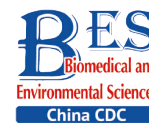


Letter to the Editor



Radiation Exposure for Patients and Staff during Different Interventional Procedures Using Anthropomorphic Phantoms: A Complete Evaluation of Different Body Regions*

ZHAO Zhi Xin^{1,&}, QIAN Pei Yi^{2,&}, WANG Hai Hua¹, QIAN Qian¹, YANG Yong¹, JING Li Yan¹,
YANG Lu Ting¹, YANG Lei^{2,#}, and WANG Qiang^{1,#}

Interventional radiological procedures performed under the guidance of X-ray imaging tools are widely used to diagnose and treat various conditions. However, radiation exposure can result in many health problems, including cataracts, skin necrosis, radiation burns, hair loss, birth defects, and cancer^[1-2]. Patient exposure during an interventional radiology procedure involves a wide dose range and can reach a level at which deterministic effects may occur^[3]. Although knowledge of radiation safety has greatly improved over the past century, radiation exposure in the healthcare environment remains a risk to both patients and medical professionals. Recently, given the increasing number of interventions and complexity of cases, there has been growing concern about the radiation exposure of patients and surgical personnel. Therefore, a special evaluation of the exposure of patients and medical staff is necessary to ensure their protection.

In most of the studies available thus far, the effective dose (ED) was presented as a measure of the stochastic radiation risk to the operator or patient, whereas few studies have provided organ doses owing to the complexity of the manipulations required to do so^[4]. Local tissue and organ doses are often much higher than whole-body doses, and an approximate assessment of the effective whole-body dose does not provide an accurate visualization of radiation damage to tissues and organs. Therefore, the assessment of organ dose is also essential to enable a more comprehensive assessment of radiation doses for medical professionals and patients. Several studies have assessed radiation exposure during interventional radiology procedures to characterize the exposure of patients and medical professionals and improve radiation protection

strategies. However, these studies have focused on a specific procedure or body region^[5].

In this work, we evaluated radiation exposure for both patients and medical staff during interventional radiology procedures by direct thermoluminescence dosimetry (TLD) with a dispersion of $\pm 1\%$, which was calibrated by the Shanghai Institute of Metrology and Testing Technology. Before the experiment, the TLD was annealed at 240 °C for 10 minutes to eliminate residual radiation dose within the TLD.

Interventional radiological procedures were performed using the Philips Allura Xper FD20 system (Philips Medical Systems, Best, Netherlands). The system was equipped with continuous and pulsed fluoroscopy and variable-frame digital subtraction angiography. To mimic a typical clinical geometric configuration, the distance from the source to the image detector was set at 90 cm. The X-ray source was positioned under a table, 50 cm from the phantom entrance surface. A Chinese Sichuan adult male CDP-1C anthropomorphic phantom was used to simulate realistic patient X-ray attenuation under 0° irradiation in the posterior-anterior (PA0° irradiation) chest position. The phantom was placed supine on a table, with the center of the chest at the center of the angiographic C-arm. An adult male ATOM 701 anthropomorphic phantom (CIRS ATOMTM, Norfolk, Virginia, USA; model 701; height, 173 cm; weight, 73 kg) was placed in the operator's position to simulate a realistic operator (Figure 1). TLDs were distributed in typical organs (such as the eye lens, thyroid, heart, and liver), and several TLDs were mounted on the surface of the phantom to sample the non-uniform dose distribution. For the patient, TLDs were distributed on the entrance surface of the head, anterior and posterior back of

doi: [10.3967/bes2023.156](https://doi.org/10.3967/bes2023.156)

*This work was supported by Zhejiang Health Science and Technology Plan [2021KY956, 2022KY1043 and 2022KY1044] and Scientific research projects of agriculture and social development in Hangzhou [20201203B220].

1. Hangzhou Hospital for the Prevention and Treatment of Occupational Disease, Hangzhou 310014, Zhejiang, China;
2. School of Public Health, Hangzhou Normal University, Hangzhou 311121, Zhejiang, China

the chest, and anterior and posterior back of the abdomen. For the operator, TLDs were distributed on the anterior side of the chest, abdomen, lower extremities, and feet. ED was estimated using the Martin-Magee's algorithm^[6]. The absorbed dose (D_T) of the organs or tissues of the simulated anthropomorphic phantom was calculated using the following Equation:

$$D_T \approx K_T = X_i \cdot C_{f1} \cdot [(\mu_{en}/\rho)_T / ((\mu_{en}/\rho)_{air})] \quad (1)$$

where D_T is the mean absorbed dose in either organ or tissue T from radiation fields external to the body in mGy; K_T is the air kerma of the relevant organ; X_i is the readout value; C_{f1} is the calibration factor of the detector; and $(\mu_{en}/\rho)_T / (\mu_{en}/\rho)_{air}$ is the mass energy absorption coefficient ratio of organ or tissue (T) to air in the simulated human model.

The radiation dose was evaluated based on digital subtraction angiography (DSA) and fluoroscopy. First, an interventional radiology procedure was performed in the DSA mode. The ATOM 701 phantom was placed at the position of the first operator. The other exposure parameters were set as follows: the imaging field of view (FOV) was 30 cm × 30 cm^[2], the ceiling-suspended lead screen and side-table lead shield were removed, and the automatic exposure control time was 3 min (80 kV, 18.0 mAs, main: vascular, application: thorax, procedure: lungs, 6 fps, patient type: normal). After exposure was completed, the TLDs were sorted and recycled. The imaging equipment was then changed to fluoroscopy mode (72 kV, 8.7 mA), and the other exposure parameters were consistent with the DSA mode. After exposure was completed, the TLDs were sorted and recycled. As illustrated in Figure 2, the highest radiation levels



Figure 1. Experimental setup involving two anthropomorphic phantoms for measuring scattered radiation doses during interventional procedures.

were achieved using the DSA image acquisition modality, which can be explained by the fact that DSA procedures require a significantly higher X-ray dose than fluoroscopy. Using DSA resulted in an approximately 30-fold increase in the ED to the patient and an approximately 8-fold increase in the ED to the operator vs. fluoroscopy (Figure 2A and B). The skin dose distribution is plotted in Figure 2C and D. For the patients, the highest skin absorbed dose was found in the upper back (chest). Doses to different organs on the skin of the operator were generally higher. During interventional radiological procedures, the skin doses to the patient were significantly higher than those to the operator owing to direct X-ray irradiation. ICRP Report No. 85^[7] states that acute radiation doses of 2 Gy may cause erythema, permanent epilation at 7 Gy, and delayed skin necrosis at 12 Gy. Our study demonstrated that a maximum skin dose of 774.838 mGy per three minutes of DSA mode irradiation was received by the patient during a given thoracic interventional procedure. Interventional procedures vary in complexity due to differences in the patients, surgical sites, and degrees of the lesions, and the irradiation time varies greatly for each procedure; therefore, the dose to the patient varies widely. When the procedure is complex and the irradiation time is long, it is possible to produce a skin dose of only 2 Gy, at which point the patient may develop symptoms such as erythema. Radiation skin injuries usually appear several weeks or months after surgery, and symptoms are rarely diagnosed in the time it takes for the injuries to appear, resulting in patients not being adequately treated. Therefore, it is necessary to carry out skin dose measurements for patients during the interventional procedure and follow-up on patients who received high doses postoperatively. Figure 2E and F demonstrate that the highest organ doses were identified in the kidney, heart, and liver of the patient, whereas for the operator, the highest doses were received by the eye lens, gonads, and liver. In interventional procedures, fluoroscopic and DSA modes generally coexist; therefore, using DSA imaging as sparingly as possible can reduce both the patient and staff radiation burden.

Three experiments were performed to study the impact of lead shields and operating positions on the radiation doses to patients and operators. First, the ATOM 701 phantom was placed in the first operator position. The interventional radiology procedure was performed in the fluoroscopy mode, and the other exposure parameters were as follows: FOV = 30 cm × 30 cm^[2]. The side-table lead

screen was installed on the lower right side of the diagnostic bed, and the ceiling-suspended lead screen was hung on the left side above the operator. After 3 min of automatic exposure (75 kV, 8.4 mA) was completed, the TLDs were sorted and recycled. Second, the lead shields were removed, and the automatic exposure control time was once more 3 minutes (72 kV, 8.7 mA) using the same parameters in the first part of this experiment. After exposure was completed, the TLDs were sorted and recycled. Finally, the lead shields were removed and the ATOM 701 phantom was placed in the second operator position. Radiation exposure was continued for 3 minutes (73 kV, 8.6 mA) using

the same parameters as in the first part of this experiment. After exposure was completed, the TLDs were sorted and recycled. In addition to lead aprons and other personal protection devices worn on the body, shields hung from the ceiling or placed on the side of a table have been shown to significantly reduce operator exposure^[4]. As shown in Figure 3 (A, C, and E), the use of a ceiling-suspended lead screen and table-side shielding attenuated the scattered radiation to the operator's ED by over 85% and the skin dose by approximately 70%. Organ doses were also reduced by varying degrees. Generally, shields should be used whenever possible to keep personnel

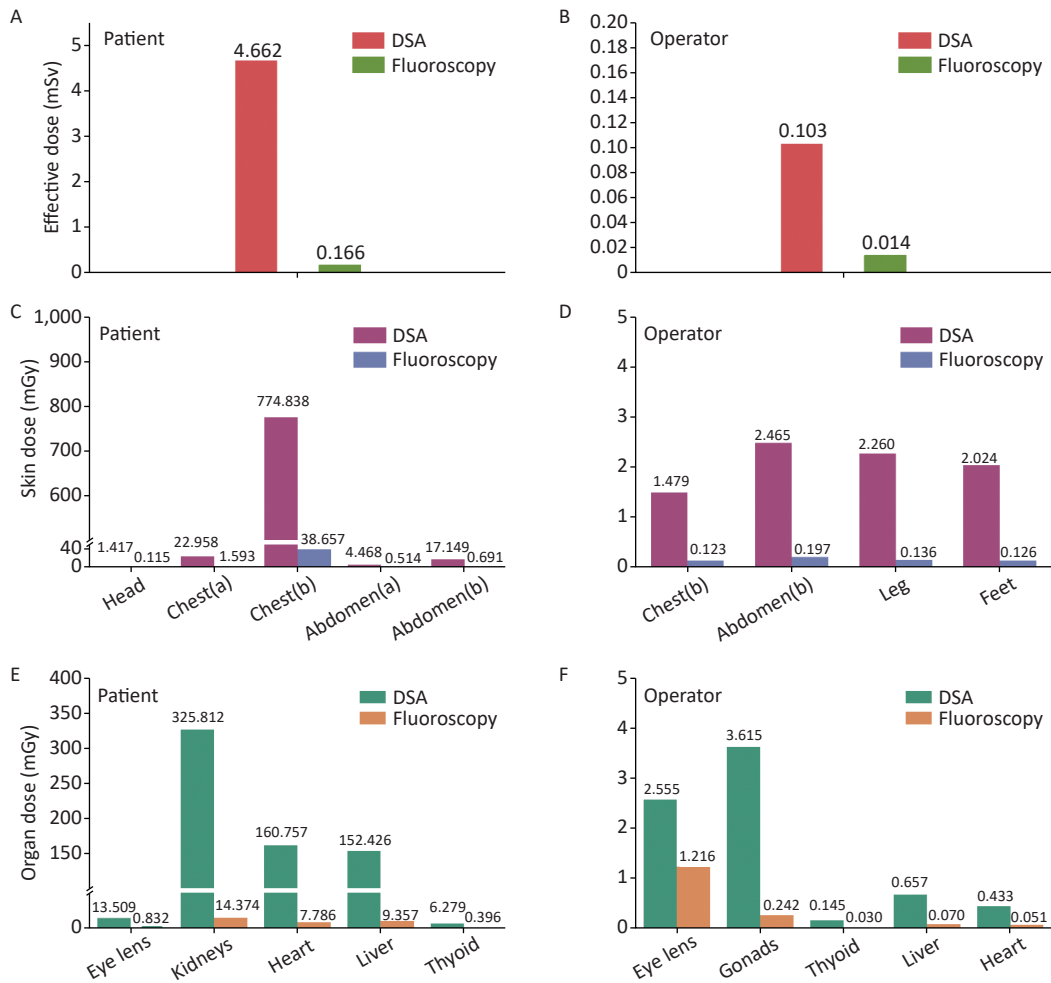


Figure 2. Effect of changing the radiation mode on patient and operator exposure. The patient radiation doses are on the left (A, C, and E), and the operator radiation doses are on the right (B, D, and F). Panels A) and B) show the effective dose for patient and operator, panels C) and D) show the skin dose for patient and operator, and panels E) and F) show the organ dose for patient and operator. Chest(a) = chest exit beam; Chest(b) = chest entrance beam; Abdomen(a) = abdomen exit beam; Abdomen(b) = abdomen entrance beam. Note the difference in y-axis scaling between two plots. DSA, digital subtraction angiography.

exposure as low as is reasonably achievable without lengthening the procedure duration or compromising patient safety. Accordingly, the regular use of radiation protection tools can drastically reduce occupational doses. Figure 3 (B, D, and F) show that the primary interventionist is exposed to considerably more radiation than the assistant. This likely reflects the position of the primary operator relative to the patient, with the operator positioned closest to the X-ray tube. The distance (different positions) provided a powerful shielding effect to the operator, with over 85% reduction in the ED to the whole body and an approximately 70% reduction in the absorbed dose for different portions of the skin. Organ doses were

also reduced by varying degrees. This explanation is strengthened by the fact that the safety equipment and fluoroscopic parameters did not differ between the two positions. Additionally, other researchers have demonstrated that increasing the distance is an important method for reducing operator radiation exposure by mimicking different operation positions in a hybrid operating room^[8]. These findings emphasize the importance of distance from the X-ray source as a factor in determining radiation exposure.

To better protect the health of medical professionals and patients, relevant measures can be taken to reduce the radiation dose in interventional medicine. However, this study had several

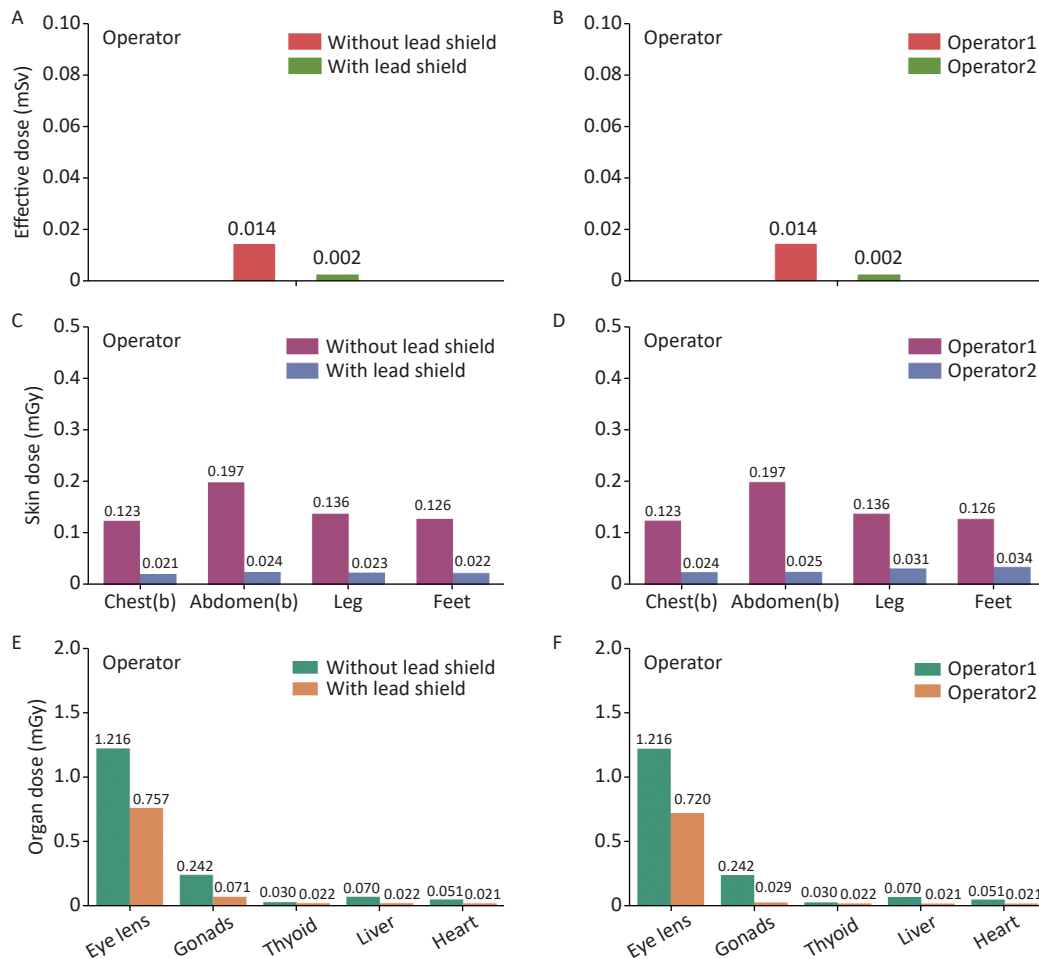


Figure 3. Efficacy of lead protection screen shielding and distance shielding for the operator. Panels (A) and (B) show the effective doses for the operator, panels (C) and (D) show the skin doses for the operator, and panels (E) and (F) show the organ doses for the operator. Chest(a) = chest exit beam; Chest(b) = chest entrance beam; Abdomen(a) = abdomen exit beam; Abdomen(b) = abdomen entrance beam; operator 1: primary operator, operator 2: assistant operator. The difference in y-axis scaling between two plots.

limitations. First, the phantom representing the operator did not wear a radiation protection garment (a lead apron). We aimed to simulate the most primitive radiation exposure scenario to measure the organ doses to the patient and operator. Second, the irradiation geometry in all exercises comprised an angulation of PA0° (undercouch exactly vertical). Patients with clinically relevant angulations were excluded. In future, these factors will be considered in the design of our subsequent studies.

[&]These authors contributed equally to this work.

[#]Correspondence should be addressed to WANG Qiang, Tel: 86-571-87758079, E-mail: zhifangwangqiang@163.com; YANG Lei, Tel: 86-571-28865010, E-mail: 20080009@hznu.edu.cn

Biographical notes of the first authors: ZHAO Zhi Xin, male, born in 1988, majoring in environmental Sciences; QIAN Pei Yi, female, born in 1997, majoring in public health.

Received: February 8, 2023;

Accepted: June 15, 2023

REFERENCES

1. Little MP, Kitahara CM, Cahoon EK, et al. Occupational radiation exposure and risk of cataract incidence in a cohort of US radiologic technologists. *Eur J Epidemiol*, 2018; 33, 1179–91.
2. Balter S, Hopewell JW, Miller DL, et al. Fluoroscopically guided interventional procedures: a review of radiation effects on patients' skin and hair. *Radiology*, 2010; 254, 326–41.
3. Loose R, Wucherer M. How to measure/calculate radiation dose in patients?. *Cardiovasc Intervent Radiol*, 2021; 44, 835–41.
4. Neto FAB, Alves AFF, Mascarenhas YM, et al. Occupational radiation exposure in vascular interventional radiology: a complete evaluation of different body regions. *Phys Med*, 2016; 32, 1019–24.
5. Artschan RER, Brettle DS, Chase K, et al. An investigation of the radiation doses to the lower legs and feet of staff undertaking interventional procedures. *Br J Radiol*, 2014; 87, 20130746.
6. Martin CJ, Magee JS. Assessment of eye and body dose for interventional radiologists, cardiologists, and other interventional staff. *J Radiol Prot*, 2013; 33, 445–60.
7. Valentin J. Avoidance of radiation injuries from medical interventional procedures. *Ann ICRP*, 2000; 30, 7.
8. Santos JS, Uusi-Simola J, Kaasalainen T, et al. Radiation doses to staff in a hybrid operating room: an anthropomorphic phantom study with active electronic dosimeters. *Eur J Vasc Endovasc Surg*, 2020; 59, 654–60.