7 medium, 0.2-0.4 weak, and < 0.2 unrelated. P values <0.017 were considered significant in the Mann-Whitney U test with Bonferroni correction, and P values <0.05 were considered significant in Chi-square test, Fisher’s exact test and correlation coefficient.

Results

Patients’ characteristics and details of the procedures are summarized in Table 1. Mean age and number of needles used between renal PCA and bone PCA, mean operative time and CT fluoroscopy time between renal PCA and liver PCA, as well as mean operative time and number of needles used between liver PCA and bone PCA exhibited statistically significant differences (p < 0.017).

Radiation exposures during PCA are summarized in Table 2 and Table 3. The mean ESD at the X-ray-side hand displayed the highest value (358.8 μGy). Considering evaluation sites representing exposure to the eyes, the highest ESD inside the safety glasses was detected on the X-ray-side cheek (167.1 +/- 75.7 μGy) (Table 2).

The results of correlation coefficients between CT fluoroscopy time and ESD values are shown in Table 2. At 10 out of 14 evaluation sites representing eye lens exposure with and without safety glasses, at all sites outside the lead apron (neck, chest and abdomen) representing body exposure, and at the X-ray tube-side hand and elbow, ESDs were linearly correlated with CT fluoroscopy time (p < 0.001). The correlation coefficient was 0.750 for the X-ray tube-side hand, showing strong equilateral correlation, and 0.690 for the X-ray tube-side cheek inside the safety glasses, showing moderate equilateral correlation. The ESD measured at 10 correlated sites during renal and liver PCA was relatively higher than that measured during bone PCA, especially on...
Table 1. Summary of patients’ characteristics and procedures

|                        | Renal (n = 32) | Liver (n = 8) | Bone (n = 6) |
|------------------------|----------------|--------------|--------------|
| Age of patients (year) |                |              |              |
| Mean ± SD              | 68.8 ± 12.7    | 61.9 ± 12.1  | 21.3 ± 7.5   |
| Median, range          | 72, 29-89      | 63, 49-85    | 22, 15-37    |
| Gender of patients     |                |              |              |
| Male                   | 26             | 4            | 3            |
| Female                 | 6              | 4            | 3            |
| Body mass index (kg/m²)|                |              |              |
| Mean ± SD              | 24.9 ± 4.1     | 22.5 ± 4.8   | 22.2 ± 2.4   |
| Median, range          | 24.1, 15.1-31.6| 20.0, 18.1-30.8| 22.5, 18.8-25.2 |
| Operative time (min)   |                |              |              |
| Mean ± SD              | 143.3 ± 27.9   | 190.6 ± 27.7 | 125.0 ± 41.0 |
| CT fluoroscopy time (s)|                |              |              |
| Mean ± SD              | 66.8 ± 26.8    | 102.9 ± 29.0 | 48.3 ± 34.6  |
| Hydro or pneumo displacement |         |              |              |
| Yes                    | 12             | 2            | 0            |
| No                     | 20             | 6            | 0            |
| Tumor size (mm)        |                |              |              |
| Mean ± SD              | 26.3 ± 8.8     | 25.1 ± 9.1   | 8.8 ± 10.5   |
| Number of needles      |                |              |              |
| Mean (range)           | 2.8 (1-4)      | 3.1 (2-4)    | 1.3 (1-3)    |

SD = standard deviation
§ ¶: Significant difference

the chest outside the lead apron and on the X-ray tube-side elbow and hand (p < 0.017, respectively) (Table 3).

The radioprotective effects of the used equipment are summarized in Figure 2. Safety glasses reduced the radiation dose by 50.6% during liver PCA, while the lead apron reduced by 79.6% the radiation dose received by the chest during liver PCA, and by 77.5% and 30.2% the dose received by the abdomen during liver and bone PCA respectively.

Discussion

This study demonstrated the radiation exposure of interventionalists during CT fluoroscopy-guided PCA at multiple sites using RPLDs. The radiation doses to the eye lens and hand during PCA procedures were first determined, and among 14 evaluation sites, the X-ray tube-side hand revealed the highest exposure. The ESDs were linearly correlated with CT fluoroscopy time in 10 out of 14 evaluation sites. When comparing radiation exposure during PCA procedures with different therapeutic targets, radiation doses during renal and liver PCA were relatively higher than those emitted during bone PCA, at the correlated sites. An explanation for this may be provided by the higher number of needles used during renal and liver PCAs compared with bone PCA; the targeted bone lesions were usually small, such as osteoid osteomas. Accordingly, CT fluoroscopy time was relatively longer and ESD was much higher in renal and liver PCA. Saidatul et al. reported that interventionalists received the highest dose on the hands (354 μGy) and the least dose on the eye lens (260 μGy), and the thyroid (73 μGy) during CT fluoroscopy-guided liver radiofrequency ablation (RFA) [15]. This observation coincides with the results of our study, especially regarding renal and liver PCA. This may be due to the need for holding the needles by forceps or by hand during the puncture, as well as due to other methods for preventing the migration and removal of the needles during renal and liver PCA and RFA.

According to the International Commission on Radiological Protection (ICRP) recommendation in 2011, the mean equivalent dose limit for the eye lens is 20 mSv per every 5 years [16]. In our study, the equivalent dose of 20 mSv to the eye lens, which was estimated by measuring the dose on the cheek inside the safety glasses (167.1 μGy), represented 120 PCA procedures. In this study, we observed linear correlation coefficients between CT fluoroscopy time and ESD.
of all evaluation sites representing exposure of the eye lens, regardless of the use of radiation protective glasses. The reason for this may be that glasses with a lead equivalent value of 0.07 mm Pb were not enough for the protection of the eye lens. The results of our study indicated that the radioprotective effect of safety glasses was inferior to that of the lead apron. In addition, the ESD at the X-ray-side cheek was higher than that measured at the X-ray-side temple. In an attempt to explain that, we speculated that scattered radiation from the bottom side triggered the high ESD at the X-ray-side cheek, as it passed between the protective glasses and the cheek. Therefore, safety glasses with a lead equivalent value of over 0.25 mm Pb and radiation protection at the bottom side are needed during CT fluoroscopy-guided PCA. Moreover, the equivalent dose limit for the skin is 500 mSv per year, while the dose measured on the hand of the X-ray tube-side (358.8 μGy) in our study represented 1394 PCA procedures. In our institution, the annual number of PCA procedures has usually been less than 50; hence, the equivalent doses of interventionalists are unlikely to exceed any dose limits.

In our institution, during CT fluoroscopy, the minimum tube current and radiation protective glasses and gloves were used for reduction of radiation exposure; however, we did not cover the patient with lead drapes. A phantom study reported that lead drapes contributed to 71% reduction in radiation dose when placed 2.5 cm away at a distance of 10 cm from the scanning plane [17].

The radioprotective effect of safety glasses consisted of a reduction of about 50% in radiation exposure. Haga et. al. reported that radiation protective glasses could reduce radiation exposure by 60% [18]. Our results demonstrated a lower protection. This may be due to the differences in the energy level and measurement techniques used. We were not able to find literature on the radioprotective effect of the lead apron. The manufacturer’s brochure states that the lead apron has a protective effect of 99% at 60 kV and 90.7% at 120 kV. These values are consistent with the rationale that the higher the energy level, the lower the radioprotective effect of the equipment. In addition, the radioprotective effect of the lead apron was lower during bone PCA than during kidney and liver PCA. This may be due to the differences between bone and other PCAs in the techniques applied. During bone PCA, especially for osteoid osteomas, the tech-

### Table 2. Radiation exposure of interventionalists and coefficient of correlation between ESD and CT fluoroscopy time in each evaluation sites

| Evaluation sites      | Radiation exposure (μGy) Mean ± SD | ESD per 120 minutes (μGy) | Correlation coefficients | P value |
|-----------------------|-----------------------------------|---------------------------|--------------------------|---------|
|                       | ESD vs. CT fluoroscopy time       |                           | P value                  |         |
| Bilateral eye lens    |                                    |                           |                          |         |
| X-ray. out. temple    | 235.4 ± 86.1                      | 188.5                     | 0.661                    | 0.000   |
| X-ray. in. temple     | 126.1 ± 60.8                      | 101.4                     | 0.622                    | 0.000   |
| opp. X-ray. in. temple| 82.1 ± 39.9                       | 65.7                      | 0.439                    | 0.000   |
| X-ray. in. cheek      | 167.1 ± 75.7                      | 134.1                     | 0.690                    | 0.000   |
| opp. X-ray. in. cheek | 96.2 ± 44.8                       | 76.9                      | 0.544                    | 0.002   |
| Neck                  | 213.9 ± 97.0                      | 171.3                     | 0.664                    | 0.000   |
| Chest                 |                                    |                           |                          |         |
| outside               | 237.3 ± 113.2                     | 190.8                     | 0.657                    | 0.000   |
| inside                | 67.6 ± 34.4                       | 53.9                      | 0.196                    | 0.191   |
| Abdomen               |                                    |                           |                          |         |
| outside               | 126.6 ± 52.4                      | 102.5                     | 0.509                    | 0.000   |
| inside                | 48.9 ± 30.7                       | 39.2                      | -0.045                   | 0.769   |
| Elbow                 |                                    |                           |                          |         |
| X-ray tube side       | 206.8 ± 159.6                     | 164.4                     | 0.456                    | 0.002   |
| opp. X-ray tube side  | 53.9 ± 40.7                       | 43.0                      | 0.151                    | 0.321   |
| Hand                  |                                    |                           |                          |         |
| X-ray tube side       | 358.8 ± 209.0                     | 287.2                     | 0.750                    | 0.000   |
| opp. X-ray tube side  | 104.3 ± 60.6                      | 83.6                      | 0.188                    | 0.216   |

ESD = entrance surface dose
X-ray. = X-ray tube side
out. = outside
in. = inside
opp. = opposite
Table 3. The mean ESD of each evaluation sites in each percutaneous cryoablation

| Evaluation site | Renal (n = 32) | Liver (n = 8) | Bone (n = 6) |
|-----------------|---------------|--------------|-------------|
| Radiation exposure (µGy) Mean ± SD | | | |
| Bilateral eye lens | 244.3 ± 83.3 | 245.2 ± 80.3 | 162.8 ± 65.4 |
| X-ray. out. temple | 135.3 ± 60.6 | 121.0 ± 52.6 | 84.2 ± 47.7 |
| X-ray. in. temple | 85.2 ± 39.8 | 81.3 ± 31.6 | 66.7 ± 43.1 |
| opp. X-ray. in. temple | 178.2 ± 74.2 | 167.0 ± 55.4 | 108.3 ± 73.5 |
| X-ray. in. cheek | 102.2 ± 45.1 | 90.1 ± 32.6 | 72.2 ± 44.7 |
| Neck | 220.3 ± 101.0 | 219.0 ± 73.2 | 160.0 ± 65.3 |
| Chest | 246.6 ± 103.3 ‡ | 286.0 ± 103.4 ‡ | 123.2 ± 91.4 ‡ |
| inside | 70.4 ± 35.3 | 58.3 ± 20.8 | 64.9 ± 38.7 |
| Abdomen | 135.5 ± 50.0 | 126.4 ± 44.0 | 82.9 ± 48.0 |
| inside | 52.4 ± 30.4 | 28.5 ± 17.5 | 57.9 ± 32.1 |
| Elbow | 224.7 ± 166.7 ‡ | 222.4 ± 135.7 ‡ | 93.1 ± 61.1 ‡ |
| X-ray tube side | 59.5 ± 42.3 | 24.6 ± 13.8 | 64.1 ± 35.0 |
| opp. X-ray tube side | 367.2 ± 198.4 ‡ | 453.4 ± 204.6 ‡ | 188.8 ± 141.2 ‡ |
| Hand | 108.4 ± 63.7 | 91.8 ± 56.2 | 99.7 ± 38.2 |

‡: Significant difference

Figure 2. Radioprotective effects at each evaluation site: The radioprotective effects of safety glasses for the eye lens are lower than those provided by the lead apron for the chest and abdomen. However, such differences are not observed upon exposure during bone percutaneous cryoablation.

niques applied differed from renal and liver PCA as interventionalists usually penetrated the sclerotic bone with a hand drill; therefore, their posture during the procedure may have differed as well.

This study had several limitations that should be acknowledged. First, this study included not only renal PCA but also liver and bone PCA procedures. The number of PCA needles and the application of hydro- or pneumo-dissection varied according to the target lesions. Thus, the distributions of radiation exposure of interventionalists at each evaluation site were extendedly compared with those of a previous study [12]. Second, RPLDs were used for measuring ESD in this study; however, in the previous study, thermoluminescent dosimeters, optically stimulated luminescence dosimeters, and electronic dosimeters were used [12]. Compared with thermoluminescent dosimeters, RPLDs have less sensitivity dispersion, less fading, and higher stability against temperature and humidity. However, dose linearity, energy characteristics, and directional dependence are similar between thermoluminescent dosimeters and RPLDs [19, 20].

In conclusion, the highest radiation exposure of interventionalists during CT fluoroscopy-guided PCA was detected at the X-ray tube-side hand. The radiation doses on interventionalists during renal and liver PCA were relatively higher than those measured during bone PCA, although radiation exposure was maintained at an acceptable level and was consistent with the recommended dose limits.

Ethics approval and consent to participate: For this type of
study, informed consent is not required.

This study has obtained IRB approval from (indicate the relevant board) and the need for informed consent was waived.

This study has been presented at JSIR & ISIR 2015.

**Conflict of interest:** Masaya Miyazaki holds an endowed chair provided by Siemens Healthineers. The other authors have no conflict of interest to declare.

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