A Cadaveric Simulation Study of Radiation Exposure to the Surgical Team during Fluoroscopic Spinal Surgery: How Much Are We Exposed?

Kazuta Yamashita[1], Yasuaki Tamaki[1], Daiki Nakajima[1], Yasuyuki Omichi[1], Yoshinori Takahashi[1], Michihiro Takai[1], Tomohiro Goto[1], Hiroaki Hayashi[2], Kosaku Higashino[1], Yoshihiro Tsuruo[3] and Koichi Sairyo[1]

1) Department of Orthopedics, Institute of Biomedical Sciences, Tokushima University Graduate School, Tokushima, Japan
2) Department of Pharmaceutical and Health Sciences, Kanazawa University Graduate School, Ishikawa, Japan
3) Department of Anatomy, Tokushima University Graduate School, Tokushima, Japan

Abstract:

Introduction: The harmful effects of long-term low-dose radiation have been well known. There are few comprehensive reports evaluating concrete real exposure doses for each part of a surgeon, assistant surgeon, scrub nurse, and anesthesiologist associated with fluoroscopic spinal procedures. This research aimed to quantify the radiation exposure dose to surgical team members during C-arm fluoroscopy-guided spinal surgery.

Methods: Seven fresh cadavers were irradiated for 1 and 3 min with C-arm fluoroscopy. The position of the X-ray source was under the table, over the table, and laterally. The radiation exposure doses were measured at the optic lens, thyroid gland, and hand in mannequins used to simulate surgical team members.

Results: A significant difference was observed in the radiation exposure dose according to the position of the X-ray source and the irradiated body area. The risk of scatter radiation exposure was the biggest for the lateral position (nearly 30-fold that for the position under the table). All radiation exposure doses were positively correlated with irradiation time.

Conclusions: The occupational radiation exposure dose to surgical team members during C-arm fluoroscopy-guided lumbar spinal procedures varies according to the X-ray source position. Our findings would help surgical team members to know the risk of radiation exposure during various fluoroscopic procedures. Surgeons in particular need to reduce their radiation exposure by using appropriate shielding and technique.

Keywords:

radiation exposure, fluoroscopy, cadaver study, minimally invasive surgery, scatter radiation, occupational radiation exposure

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Introduction

Fluoroscopy images provide surgeons and physicians with useful information that would help determine the proper and valid procedures. Spine surgery and procedures are heavily dependent on C-arm fluoroscopy for determining the vertebral levels, insertion point, and angle of pedicle screw and assessing instrumentation during reconstructive procedures. Minimally invasive spine surgery is now used to treat a variety of degenerative and trauma-related spinal disorders and deformities.

However, surgical team members are exposed to scatter radiation owing to their proximity to the fluoroscope and the long duration and high frequency of fluoroscopy-guided procedures. Radiation exposure associated with fluoroscopy has raised concerns regarding potential health effects, especially cancer development[1,2]. The degree of risk associated with radiographic imaging has been extensively debated for many years[3,4].

Although there are many studies about the radiation exposure dose during irradiation of phantom[5-7] or cadaveric torsos[5,6], to the best of our knowledge, few studies have accurately simulated the real clinical setting to investigate the radiation exposure dose to the surgical team, including the

Corresponding author: Kazuta Yamashita, yamashita.kazuta.2@tokushima-u.ac.jp
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Table 1. Demographic and Anthropometric Characteristics of the Cadavers.

	Age	Gender	Weight (kg)	Height (cm)	BMI (kg/m^2)	Diameter of trunk (cm)	
						AP	Lateral
cadaver 1	69	Male	61	171	23.6	22	34
cadaver 2	76	Female	65	169	23.3	22	32
cadaver 3	71	Male	42	167	15.1	18	30
cadaver 4	83	Female	43	147	19.9	16	27
cadaver 5	94	Male	40	155	16.7	16	27
cadaver 6	51	Male	100	175	32.7	23	38
cadaver 7	65	Male	60	156	24.7	20	30
Ave	72.7±13.6		58.7±20.9	162.9±10.2	22.3±5.9	19.6±2.9	31.1±3.9

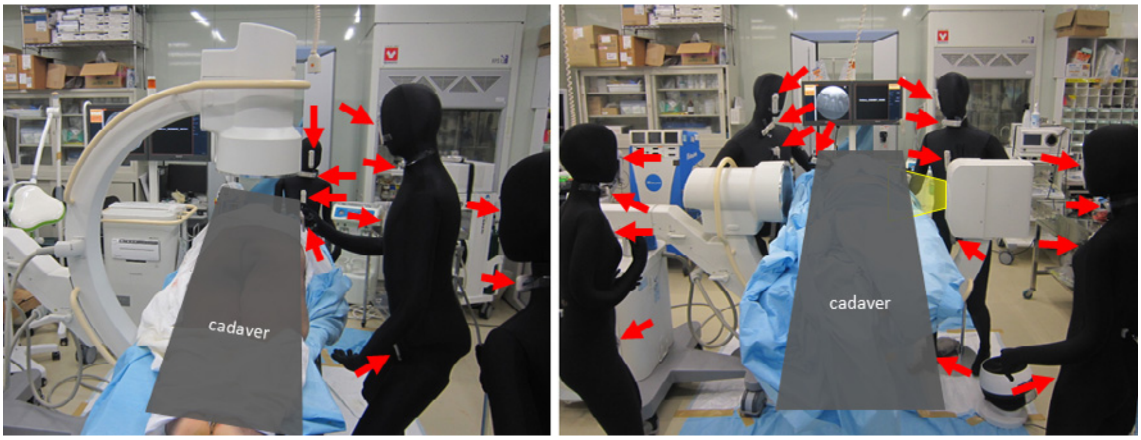

Figure 1. Photograph showing the placement of the cadavers and mannequins used in this study.
The X-ray source is under the table in the left panel and in the lateral position in the right panel. The arrows indicate real-time dosimeters mounted onto individual arrays located at each anatomic site.

scrub nurse and anesthesiologist, in fluoroscopic spine surgery with real-time imaging.

This study aimed to quantify the real radiation exposure dose from C-arm fluoroscopy at various anatomic sites in surgical team members under various conditions during spine surgery.

Materials and Methods

Seven defrosted intact fresh cadavers (five males, two females) were used to simulate patients. The mean height was 162.9 (range, 147-175) cm, and the mean body weight was 58.7 (range, 40-100) kg. The mean lateral width of the trunk was 31.1 (range, 27-38) cm, and the mean anteroposterior width of the trunk was 19.6 (range, 16-23) cm (Table 1). Five mannequins with movable joints were used to simulate the surgical team. Two mannequins were used as surgeons (height, 180 cm) and three as nurses and the anesthesiologist (height, 160 cm). Real-time dosimeters were used to measure the radiation exposure dose during simulation of common fluoroscopic spinal procedures (Fig. 1, 2). The study was approved by our hospital ethics committee.

Instrumentation

The cadavers were exposed to radiation using a BV Vectra C-arm fluoroscopy system (Philips, Eindhoven, Netherlands). The distance of the focus-to-image intensifier was 80 cm. The machines were calibrated at 6-month intervals. An adjustable radiolucent surgical table (MOT-5602BW; Mizuho Medical Co., Ltd, Tokyo, Japan) was used to position the cadavers. A total of 16 real-time dosimeters (MYDOSE mini, Hitachi Aloka Medical, Tokyo, Japan) with a single setting were mounted onto individual arrays on each mannequin. These dosimeters can accurately detect radiation exposure in the range of 0-9999 millisieverts (mSv). The radiation dose was recorded in microsieverts (μSv).

C-arm setting

The C-arm fluoroscopy system was set to automatic mode so that the technical factors, including voltage and electric current, were automatically adjusted to optimize image quality. The system was tested in three different configurations. First, the X-ray source of the system was positioned under the radiolucent table with the distance between the source and table set to 30 cm (Fig. 3). Second, the X-ray source was positioned over the radiolucent table with the distance

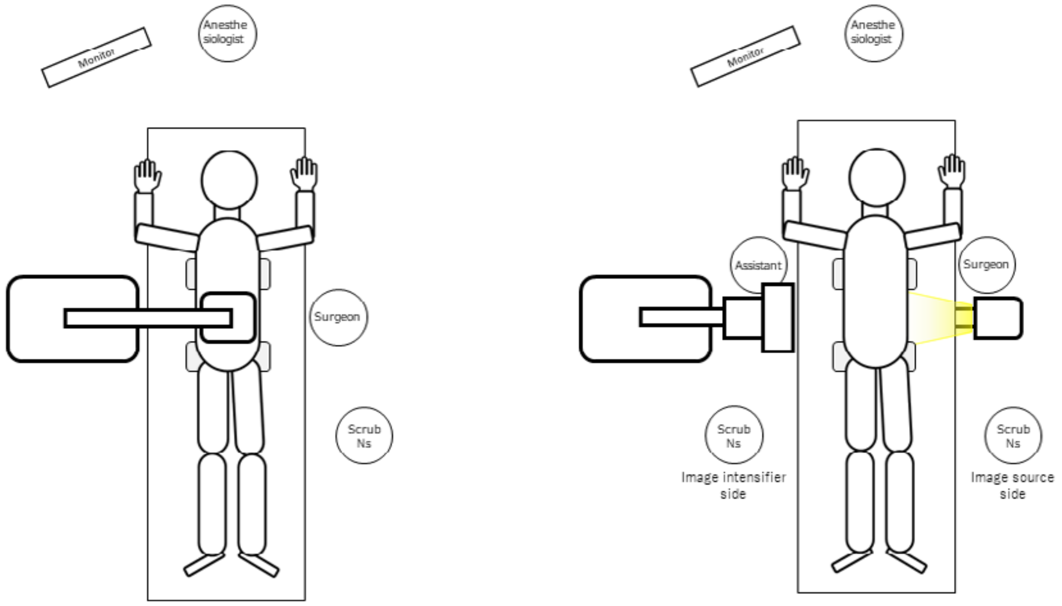

Figure 2. Location of the cadaver, mannequin, and C-arm fluoroscopy system. The X-ray source is under or over the table in the left panel and in the lateral position in the right panel.

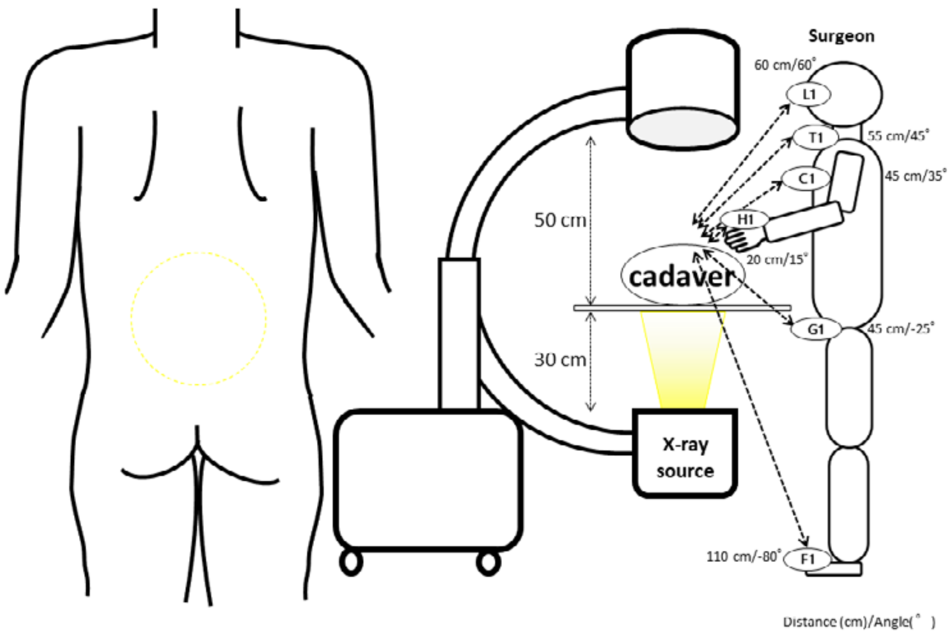

Figure 3. The position of the X-ray source and dosimeters during testing.
The X-ray source is under radiolucent table.
The distance and angle of each dosimeter from the center of the irradiation field were as follows: Surgeon (L1; 60 cm/60°, T1; 55 cm/45°, H1; 20 cm/15°, C1; 45 cm/35°, G1; 45 cm/−25°, F1; 110 cm/−85°), Scrub nurse (L2; 105 cm/25°, T2; 110 cm/10°, C2; 105 cm/5°, G2; 110 cm/−20°, F2; 110 cm/−70°), Anesthesiologist (L3; 185 cm/10°, T3; 185 cm/5°, C3; 185 cm/0°, G3; 185 cm/−10°, F3; 185 cm/−20°)

between the source and table set to 50 cm (Fig. 4). Third, the X-ray source was positioned to the side of the cadaver with the distance between the source and surface of the cadaver set to 25 cm (Fig. 5). The cadavers were then irradiated for 1 and 3 min. The beam was centered on the L3 vertebra. C-arm fluoroscopic imaging was performed in continuous mode without magnification or collimation. The technical X-ray source factors (i.e., kilovolt peak (kV) and milliamperes (mA)) were recorded for each test.

Dosimeter positioning

The X-ray source position: under the table or over the table

All 16 dosimeters measured the scatter radiation exposure

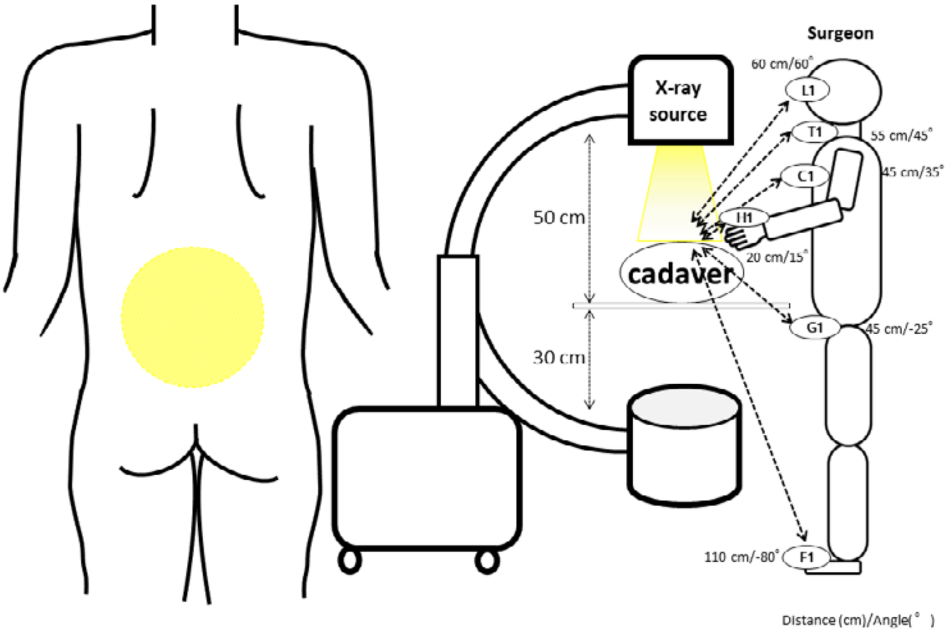

Figure 4. The position of the X-ray source and dosimeters during testing.
The X-ray source is over radiolucent table.
The distance and angle of each dosimeter from the center of the irradiation field were as follows: Surgeon (L1; 60 cm/60°, T1; 55 cm/45°, H1; 20 cm/15°, C1; 45 cm/35°, G1; 45 cm/−25°, F1; 110 cm/−85°), Scrub nurse (L2; 105 cm/25°, T2; 110 cm/10°, C2; 105 cm/5°, G2; 110 cm/−20°, F2; 110 cm/−70°), Anesthesiologist (L3; 185 cm/10°, T3; 185 cm/5°, C3; 185 cm/0°, G3; 185 cm/−10°, F3; 185 cm/−20°)

of each organ for the surgeon, scrub nurse, and anesthesiologist. When the X-ray source was positioned under and over the table (Fig. 1, 2, 3, 4), 16 real-time dosimeters were mounted onto individual arrays as follows. The first to the sixth dosimeters were positioned for the surgeon. The first dosimeter was fixed at the position of optic lens (L1). The second was fixed at the position of the thyroid gland (T1). The third was fixed at the position of the hand (H1). The fourth was fixed at the position of the chest (C1). The fifth was fixed at the position of the gonad (G1). The sixth was fixed at the position of the foot (F1). Similarly, the 7th to 11 th dosimeters were positioned for scrub nurse (L2, T2, C2, G2, F2), and the 12th to 16th dosimeters were positioned for the anesthesiologist (L3, T3, C3, G3, F3) (See Fig. 2, 3, 4). The distance and angle of each dosimeter from the center of the irradiation field were as follows: surgeon (L1; 60 cm/60°, T1; 55 cm/45°, H1; 20 cm/15°, C1; 45 cm/35°, G1; 45 cm/−25°, F1; 110 cm/−85°); scrub nurse (L2; 105 cm/25°, T2; 110 cm/10°, C2; 105 cm/5°, G2; 110 cm/−20°, F2; 110 cm/−70°); and anesthesiologist (L3; 185 cm/10°, T3; 185 cm/5°, C3; 185 cm/0°, G3; 185 cm/−10°, F3; 185 cm/−20°).

The X-ray source position: lateral position

All 27 dosimeters measured the scatter radiation exposure of each organ for the surgeon (stood at the X-ray source side), assistant surgeon (stood at the image intensifier side), scrub nurse at the X-ray source side, scrub nurse at the image intensifier side, and anesthesiologist. When the X-ray source was positioned at the side of the cadaver (Fig. 1, 2, 5), 27 real-time dosimeters were mounted onto individual arrays as follows. As described for under and over the table, the 1st to 6th dosimeters were positioned for the surgeon (L1, T1, H1, C1, G1, F1), the 7th to 12th dosimeters were positioned for the assistant surgeon (L4, T4, H4, C4, G4, F4), the 13th to 7th dosimeters were positioned at the scrub nurse at the X-ray source side (L2, T2, C2, G2, F2), the 18th to 22nd dosimeters were positioned for the scrub nurse at the image intensifier side (L5, T5, C5, G5, F5), and the 23rd to 27th dosimeters were positioned for the anesthesiologist (L3, T3, C3, G3, F3) (see Fig. 2, 5a, 5b). The distance and angle of each dosimeter from the center of the irradiation field were as follows: surgeon (L1; 60 cm/60°, T1; 55 cm/45°, H1; 20 cm/15°, C1; 45 cm/35°, G1; 45 cm/−25°, F1; 110 cm/−80°); assistant (L4; 60 cm/60°, T4; 55 cm/45°, H4; 20 cm/15°, C4; 45 cm/35°, G4; 45 cm/−25°, F4; 110 cm/−80°); scrub nurse at the X-ray source side (L2; 105 cm/25°, T2; 110 cm/10°, C2; 105 cm/5°, G2; 110 cm/−20°, F2; 110 cm/−70°); scrub nurse at the image intensifier side (L5; 105 cm/25°, T5; 110 cm/10°, C5; 105 cm/5°, G5; 110 cm/−20°, F5; 110 cm/−70°); and anesthesiologist (L3; 185 cm/10°, T3; 185 cm/5°, C3; 185 cm/0°, G3; 185 cm/−10°, F3; 185 cm/−20°).

Statistical analysis

Each exposure dose was analyzed and compared using the unpaired *t*-test (SPSS software 11.0 J, Tokyo, Japan). *P*-value <0.05 indicated statistical significance.

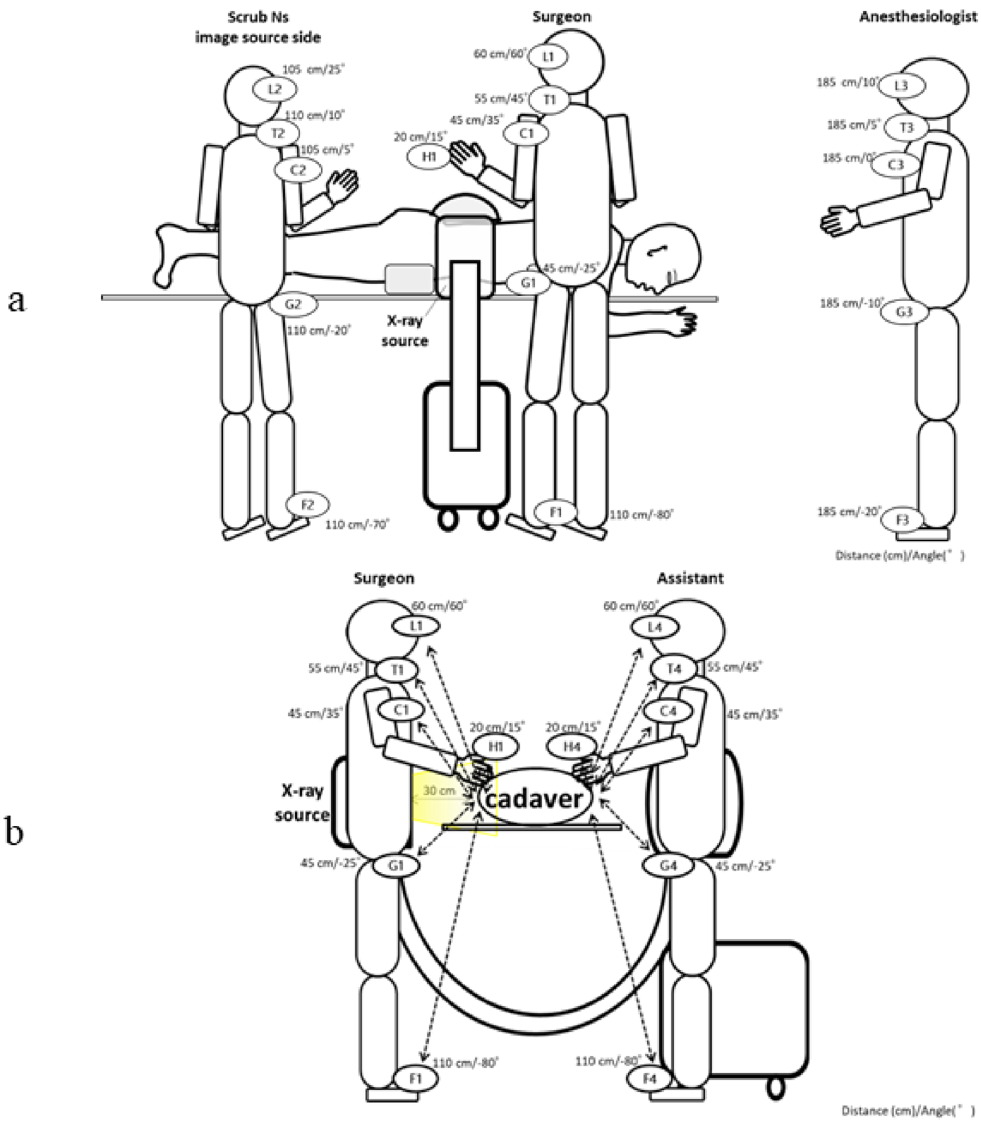

Figure 5. The position of the X-ray source and dosimeters during testing.
The X-ray source is positioned at the lateral side of the cadaver.
a; View from the lateral side
b; View from the cranial side
The distance and angle of each dosimeter from the center of the irradiation field were as follows: Surgeon (L1; 60 cm/60°, T1; 55 cm/45°, H1; 20 cm/15°, C1; 45 cm/35°, G1; 45 cm/−25°, F1; 110cm/−80°), Assistant (L4; 60 cm/60°, T4; 55 cm/45°, H4; 20 cm/15°, C4; 45 cm/35°, G4; 45 cm/−25°, F4; 110 cm/−80°), Scrub nurse at the X-ray source side (L2; 105 cm/25°, T2; 110 cm/10°, C2; 105 cm/5°, G2; 110 cm/−20°, F2; 110 cm/−70°), Scrub nurse at the image intensifier side (L5; 105 cm/25°, T5; 110 cm/10°, C5; 105 cm/5°, G5; 110 cm/−20°, F5; 110 cm/−70°), Anesthesiologist (L3; 185 cm/10°, T3; 185 cm/5°, C3; 185 cm/0°, G3; 185 cm/−10°, F3; 185 cm/−20°)

Results

X-ray source positioned under the table

The mean voltage and mean electric current of C-arm fluoroscopy were 65.6 kV and 1.89 mA, respectively. The mean radiation exposure to the surgeon, scrub nurse, and anesthesiologist for 1 and 3 min of exposure are presented in Table 2.

X-ray source positioned over the table

The mean voltage and mean electric current of C-arm fluoroscopy were 66 kV and 1.94 mA, respectively. The mean radiation exposure to the surgeon, scrub nurse, and anesthesiologist for 1 and 3 min of exposure are presented in Table 2.

X-ray source positioned laterally

The mean voltage and mean electric current of C-arm

Table 2. Average Scatter Radiation Exposure during a Fluoroscopic Procedure when the X-ray Source Is Located under or over the Operating Table.

		kV	mAs	μSv															
				Surgeon						Scrub Ns					Anesthesiologist				
				L1	T1	H1	C1	G1	F1	L2	T2	C2	G2	F2	L3	T3	C3	G3	F3
Under table	1 min	65.6±6.9	1.89±0.56	0.94±0.8§	1.86±1.1	17±6.6	2±0.6	5.86±3.8†	4.57±3.3	0.09±0.1	0.04±0.1	0.33±0.5	1.09±1.5	0.86±0.7	0±0	0±0	0±0	0±0	0±0
	3 min			2.57±2.1	5.57±2.9	51.7±21.4	5.57±1.9	17.8±11.9	14.2±10.1	0.43±0.5	0.43±0.5	1.29±1.6	3.14±4.3	2.43±2.3	0±0	0±0	0±0	0±0	0±0
Over table	1 min	66±6.9	1.94±0.52	9.43±5.4§	9.86±7.6*	90±95*	14±10.4	1.29±1.1†	0.09±0.2	2.15±2.3	1.15±1.3	1.15±0.9	0±0	0.04±0.1	0.39±0.7	0.14±0.4	0±0	0±0	0±0
	3 min			28.8±16.1	29.7±22.9	270±284	41.9±31	4.29±4.2	0.86±1.2	6.57±6.5	3.57±3.9	2.86±2.9	0.143±0.4	0.14±0.4	1.71±2.3	0.86±1.2	0.29±0.8	0.29±0.8	0.14±0.4
Over/Under ratio				11.2	5.3	5.2	7.5	0.2	0.06	15.3	8.3	2.2	0.04	0.05					

*$P<0.01$, §$P<0.01$, †$P=0.0107$. Unpaired *t*-test. L, optic lens; T, thyroid gland; H, hand; C, chest; G, gonads; F, foot

fluoroscopy were 87.4 kV and 2.89 mA, respectively. When the source was positioned laterally, these parameters were higher than those of fluoroscopy with the source positioned under or over the table. The mean radiation exposure to the surgeon, assistant surgeon, scrub nurse at the X-ray source side, scrub nurse at the image intensifier side, and anesthesiologist for 1 and 3 min of exposure are presented in Table 3.

For the surgeon, the scatter radiation exposure dose of the H1 dosimeter, which was closest from the irradiation field, was significantly higher than that of the T1 dosimeter when the source was positioned over the table and laterally ($P<0.01$) (Table 2*, Table 3*). A large difference was observed in the scatter radiation exposure between the X-ray source positions. For example, the scatter radiation exposure dose of the L1 dosimeter when the X-ray source was over the table was significantly higher than that of the dosimeter when the source was under the table ($P<0.01$) (Table 2§), and the over/under ratio was 11.2. Similarly, the scatter radiation exposure dose of the G1 dosimeter when the X-ray source was under the table was significantly higher than that of the dosimeter when the source was over the table ($P=0.01$) (Table 2†), and the over/under ratio was 0.2. The scatter radiation exposure doses of the L1, T1, H1, C1, and G1 dosimeters when the source was positioned laterally were significantly higher than those of the dosimeters when the source was under and over the table ($P<0.01$), and the lateral/under ratios were 28.6, 28.4, 27.7, and 6.7, respectively (Table 3).

When the X-ray source was positioned laterally, the scatter radiation exposure of the H1 dosimeter was significantly higher than that of the H4 dosimeter ($P<0.01$) (Table 3†). Similarly, the scatter radiation exposure of the L1 dosimeter was higher than that of the L4 dosimeter, but the differences were not significant ($P=0.34$) (Table 3§). For scrub nurse, the scatter radiation exposure of the L2 dosimeter was significantly higher than that of the L5 dosimeter ($P=0.026$) (Table 3⁑).

A significant positive correlation was observed in the relationship between the radiation exposure dose of scatter radiation (the L1, H1, and G1 dosimeters of the surgeon) for C-arm fluoroscopy and irradiation time (Fig. 6).

Discussion

In this study, we systematically quantified the radiation exposure dose to the surgical team members during the use of C-arm fluoroscopy to image the lumbar spine with the X-ray source in different positions. We identified the real exposure doses at different anatomic sites in the surgeon, assistant surgeon, scrub nurses, and anesthesiologist. The main findings in this study were as follows: 1) the scatter radiation exposure was greater when C-arm fluoroscopy was performed with the X-ray source in the lateral position than when under or over the table, and 2) the scatter radiation exposure was much higher on the X-ray source side than on the image intensifier side when the source was positioned

Table 3. Average Scatter Radiation Exposure during a Fluoroscopic Procedure when the X-ray Source Is Located in the Lateral Position.

		kV	mAs	μSv											
				Surgeon						Assistant					
				L1	T1	H1	C1	G1	F1	L4	T4	H4	C4	G4	F4
Lateral Position	1 min	87.4±13.9	2.89±0.09	24.3±16.5§	51.6±42.9*	466.4±331*†	60.9±49.8	39.4±41.9	2.54±1.5	16.7±11.6§	15.4±6.1	38.7±25.6†	10.7±5.9	1.75±2	2±1.3
	3 min			73.7±49.7	158.4±130	1412±973	196.1±163.7	119.1±125.7	8.14±5	50.1±34.9	46±18.9	111.6±75.5	32.9±18.6	5.43±6.1	5.86±3.6
Lateral/Under ratio				28.6	28.4	27.7	35.2	6.7	0.57						

		kV	mAs	Scrub Ns X-ray source side					Scrub Ns image intensifier side					Anesthesiologist				
				L2	T2	C2	G2	F2	L5	T5	C5	G5	F5	L3	T3	C3	G3	F3
Lateral position	1 min	87.4±13.9	2.89±0.09	17.7±13.2‡	16.7±14.3	17.3±15	8.86±9.9	2.21±3.1	4.43±4.5‡	2.14±2.6	1.57±1.9	0.47±0.5	1.57±1.8	1.77±1.8	1.71±1.4	1.04±1.3	1.29±1.4	0.71±0.9
	3 min			54±39.6	50.7±43	52±45.6	26.4±29.2	7±9.1	13.6±12.9	6.57±7.8	4.57±5.2	1.71±1.4	5.29±5.4	5.14±5.1	4.57±3.6	3.29±3.9	3.71±3.3	2.29±3
Lateral/Under ratio				125	117	40.3	8.4	2.8										

*$P<0.01$, §$P=0.339$, †$P<0.01$, ‡$P=0.027$. Unpaired *t*-test. L, optic lens; T, thyroid gland; H, hand; C, chest; G, gonads; F, foot

laterally.

In this study, as expected, a positive correlation was observed between the radiation exposure dose measured at all sites and the irradiation time at every position of the X-ray source. The surgeon should use one-shot or pulsed fluoroscopy[7]. Pulsed irradiation is useful for reducing the irradiation time when performing a procedure that requires continuous irradiation, such as balloon kyphoplasty. In a cadaveric study by Yamashita et al., radiation exposure associated with the use of pulsed fluoroscopy (8 times per second) was reduced by approximately 30% for the patient and approximately 70% for the surgeon's hand and thyroid gland when compared with the use of continuous fluoroscopy[8].

Many studies have demonstrated that the bigger the distance between the X-ray source and the surgeon, the smaller the radiation exposure to the surgeon[9]. In the present study, the radiation exposure doses to the scrub nurse and anesthesiologist were much lower than those to the surgeon and assistant surgeon as the scrub nurse and anesthesiologist were farther from the irradiated field. The anesthesiologist was exposed to almost zero radiation, except when the X-ray source was positioned laterally.

Spine surgeons have difficulty putting an adequate distance between themselves and the irradiated field as they normally need to be close to the trunk of the patient when performing a spinal procedure. In our study, the surgeon's hands were exposed to a very high radiation dose as their hands are usually the body part closest to the irradiated field during surgery. We calculated that the surgeon's optic lens was exposed to a radiation dose of 24.3 μSv/min when the X-ray source was positioned laterally. Thus, it would take 833 min of exposure to reach the annual dose safety limit for the optic lens. Similarly, it would require 1072 min of exposure to reach the annual dose safety limit for the hand. However, these times would be much shorter if the surgeon's hands stray into the main X-ray irradiation area. Surgeons should keep their hands as far away from the irradiated field as possible during fluoroscopic screening.

The results of the current study indicated that the scatter radiation exposure dose of the lens when the X-ray source was located over the table was 11.2 times bigger than that when the source was under the table. Yamashita et al. demonstrated that direct radiation was attenuated to less than 100th after passing through the body[10]. The body of the patient itself might work functionally as a protective barrier for the surgeon. When the anterior-posterior fluoroscopic spine view is needed, the surgeon should employ fluoroscopy as the X-ray source is located under the table.

In this study, we observed a large scatter radiation exposure at all sites measured in the surgeon when the X-ray source was positioned laterally. In this position, the surgeon's optic lens, thyroid gland, hand, and chest were exposed to radiation doses that were nearly 30 times higher than those recorded when the X-ray source was under the table (Table 3). The lateral trunk width is normally greater than the anteroposterior trunk width, and more X-ray beams

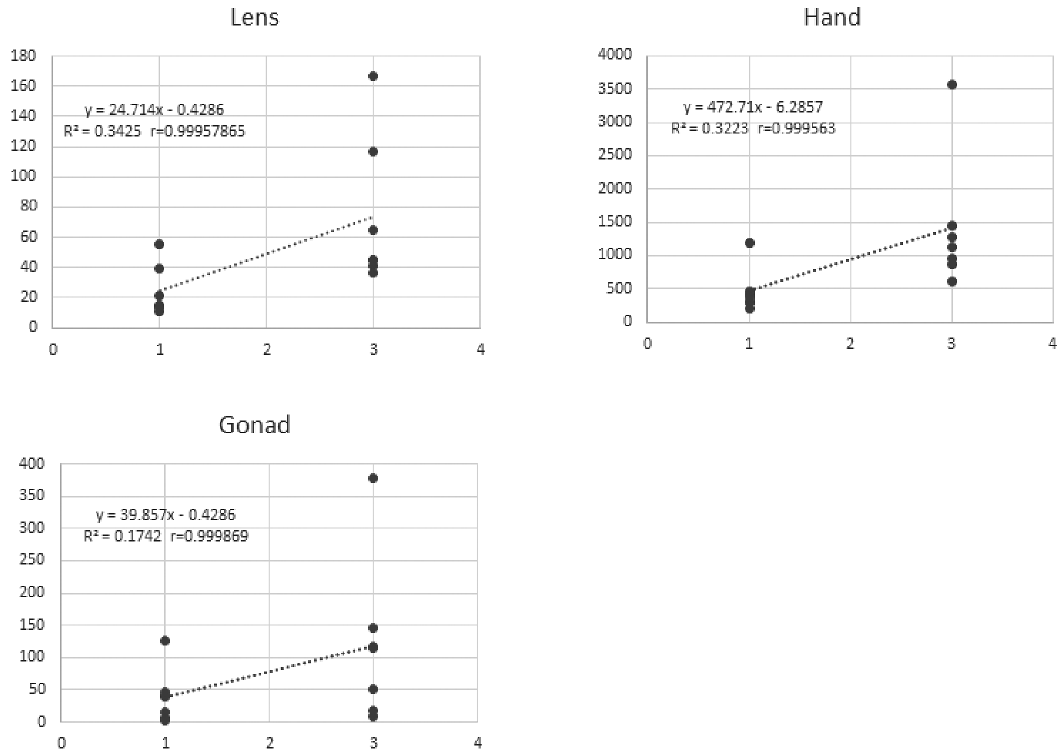

Figure 6. Correlation between the radiation doses and exposure time.
Radiation doses to the optic lens, hand, and gonads of the surgeon during a fluoroscopic procedure with the X-ray source in the lateral position.

are needed to penetrate a thicker section of the body for maintaining image quality. The highest dose occurs when imaging the thickest part of the patient, which is why a lateral image results in more radiation than an anteroposterior image[10]. This is especially pertinent for the spine surgeon. Jones et al. reported that the radiation doses of the surgeon's hand in the spine procedures were 10-12 times greater than those during the non-spine procedures, such as femoral and tibial intramedullary nailing, hip pinning, and application of an external fixator[6].

Furthermore, we found a difference in the scatter exposure dose between the surgeon and assistant surgeon when the X-ray source was positioned laterally. The scatter radiation exposure of the surgeon was much higher than that of the assistant surgeon. And there could be a similar thing about the scrub nurse. After the patient's body is irradiated, most of the scatter radiation reflects on the X-ray source side, which is why exposure on the X-ray source side is much greater than that on the image intensifier side when the X-ray source is positioned laterally. Surgeons and scrub nurses ought to work on the image intensifier side rather than on the X-ray source side.

Several studies have demonstrated that the use of protective equipment, including lead gloves, a lead apron, and a thyroid shield, can reduce scatter radiation exposure to the surgeon[11-13]. Although we did not investigate the effectiveness of different types of protective equipment in this study, our findings indicate that the surgeon and assistant surgeon should wear protective equipment to shield their optic lenses, thyroid gland, hands, chest, and gonads, especially when the X-ray source is positioned laterally.

This study had some limitations. First, only seven cadavers were used, and their age was relatively high. However, they varied widely in body size. Second, only one fluoroscopic machine was used to investigate the radiation exposure dose to the surgical team. Older fluoroscopic machines have been reported to require a higher tube voltage and higher electric current to obtain a clear fluoroscopic view, which exposes the surgical team to large amounts of radiation[14]. However, in spite of these limitations, the study provides accurate data on radiation exposure during the use of C-arm fluoroscopy to image the human body during a simulated spinal surgical procedure with the X-ray source in different positions.

In conclusion, this study demonstrates that the radiation exposure dose significantly changes with the X-ray source position and is especially high when the source is positioned laterally. Spine surgeons and other operating ream member should evaluate their exposure dose with every procedure and protect themselves using appropriate shielding and techniques.

Disclaimer: Kazuta Yamashita is one of the Editors of Spine Surgery and Related Research and on the journal's Editorial Committee. He was not involved in the editorial evaluation or decision to accept this article for publication at all.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

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References

1. Giordano BD, Grauer JN, Miller CP, et al. Radiation exposure issues in orthopaedics. J Bone Joint Surg Am. 2011;93(12):e69(1-10).
2. Valone LC, Chambers M, Lattanza L, et al. Breast radiation exposure in female orthopaedic surgeons. J Bone Joint Surg Am. 2016;98(21):1808-13.
3. Linet MS, Kim KP, Miller DL, et al. Historical review of cancer risks in medical radiation workers. Radiat Res. 2014;174(6):793-808.
4. Yoshinaga S, Mabuchi K, Sigurdson AJ, et al. Cancer risks among radiologists and radiologic technologists: review of epidemiologic studies. Radiology. 2004;233(2):313-21.
5. Giordano BD, Baumhauer JF, Morgan TL, et al. Cervical spine imaging using standard C-arm fluoroscopy: patient and surgeon exposure to ionizing radiation. Spine. 2008;33(18):1970-6.
6. Jones DP, Robertson PA, Lunt B, et al. Radiation exposure during fluoroscopically assisted pedicle screw insertion in the lumbar spine. Spine. 2000;25(12):1538-41.
7. Ortiz AO, Natarajan V, Gregorius DR, et al. Significantly reduced radiation exposure to operators during kyphoplasty and vertebroplasty procedures: methods and techniques. AJNR Am J Neuroradiol. 2006;27(5):989-94.
8. Yamashita K, Higashino K, Hayashi H, et al. Pulsation and collimation during fluoroscopy to decrease radiation: a Cadaver Study. JB JS Open Access. 2017;2(4):e0039.
9. Mehlman CT. Radiation exposure to the orthopaedic surgical team during fluoroscopy: "how far away is far enough?" J Orthop Trauma. 1997;11(6):392-8.
10. Yamashita K, Higashino K, Wada K, et al. Radiation exposure to the surgeon and patient during a fluoroscopic procedure: how high is the exposure dose? A cadaveric study. Spine. 2016;41(15):1254-60. DOI: 10.1097/BRS.0000000000001542.
11. Theocharopoulos N, Perisinakis K, Damilakis J, et al. Occupational exposure from common fluoroscopic projections used in orthopaedic surgery. J Bone Jt Surg Am. 2003;85(9):1698-703.
12. Badman BL, Rill L, Butkovich B, et al. Radiation exposure with use of the mini-c-arm for routine orthopaedic imaging procedures. J Bone Joint Surg Am. 2005;87(1):13-7.
13. Barry TP. Radiation exposure to an orthopedic surgeon. Clin Orthop Relat Res. 1984;(182):160-4.
14. Mahajan A, Samuel S, Sasran AK, et al. Occupational radiation exposure from C Arm fluoroscopy during common orthopaedic surgical procedures and its prevention. J Clin Diagn Res. 2015;9(3):1-4.