Observational Study

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Does nonexistent of your hands on the screen guarantee no radiation exposure to your body? – Study on exposure of the practitioner's hands to radiation during C-arm fluoroscopy-guided injections and effectiveness of a new shielding device

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Abstract

Observational phantom study.

This study aimed to evaluate the radiation exposure dose of practitioner's hands when performing C-arm guided procedures and to determine the usefulness of our newly designed radiation shielding device.

C-arm guided procedures including lumbar transforaminal epidural steroid injections (TFESIs) are commonly used for pain control induced by lumbar radiculopathy. The practitioner's hands are vulnerable to radiation exposure because of the long exposure time and short distance from the radiation resource. No studies to date have reported the cumulative exposure of the physician's hands according to location and exposure time.

Using a chest phantom irradiated with X-rays under lumbar TFESI conditions, cumulative scatter radiation dose was measured at 36 points using a dosimeter. The measurements were checked at 1, 3, 5, 10 minutes of radiation exposure. The experiment was repeated using our newly designed shielding device.

Significant radiation accumulation was observed in the field where the practitioner's hands might be placed during C-arm guided procedures. The further the distance from the radiation resource and the shorter the exposure time, the smaller was the cumulative radiation expose dose. The new shielding device showed an excellent shielding rate (66.0%–99.9%) when the dosimeter was within the shielding range. However, at some points, increased accumulated radiation exposure dose was observed, although the dosimeter was within the range of the shielding device.

To reduce radiation exposure of the practitioner's hands when performing C-arm-guided procedures, the radiation exposure time should be decreased and a greater distance from the radiation resource should be maintained. When using our shielding device, placing the hand close to the device surface and minimizing the time using fluoroscopy minimized the radiation exposure of the hand.

Abbreviations: PEN = percutaneous epidural neuroplasty, TFESI = transforaminal epidural steroid injection.

Keywords: C-arm, fluoroscopy, hand protection, phantom study, practitioner, radiation exposure, shielding device

1. Introduction

Fluoroscopically assisted medical procedures are currently performed in many areas including lumbar transforaminal epidural steroid injections (TFESIs), percutaneous epidural neuroplasty (PEN), and ballooning PEN to treat pain originating from the lumbar spine. Most of these procedures are performed

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with C-arm fluoroscopy to obtain real-time anatomical information. C-arm fluoroscopy provides physicians with invaluable images that facilitate precise and effective intervention.

During C-arm guided injection procedures, as effective as they may be, patients are exposed to either direct or scatter radiation, while physicians are also exposed to scatter radiation. Scatter radiation is radiation that is scattered around the patient's tissue when the patient is directly exposed to the radiation beam. Accumulated exposure of radiation on the human body increases the risk of malignancies, skin problems, hematologic diseases, and ocular diseases.[1–4] To ensure the safety of the patient and the operator, it is important to measure the exact cumulative radiation exposure at each site. According to European Radiation Safety Standards, which provides the radiation exposure limits for both public and occupational workers, radiation exposure should not exceed 1 mSv/y for the body, 25 mSy/y for the thyroid, and 50 mSv/y for the hand.[5]

When performing C-arm guided procedures, the operator's hands are particularly vulnerable to scatter radiation. However, the exposure of the hands is often overlooked. Although the use of shielding gloves for hand protection reduces exposure by 33% to 86%;,[6–9] operators often prefer working without shielding gloves because these equipment interfere with the fine movement and sensation of the hand during the procedure.

In this study, we measured scatter radiation according to the direction and distance of a phantom from the radiation source, considering that the practitioner places their hand on the body of the patient during some time of the procedure. The purpose of our study was to find the location of relatively low exposure to scatter radiation in order to minimize the amount of exposure and protect the hands of the practitioner during C-arm guided procedures. We also sought to verify the effectiveness of a new, custom-designed shielding device.

2. Materials and methods

Fluoroscopic examinations were performed on an anthropomorphic phantom model (chest phantom PBU- 60, Kyoto Kagaku Inc, Kyoto, Japan), which was used to simulate the patient located on the operating table. Fluoroscopic screening was focused on the xiphoid process. This phantom was composed of human bones surrounded by acrylic with approximately the same density as human soft tissue and was of the type usually used for scatter radiation dose measurements.[10,11] A Philips mobile C-arm system (Artis Zee Biplane, 154719, Erlangen, Germany) was used for the fluoroscopic examinations, at 80 kVp, 5 mA, and a 17-cm field of view. To ensure that the radiation doses generated by C-arm fluoroscopy remain consistent, the auto brightness control option, which maintains the intensifier exposure rate according to the subject's thickness by adjusting various factors, was not used in this study. The standard C-arm configuration was used. In this configuration, the X-ray tube is located near the floor and the X-ray beam is projected toward the ceiling. The distance between the chest phantom on the operating table and the X-ray tube was 50 cm (Fig. 1).

Real-time radiation exposure data were collected using a commercially available multi-channel dosimetry system that contains a bedside monitor capable of displaying real-time

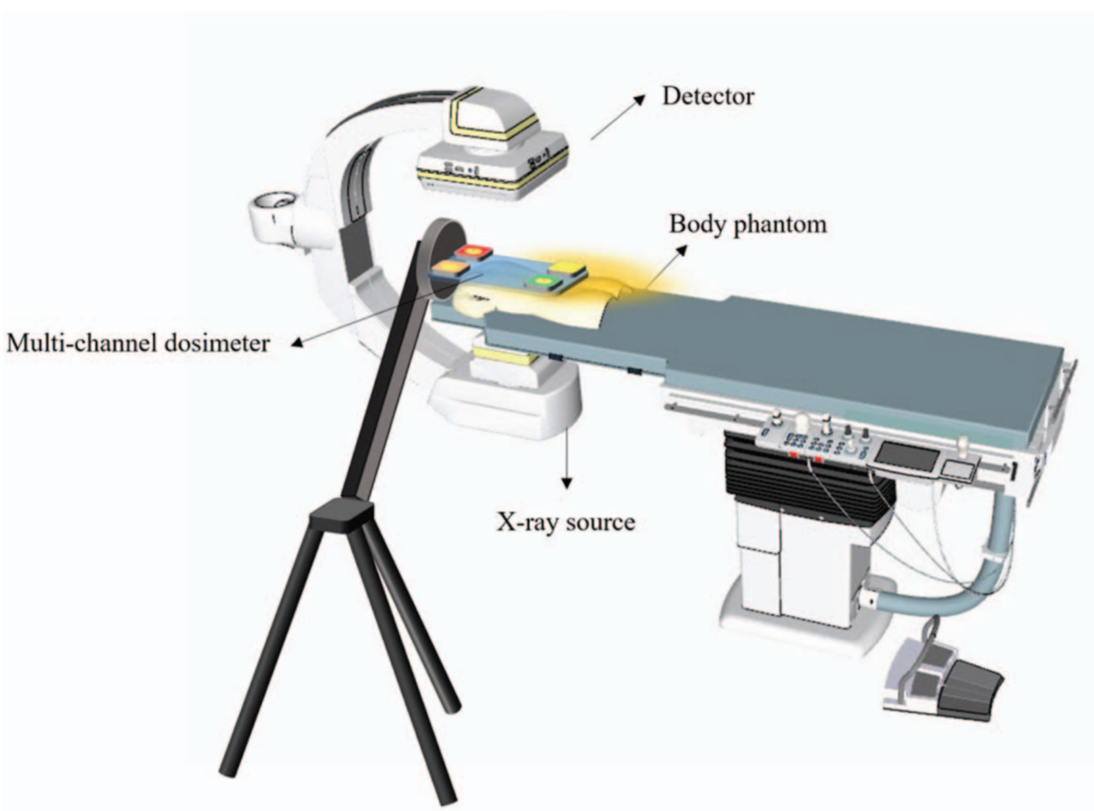

Figure 1. The chest phantom was laid on the operating table 50 cm above the X-ray tube. The fluoroscopic image was focused on the xiphoid process. Real-time radiation exposure data were collected using a commercially available multi-channel dosimetry system.

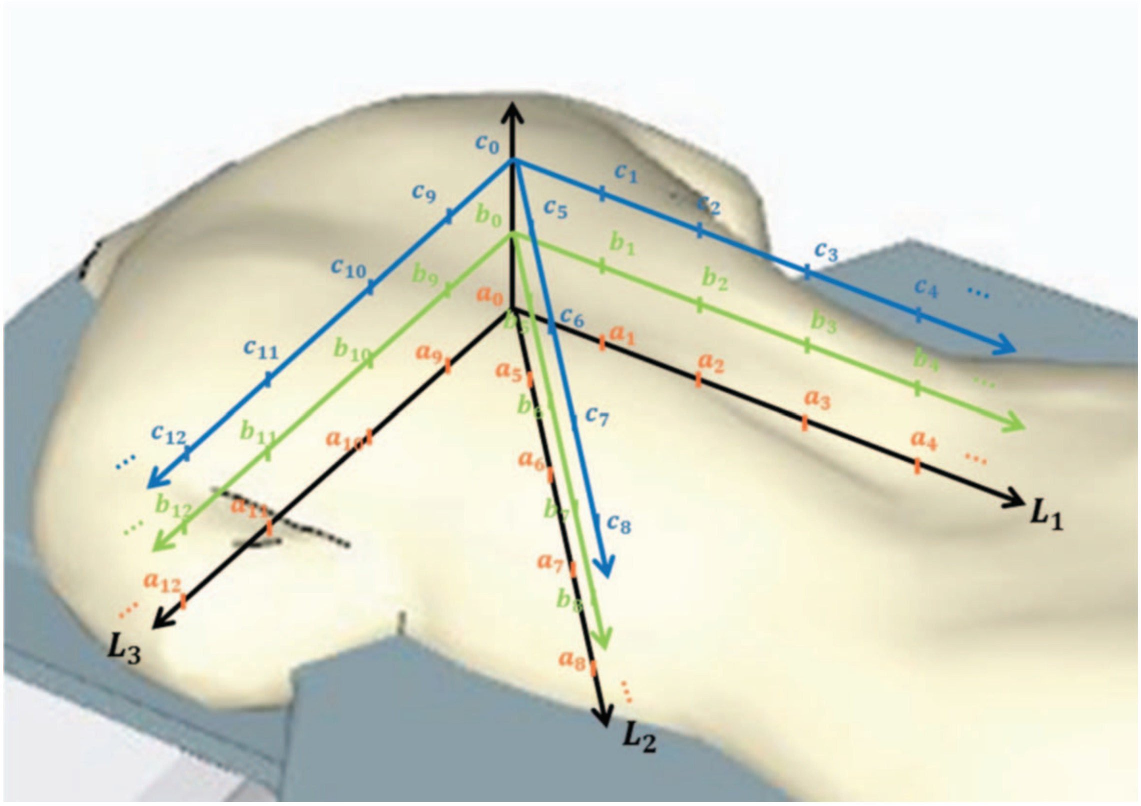

Figure 2. Air kerma rates as scatter radiation doses were collected at horizontal distances of 0 cm, 10 cm, 20 cm, and 30 cm from the xiphoid process of the chest phantom at 3 angular positions of 0° (L1), 45° (L2), 90° (L3), and 3 height planes, that is, 0 cm (A), 5 cm (B), and 10 cm (C). Measurements were made at 1, 3, 5, and 10 minutes.

radiation exposure data (RaySafe i2, Unfors RaySafe, Billdal, Sweden) during 10 minutes of continuous use of C-arm fluoroscopy. Radiation measurement was performed at horizontal distances of 0 cm, 10 cm, 20 cm, and 30 cm from the xiphoid process of the chest phantom, at 3 angular positions: 0° (L1), 45° (L2), 90° (L3), and 3 heights: at planes 0 cm (a), 5 cm (b), and, 10 cm (c) above the phantom, or above the shielding device (Fig. 2). Measurements were made at 1, 3, 5, and 10 minutes during continuous exposure.

We then repeated the same experiment using a newly designed shielding device. The equipment consists of 2-mm-thick pure lead and 3.2-mm-thick stainless steel, and it is shaped so that practitioners can insert their hands through the hole during procedure and can rest the hands outside the equipment for radiation protection. In Figure 3, the relationship between the chest phantom, shielding device, and the C-arm fluoroscopy device is shown.

Dose data are shown for each dosimetry measurement separately; these data included the current dose rate (μSv/h) and accumulated procedure dose (μSv). To ensure accurate functionality, the multi-channel dosimetry system was calibrated before being introduced into the clinical routine.

This study was exempted from requiring approval of the institutional review board of our institute because it involved no human subjects. This work was supported by a Biomedical Research Institute grant, Kyungpook National University Hospital (2018).

2.1. Statistical analysis

Descriptive statistics were used to present data.

3. Results

3.1. Radiation exposure without shielding device

Table 1 shows the radiation exposure dose in the absence of a shielding device. The radiation exposure dose was the lowest when the dosimeter was placed at a8 of L2 of the Phantom; plane "a" demonstrated a total accumulation of 36.6 μSv during 1 minute of exposure. Radiation exposure dose was the highest when the dosimeter was placed at a9 of L3, which detected a total accumulation of 2511.6 μSv during 10 minutes of exposure.

Measurements were then taken at plane "b," which was 5 cm higher than plane "a". The lowest radiation exposure dose was measured at b8 of L1 (26.7 μSv) after 1 minute of exposure, while the radiation exposure dose was the highest at b5 of L2 (2169.0 μSv) after 10 minutes of radiation exposure. A decrease of 1% to 28% in radiation exposure dose was observed for plane "b" when compared to plane "a".

Next, the same experiment was conducted at plane "c", which was 10 cm higher than plane "a". The radiation exposure dose was the lowest at c8 of L2 after 1 minute of exposure (33.1 μSv), and the highest at c9 of L3 after 10 minute of radiation exposure (2201.1 μSv). A decrease of 1–38% in radiation exposure dose was observed compared to plane "a".

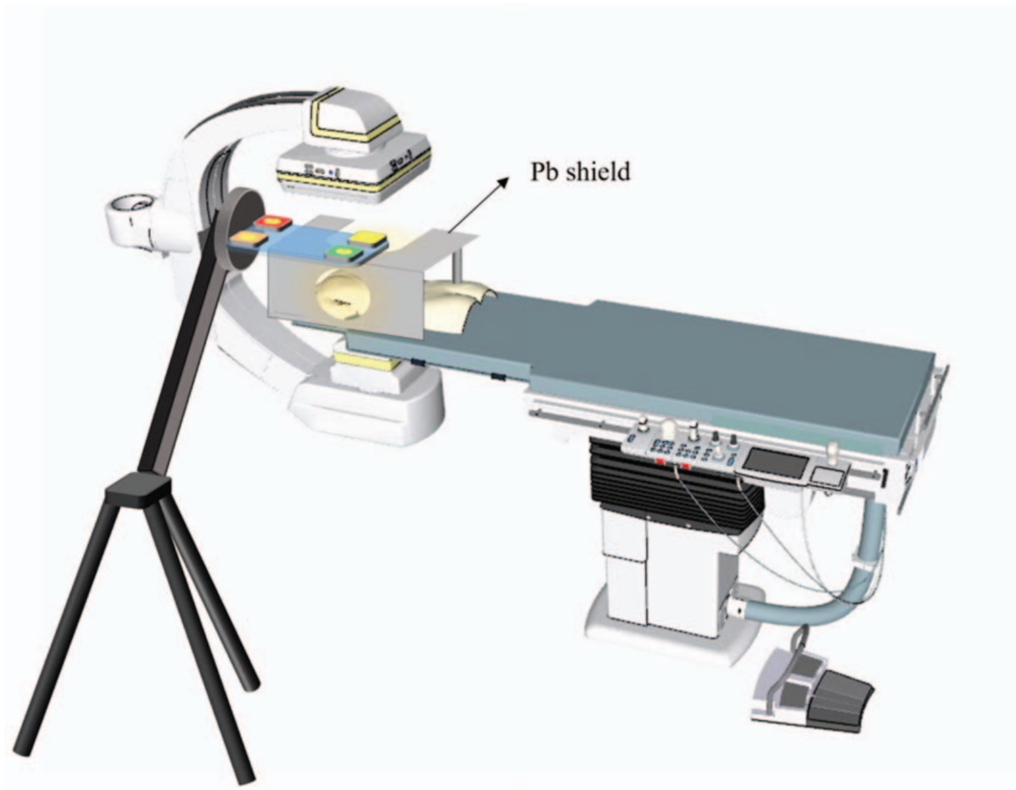

Figure 3. A photographic depiction of the relationship between the chest phantom, shielding device, and the C-arm controller. The C-arm is in the inverted configuration.

The measured radiation exposure dose was higher as the center of procedure field and the dosimeter coincided. When the dosimeter was at the same distance, radiation exposure dose positively correlated with radiation exposure time.

3.2. Radiation exposure with shielding device

Table 2 shows the radiation exposure dose measurements taken while using a shielding device. The radiation exposure dose at plane "a", which was the shielding device surface, showed the lowest value 0.5 μSv at a2 of L1 after 1 minute of exposure. The radiation exposure dose was the highest at a10 of L3 after 10 minutes of radiation (1339.5 μSv). Because a3 and a4 of L1 and a10, a11, and a12 of L3 were located outside of the shielding device, the radiation exposure doses were relatively high.

Next, measurements were taken at plane "b", which was 5 cm higher than plane "a". The radiation exposure dose was the lowest at b6 of L2 after 1 minute of exposure (0.4 μSv), and the accumulated radiation exposure dose was the highest at b10 of L3 after 10 minutes of exposure (1187.6 μSv).

Third, measurements were taken at plane "c", which was 10 cm higher than plane "a". The radiation exposure at c6 of L2 for 1 minute was the lowest (0.8 μSv), and the radiation exposure at c10 of L3 for 10 minutes was the highest (913.6 μSv).

As for plane "a", the radiation exposure doses were relatively high at b3, b4, c3, and c4 of L1, and b10, b11, b12, c10, c11, and c12 of L3, because they were located outside of the shielding device. A shielding rate of 66.0% to 99.9% was observed within the shielding device area; the shielding device thus significantly reduced the exposure dose. The shielding rate decreased as the distance from the shielding device increased, and a8 of L2 at plane "c" plane showed a shielding rate of 8.2% to 9.8%.

4. Discussion

This study revealed that the areas where a practitioner's hands would be located during fluoroscopically assisted procedures are exposed to a significant amount of radiation. The amount of exposure increased as the distance from the radiation resource decreased and as the exposure time increased. The shielding device we designed showed an excellent shielding rate (66.0%–99.9%) within the shielding device area. However, the study also showed that even in the presence of a shielding device, areas outside of the shielding range or areas far from the device can be exposed to a considerable amount of radiation. The radiation exposure dose increased as the vertical distance increased within the shielding device range. This phenomenon is thought to be caused by secondary scatter radiation.

Various approaches, such as using a personal protective device, decreasing fluoroscopy time, and modifying the position of the C-arm are used to reduce radiation exposure dose in the operating room.[12] In our study, we investigated the effect of a shielding device and the length of time that the hands are placed in direct radiation on radiation exposure dose. The amount of radiation exposure dose at the site where operator's hands are typically placed during intervention, or for watching fluoroscopy, as in procedures such as ballooning, was high. The closer the distance from the radiation source and the longer the exposure time, the greater was the radiation exposure dose (Table 1). Use of our shielding device significantly reduced the exposure dose within

Table 1

Radiation exposure dose at different points, without use of the shielding device.

Dosimeter placement	Exposure (μSv)			
	1 min	3 min	5 min	10 min
"a" plane				
L1				
a1	223.3	622.7	1015.8	2031.2
a2	198.2	546.2	889.6	1780.4
a3	86.6	235.9	389.1	764.3
a4	45.5	129.5	212.0	418.4
L2				
a5	220.0	615.1	1026.9	2177.4
a6	160.4	456.3	760.8	1512.2
a7	59.6	165.7	275.6	550.2
a8	36.6	102.3	170.7	339.9
L3				
a9	254.1	756.7	1257.7	2511.6
a10	215.1	643.2	1069.8	2130.5
a11	145.5	429.5	715.2	1423.4
a12	82.7	246.2	411.4	821.1
"b" plane				
L1				
b1	213.1	612.3	1007.4	2014.4
b2	145.3	436.4	726.8	1425.5
b3	77.0	229.8	382.5	766.2
b4	44.9	125.4	202.3	408.1
L2				
b5	205.8	584.6	1020.1	2169.9
b6	145.0	414.9	712.1	1401.3
b7	50.3	152.1	268.3	504.1
b8	26.7	77.9	157.7	300.2
L3				
b9	198.3	588.5	977.7	1988.1
b10	159.8	488.1	793.8	1554.3
b11	106.1	313.6	512.6	1024.6
b12	69.5	205.7	342.6	684.2
"c" plane				
L1				
c1	211.8	610.1	1002.1	2015.0
c2	123.3	367.9	620.1	1238.1
c3	73.7	221.0	372.4	741.2
c4	44.3	129.1	211.9	412.8
L2				
c5	165.7	491.8	814.8	1644.2
c6	110.0	328.3	542.9	1079.8
c7	52.1	159.3	274.1	545.7
c8	33.1	101.5	171.0	335.5
L3				
c9	224.7	666.3	1106.1	2201.1
c10	160.2	478.0	801.8	1594.8
c11	108.0	316.0	525.1	1045.5
c12	80.9	238.7	396.3	790.1

"a" plane: on the phantom surface, "b" plane: 5 cm above the "a" plane, "c" plane: 10 cm above the "a" plane. L1, L2, and L3 are the angular line at which the dosimeter is placed. L1 is parallel to the spine. L1: 0°, L2: 45°, L3: 90°. Each point on the line was placed away from the center at 5-cm intervals.

Table 2

Radiation exposure dose at different points with device.

Dosimeter placement	Exposure (μSv)			
	1 min	3 min	5 min	10 min
"a" plane				
L1				
a1	1.9	4.3	6.7	12.5
a2	0.5	1.8	1.8	2.3
a3	108.3	328.0	549.0	1093.2
a4	67.7	198.2	331.7	660.2
L2				
a5	2.9	8.0	13.1	23.3
a6	0.7	2.0	3.2	6.0
a7	2.5	8.1	13.6	25.1
a8	6.0	16.7	27.5	52.4
L3				
a9	0.7	2.9	5.1	11.0
a10	135.7	404.6	675.1	1339.5
a11	106.2	315.1	526.8	1048.7
a12	37.5	112.2	187.5	372.4
"b" plane				
L1				
b1	1.1	3.2	5.5	10.0
b2	0.5	1.5	2.7	5.1
b3	101.1	308.2	514.2	1025.4
b4	59.3	177.3	296.6	589.9
L2				
b5	1.2	2.8	4.8	9.9
b6	0.4	1.2	2.1	3.9
b7	1.0	3.9	7.5	15.0
b8	5.0	14.6	24.7	47.6
L3				
b9	1.1	3.1	5.2	11.2
b10	119.2	357.6	599.1	1187.6
b11	85.6	258.5	421.9	836.3
b12	27.6	82.8	137.7	262.5
"c" plane				
L1				
c1	18.9	57.2	95.1	201.2
c2	0.9	2.8	5.0	9.8
c3	20.3	62.5	105.2	206.4
c4	53.6	163.7	272.5	539.7
L2				
c5	32.1	0.8	3.5	30.4
c6	0.8	2.4	3.9	7.1
c7	3.5	9.6	15.8	29.9
c8	30.4	92.8	154.3	302.7
L3				
c9	75.0	220.5	362.5	748.9
c10	89.1	275.4	458.0	913.6
c11	91.7	273.9	454.4	906.9
c12	39.2	117.9	195.8	388.8

"a" plane: on the shielding device surface, "b" plane: 5 cm above the "a" plane, "c" plane: 10 cm above the "a" plane. The other settings are the same as in Table 1.

the shielding device range; however, there was a point where radiation accumulation was as high with as without the shielding device. In addition, higher radiation exposure dose was observed with the device at point a3 and a4 of the "a" plane, b3 and b4 of the "b" plane, and c4 of the "c" plane than without the device. This is considered to be due to a non-shielding area, given the shape of the shielding device, which has an open part to allow execution of the procedure, as well as due to secondary scatter radiation.

In previous studies on radiation exposure doses of surgeons using C-arm fluoroscopy intraoperatively,[13] scatter radiation exposure dose according to various distances and angles was measured using a phantom. Radiation was measured with increasing distance between the phantom and the surgeon, but the angle at which the surgeon was located was not focused on,[13] as they only measured the amount of scattering radiation in the range of more than 40 cm from X-ray beam. In contrast, we measured the amount of scattering radiation within procedure field.

In actual clinical practice, the body part that is most exposed to radiation during surgery or interventional procedure is the hands. In particular, the third fingertip is reported to be most affected in the absence of shielding.[14] Whitby et al[15] also showed a higher radiation dose at the end of the middle and ring finger of radiologists and cardiologists performing interventional procedures in the anteroposterior plane. In particular, it has been reported that the cumulative radiation dose causing percutaneous damage to the hands, increases during the procedure.[16,17] Shim et al[18] have reported a case of overall redness, swelling, warmth, pain, pruritus, and stiffness of the interphalangeal joint, fingernail atrophy, and soft tissue necrosis of the bilateral hands in an orthopedic surgeon who performed many spinal injections. The radiation dose to the hand is increased due to exposure to scatter radiation as well as direct radiation.[19] Arnstein et al[20] reported that 100-fold increased radiation exposure was observed when the hand of the surgeon entering the X-ray tube was located within 15 cm of the procedure field's center. In another study, radiation exposure of 40 μSv per minute was observed at the hand placed in the X-ray tube.[21] It is considered that within even about 12 minutes, the annual allowable radiation dose has been reached; it is recommended that the appropriate exposure time and use of appropriate radiation shielding devices be used given the danger of exposing hands directly to radiation. Our study also showed that the highest radiation dose in each plane was observed at exposure of 10 minutes, regardless of whether the shielding device was used; it is therefore necessary to establish and adhere to the most appropriate time for the procedure.

Various shielding devices have been recommended for reducing radiation exposure, and several shielding devices are used in actual fluoroscopy procedures. These devices include apparel, such as aprons, thyroid shields, eyewear, and gloves. There are also floor-mounted, ceiling, and procedure table shields, and mobile shields that are placed on patients. According to our experimental results, the highest density of scatter radiation occurs in the regions where the practitioners' hands are placed, which emphasizes the importance of wearing shielding gloves for safety. However, the usage rate of such gloves is low in practice, due to the discomfort of reduced feeling during interventional procedures and the costs of using disposable gloves made of lead vinyl.

The use of the shielding device designed in our study resulted in a high shielding rate and reduced radiation exposure dose. In another study, a 42.9% to 86.1% shielding rate was obtained when using a shielding drape made of a lead sheet during vertebroplasty.[6] Another study also reported a shielding rate of 98.7% when using a shielding method involving a lead sheet.[22] Sergio et al[23] suggested that using a disposable shielding pad made of lead-free tungsten antimony could reduce radiation exposure due to a direct X-ray beam exposure. However, the above studies did not consider the various directions of scatter radiation[6,22] and did not show significantly improved shielding, despite using multiple shielding layers.[23] In addition, these studies did not considered radiation exposure in the intervention field in which the practitioner's hands would be placed, unlike in our study. When using our shielding device, the maximum shielding rate was above 99.7%, at a2 of L1 in the "a" plane.

Our study had some limitations. First, we only measured the C-arm fluoroscopy standard configuration to measure the radiation exposure dose to the practitioner's hands in the experiment. However, there is an increased risk of scatter radiation exposure at the operation site. Thus, a study of direct and scatter radiation generated in a variety of configurations, such as inverted, standard, translateral, and translateral (tube) is required. Second, we did not perform scatter radiation measurements using various procedures and phantoms representing patients. This should be addressed in future studies. Third, our experiments were only conducted to measure radiation exposure during lumbar procedures, such as TFESIs; further studies should be conducted at various spinal levels, such as cervical level procedures. Fourth, it is necessary to measure the scatter radiation dose that is generated by the procedure table and procedure devices, besides the radiation scattered by the patient. Fifth, this experiment was conducted in vitro, and further studies involving in vivo environments should be conducted. The position of the hand during procedures is not consistent in reality, and therefore in vivo studies may better reflect the accumulation of radiation in the everyday clinical field.

We investigated the amount of radiation exposed to the surgeon's hand in the procedure field and also recorded the amount of radiation in the presence of a newly designed shielding device. Although the shielding effect of the shielding device has been proven in our experiment, the use of this shielding device is problematic, as it runs the risk of falling, due to its heavy weight, which can inconvenience both the surgeon and the patient, and can cause failure of the C-arm machine during surgery. Therefore, it is necessary to develop a customized shielding device for the field of interventional procedures. In addition, the surgeon needs to consider various factors for reducing radiation exposure, such as altering the procedure time and procedure location, and remaining as far away as possible from a 45-degree angle in order to reduce radiation exposure.

5. Conclusion

C-arm fluoroscopy-guided procedures including TFESI involve a marked risk of radiation exposure of the hands. In order to reduce the radiation exposure of the hands, it is necessary to reduce the exposure time during the procedure and to keep an appropriate distance from the radiation resource. Using appropriate shielding device, such as shielding gloves, is highly recommended. When using a shielding device such as the one we designed, it is recommended to keep the hands as close as possible to the device surface, to remain within the device's shielding range, and that fluoroscopy be performed as rapidly as possible to reduce the risk of radiation exposure.

Author contributions

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