

Radiation Exposure and Protection in Computed Tomography Fluoroscopy

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Abstract

Computed tomography (CT) fluoroscopy-guided procedures, such as those used for percutaneous biopsy, drainage, and radiofrequency ablation, are highly safe and quite often very successful due to the precision offered by the real-time, high-resolution tomographic images. Even so, international guidelines raised concerns regarding operator exposure to high doses of radiation during these procedures. In light of these concerns, operators conducting CT fluoroscopy-guided procedures not only need to be cognizant of the exposure risk but also exhibit sufficient knowledge of radiation protection. This paper reviews the current literature on experimental and clinical studies of radiation exposure doses to operators during CT fluoroscopy-guided procedures. In addition to the literature review, this paper also introduces different approaches that can be implemented to ensure appropriate radiation protection.

Key words: radiation safety, interventional radiology, CT fluoroscopy

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1. Introduction

Computed tomography (CT) fluoroscopy-guided procedures are methods of image-guided puncture used in procedures such as percutaneous biopsy, drainage, and radiofrequency ablation. Because procedures are guided by real-time, high-resolution tomographic images, precise punctures can be made into small lesions and lesions deep in the body. CT fluoroscopy-guided procedures reportedly show high rates of success and safety [1].

However, concerns have been raised about the high radiation exposure doses to operators in the joint guideline of the Cardiovascular and Interventional Radiology Society of Europe and the Society of Interventional Radiology and by International Commission on Radiological Protection (ICRP) Publication 87 [2, 3].

Operators who conduct CT fluoroscopy-guided procedures need to acquire sufficient knowledge of operator exposure

during CT fluoroscopy and radiation protection. This review examines the literature on experimental and clinical studies on radiation exposure doses to operators during CT fluoroscopy-guided procedures. The review also examines necessary methods for implementing proper radiation protection, such as ensuring distance from the CT scan plane, shortening the exposure time, providing shielding from scattered radiation, adjusting CT fluoroscopy parameters, and using the radiation exposure-reducing functions of CT scanners.

2. Literature Search

A literature search of PubMed was conducted using “CT fluoroscopy” as the search term. Articles published between 1996 and 2021 were targeted in this search. Articles deemed to be related to operator exposure to radiation and radiation protection during CT fluoroscopy-guided procedures were selected. Articles about clinical studies and experimental

studies using a phantom were also included. Articles referenced in the selected articles were also added if they were deemed to be related to operator exposure to radiation and radiation protection. A total of 23 articles were ultimately examined.

3. Measuring the Operator Radiation Exposure Dose

The joint guideline from the Cardiovascular and Interventional Radiology Society of Europe and the Society of Interventional Radiology states that excessive radiation exposure can occur, particularly to the hands of operators, during CT fluoroscopy-guided procedures [2]. ICRP Publication 87 also mentions that the hands of operators can be exposed to high doses of radiation and recommends that exposure of the hands to direct radiation be avoided by using aides to reduce exposure, such as needle holders [3]. In many experimental and clinical studies, the radiation exposure doses to operators were assessed by measuring the radiation exposure dose to their hands.

1) Radiation exposure doses to operators in clinical studies

Some studies reported radiation exposure to operators during CT fluoroscopy-guided percutaneous biopsy, drainage, and radiofrequency ablation procedures. The tube voltage for CT fluoroscopy was 120-140 kV in those studies, with 120 kV as the most common voltage setting. The most common tube current was 20-30 mA, with the maximum being 70 mA. In studies that measured the effective radiation exposure dose to operators in each procedure, the lowest dose was on average 0.74 μ Sv/procedure, and the highest was on average 54 μ Sv/procedure [1, 4-8].

In studies that measured radiation exposure dose to the hands of operators, the lowest dose was on average 32.7 μ Sv/procedure, and the highest was on average 2.1 mSv/procedure [1, 4-6, 8-10]. The operators were exposed to scattered radiation in all these cases, but radiation exposure dose to the hands was much higher compared with that to other areas of the body. The occupational radiation exposure dose limit recommended by the ICRP is 100 mSv for the total effective dose over 5 years, 50 mSv for the maximum annual dose during this period, and 500 mSv for the annual equivalent dose to the skin. When the reported maximum dose is converted based on the dose recommended by the ICRP, the number of CT fluoroscopy-guided procedures that can be performed in one year may be limited to 925 (based on effective dose) or 238 (based on dose to the skin of the hands).

In studies that measured radiation exposure doses to the eyes of operators, the lowest dose was on average 10 μ Sv/procedure, and the highest was on average 260 μ Sv/procedure [4, 8, 9]. When this maximum radiation exposure dose is converted based on the 5-year mean dose limit of 20 mSv/year for occupational exposure to the crystalline lens

recommended by the ICRP, the number of CT fluoroscopy-guided procedures that can be performed in one year may be limited to 76. Among the effective dose, equivalent dose to the skin, and equivalent dose to the crystalline lens, the crystalline lens dose is the most likely to reach the dose limit.

Pereira et al. measured radiation exposure doses to the four limbs of the operator [6]. The mean radiation exposure doses to the left arm, left knee, and left foot of the operator were 0.25 mSv/procedure, 0.06 mSv/procedure, and 0.08 mSv/procedure, respectively. Measurements of the radiation dose to the thyroid of the operator showed a mean dose of 29 μ Gy/procedure for procedures with an exposure time of 2-3 min and 73 μ Gy/procedure for procedures lasting 9-10 min [9].

Without proper protection, operators are faced with the possibility of the exposure dose reaching the dose limit and thus no longer being able to engage in work involving radiation. Particular caution is required for the eyes, because the eye dose is the most likely to reach the dose limit.

2) Measuring operator exposure doses in experimental studies

Some studies reported measuring exposure doses to various body parts, including the trunk, hands, and eyes of the operators during CT fluoroscopy. Because experimental studies using a phantom do not incur radiation exposure to humans, some studies also measured exposure doses due to direct radiation in addition to scattered radiation [11-14]. The tube voltage used most often for CT fluoroscopy in these studies was 120 kV. The minimum voltage was 80 kV, and the maximum voltage was 135 kV. Tube current ranged from 10 to 135 mA. Exposure time ranged from 1 sec to 1 min. Many studies reported measuring scattered radiation at a distance of ≤ 10 cm from the CT scan plane, as the assumed distance of the operator's hand from the scan plane [12-15]. In a study by Figueira et al. radiation exposure dose to the operator's hand placed within the area of the CT scan plane was 18.1 mGy/sec under a tube voltage of 120 kV and tube current of 100 mA [11]. This was assumed to be a case of direct radiation exposure to the hand of the operator. In a measurement performed with the operator's hand located several centimeters from the CT scan plane and assuming direct radiation exposure to the hand of the operator was avoided, the radiation exposure dose from scattered radiation alone was 0.47 mGy/sec. The dose including direct radiation exposure was 38-fold higher than the exposure dose from scattered radiation alone.

A study by Kato et al. suggested the possibility of reaching a dose of 120 mGy/procedure (1.47 mSv/sec) from exposure to direct radiation under a tube voltage of 80 kV and tube current of 30 mA [16]. In contrast, the exposure dose from scattered radiation with the hand located 4 cm away from the CT scan plane was 0.025 mSv/sec, indicating that the exposure dose including direct radiation was 58-fold higher than in the case of scattered radiation alone. Further-

more, because the dose limit for the equivalent dose to the skin recommended by the ICRP is 500 mSv/year, when the hand of an operator is exposed to direct radiation during a procedure, the number of procedures that could be performed in a year was limited to four. Therefore, procedures in which the hand of the operator is exposed to direct radiation are not acceptable.

4. Methods for Reducing the Operator Radiation Exposure Dose

Ensuring distance from the CT scan plane, shortening the exposure time, providing shielding from scattered radiation, adjusting CT fluoroscopy parameters, and using the radiation exposure-reducing functions of CT scanners are methods of reducing the radiation exposure dose to the operator.

1) Ensuring distance from the CT scan plane

In an experiment conducted by Stoeckelhuber et al. radiation exposure dose to the hand of the operator was measured when a needle holder was used to keep the hand at a distance from the CT scan plane [14]. The radiation dose was reduced by 30% when a 35 cm-long needle holder (effective length, 30 cm) was used as compared with when a 15-cm-long needle holder (effective length, 10 cm) was used, because the operator's hand was further from the CT scan plane. Irie et al. reported that the radiation dose to the operator's hand was reduced by 84% when a 15-cm-long needle holder was used as compared with a 7-cm-long needle holder [10]. Therefore, these findings demonstrate the extreme importance of maintaining even a small distance from the scan plane in radiation protection.

Inaba et al. compared left and right differences in radiation exposure doses to the eyes, neck, and hands of the operator by measuring both sides far from and near to the CT scan plane [4]. The median radiation dose to the far eye was 2.4 μ Sv/procedure, whereas the median dose to the near eye was 27.1 μ Sv/procedure, showing an 11-fold difference. In an experiment using a phantom, Nishizawa et al. measured the radiation doses to both eyes, upper arms, back of the hands, and fingers of the operator [13]. Radiation doses were 15.3 μ Gy/min to the right eye, 3.1 μ Gy/min to the left eye, 18.1 μ Gy/min to the right upper arm, 2.8 μ Gy/min to the left upper arm, 240 μ Gy/min to the right back of the hand, 140 μ Gy/min to the left back of the hand, 8.4 μ Gy/min to the right fingers, and 6.9 μ Gy/min to the left fingers. Therefore, differences in radiation dose were observed between left and right in all cases in that study. These studies show that when measuring the radiation dose to the eyes or hands of the operator during CT fluoroscopy-guided procedures, the radiation exposure dose may be underestimated if the dosimeter is not mounted on the side near the CT scan plane. In an experiment conducted by Ekpo et al. the effect of the height of the measuring position from the floor was examined with respect to radiation exposure dose to the operator's eye near to the CT scan plane [17]. No significant

differences were seen in the radiation dose to the eyes of the operator in measurements taken at heights of 160 cm, 180 cm, or 200 cm from the floor. Therefore, the height of the operator is thought to exhibit little effect on radiation exposure dose to the eyes.

2) Shortening the exposure time

The operator radiation exposure dose can also be reduced by shortening the exposure time through intermittent instead of continuous irradiation.

Silverman et al. proposed a quick-check method, in which irradiation is only performed while confirming the position and direction of the puncture needle [18]. The mean exposure time of 20 procedures performed using the quick-check method involving intermittent irradiation was 41 sec, compared to 90 sec for 75 procedures performed using the real-time method involving continuous irradiation, showing a significant difference in exposure time.

3) Shielding

During CT fluoroscopy-guided procedures, the operator exhibits difficulty moving far from the CT scan plane because the device is operated within the area of the CT scan plane. Furthermore, because the space between the CT scan plane and operator is surrounded by the CT gantry and is therefore narrow, getting close to the CT scan plane is difficult using a lead acrylic X-ray protective shield suspended from the ceiling or a curtain shield to protect the lower body used in procedures under conventional X-ray fluoroscopy. Therefore, a dedicated protective device suited to CT fluoroscopy is needed.

In contrast, radiation often scatters from the body surfaces of the patient within the CT scan plane, which is why many studies described the use of a drape-like radiation protection shield covering the patient's body close to the CT scan plane [4, 15, 16, 19].

In a study by Inaba et al. both the radiation dose to the hand of the operator and the effective dose were significantly reduced when a drape was placed over only the upper part of the patient's body [4]. The radiation dose to the hand without using a drape was 32.7 μ Sv/procedure, and it decreased to 17.6 μ Sv/procedure when a drape was used. In an experiment by Nawfel et al. when a 0.5 mm lead-equivalent drape was placed 2.5 cm from the CT scan plane, the radiation dose measured at 10 cm away from the CT scan plane and under a tube voltage of 120 kV and tube current of 50 mA was 6.8 μ Gy/sec, representing a 71% reduction from the 23.6 μ Gy/sec radiation dose without using the drape [15].

Protection for the operator using a radiation protection shield during CT fluoroscopy only tends to be provided in the area above the CT table. However, because CT involves 360° irradiation, radiation can scatter from the underside of the CT table and from the side and underside of the patient. To prevent such radiation scatter, the area below the CT table also needs to be protected.

Some CT scanners are equipped with a function to recon-

struct CT images by only scanning 240° and stopping irradiation in the remaining direction. The function could reduce the radiation exposure dose to the upper half of the operator's body by stopping irradiation in the upper area. However, because radiation exposure to the lower half of the operator's body due to scattered radiation that occurs from the side and underside of the patient is not reduced, a shield is needed to protect this area. Mahnken et al. reported a mean reduction of 32.8% in the radiation dose to the operator's feet when a curtain-style lead shield for the lower body was attached to the CT table [20].

Several studies described the use of protective gloves, lead glasses, and a small lead plate shield covering only the operator's hand. In a study by Irie et al. the radiation dose to the operator's hand was reduced to 76% of the radiation dose when a 2 mm-thick lead plate covered the hand [10]. Ekpo et al. found that the use of 0.75-mm lead-equivalent lead glasses reduced the radiation dose to the eyes of the operators from approximately 7 µGy to approximately 3 µGy [17]. In an experiment by Neeman et al. using protective gloves made of bismuth, the radiation dose at a position 5 cm from the CT scan plane under a tube voltage of 120 kV and tube current of 30 mA was reduced by 71.8% and by 34.7% at a position 10 cm away [19]. Stoeckelhuber et al. reported a 76.6% reduction in the radiation dose to the back of the operator's hand when 0.4 mm lead-equivalent bismuth gloves were worn [14]. Furthermore, the radiation dose to the operator's hand was reduced by 99.6% when a needle holder was combined with a drape and protective gloves.

4) Adjusting CT fluoroscopy parameters

Some studies compared radiation exposure doses under different tube voltage, tube current, and slice thickness parameters. A study by Ekpo et al. described a 26% increase in the radiation dose to the eyes of the operator when the tube voltage was changed from 120 kV to 135 kV, and the researchers described a 2-fold increase in the radiation dose when the tube current was changed from 10 mA to 20 mA [17]. Irie et al. reported a 71% reduction in the radiation dose at a position 10 cm away from the CT scan plane when the slice thickness was changed from 5 mm to 1 mm [10]. Furthermore, when tube voltage and tube current were changed from 135 kV and 50 mA to 120 kV and 30 mA, respectively, the radiation dose was reduced to 40% of the radiation dose at a position 7 cm away from the CT scan plane.

However, changing the settings on the CT scanner can lower the quality of CT images. Yamao et al. evaluated the quality of images under multiple tube voltages and tube currents by measuring signal-to-noise ratios and contrast-to-noise ratios and by scoring by four readers [21]. They found that the minimum radiation dose to obtain images of acceptable quality for procedures involving the lung field was 1.18 mGy/sec (120 kV, 10 mA). Also, they reported that image quality did not improve much even when the radiation dose

was increased to ≥ 1.48 mGy/sec (135 kV, 10 mA). With an 80-kV tube current, image quality did not improve despite the increase in radiation dose, and this was attributed to the low transmission energy, with the X-rays consequently being absorbed by subcutaneous tissues and bone.

5) Radiation exposure-reducing functions of CT scanners

Some CT scanners are equipped with a function to reconstruct CT images by only scanning 240° and stopping irradiation in the remaining direction [12, 22, 23]. When irradiation from above was stopped using partial exposure mode (Canon Medical Systems, Tochigi, Japan), the radiation dose, which included exposure to direct radiation within the CT scan plane above the CT table, was reduced by 84% from 2.33 mGy to 0.35 mGy [22]. When irradiation from above was stopped using angular beam modulation (Siemens Medical Solutions, Forchheim, Germany), the radiation dose, which included exposure to direct radiation within the CT scan plane above the CT table, was reduced by 72% from 4.69 mSv/sec to 1.32 mSv/sec [12]. Furthermore, the radiation dose from exposure to scattered radiation at a position 10 cm from the CT scan plane above the CT table was reduced by 27% from 0.11 mSv/sec to 0.08 mSv/sec. When irradiation was stopped at the side of the upper half of the operator's body using a partial angle scan (GE Healthcare, Wisconsin, USA), the radiation dose to the operator's chest was 35.2% lower than when a 360° scan was performed [23]. When irradiation was stopped at the opposite side, the radiation dose was increased by 33.9%.

The same studies also evaluated CT images when using these functions. Evaluation of the partial exposure mode revealed a decrease in contrast-to-noise ratios and an increase in standard deviations, but acceptable image quality was obtained by adjusting window conditions [22]. Evaluation of angular beam modulation revealed no difference in noise [12].

5. Conclusions

Since CT fluoroscopy-guided procedures expose operators to high doses of radiation, appropriate radiation protection is needed. The radiation exposure dose to the operators differs considerably between scattered radiation and direct radiation. Therefore, exposing the operator to direct radiation is unacceptable. To keep the hands of the operators several centimeters away from the CT scan plane greatly reduced the radiation exposure dose. Therefore, the use of a needle holder is effective.

Using a shield is an effective means of protection, but CT irradiation is performed from 360°, so the underside of the CT table needs to be shielded in addition to the topside. Using a function in which scanning is only performed over a range of 240° by stopping X-ray irradiation above the CT table reduces radiation exposure to the hands and chest of the operator, but it does not reduce the radiation dose below

the CT table. Therefore, a shield below the table is also warranted.

In procedures involving the chest, images of sufficient quality are easily obtained even when the CT radiation dose is set relatively low, and acceptable image quality is also said to be obtained under a tube voltage of 120 kV and tube current of 10 mA. Many studies reported the tube current being set between 20 and 30 mA.

The radiation exposure dose to the operator can be significantly reduced even if a single measure for radiation protection is taken, so starting with the implementation of feasible measures is therefore necessary.

Conflict of Interest: None

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