Pulsation and Collimation During Fluoroscopy to Decrease Radiation

A Cadaver Study

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Background: Awareness of the harmful effects of long-term low-dose radiation is rising. Many studies have assessed both patient and physician exposure to radiation in association with the use of fluoroscopy in the operating room. However, to our knowledge, previous studies have not assessed, in a detailed fashion, the reduction in radiation exposure that pulsation and collimation provide.

Methods: Seven fresh cadavers were irradiated for 5 minutes with C-arm fluoroscopy with use of standard x-ray and pulsed and collimated x-ray beams. The x-ray sources were placed under the table, over the table, and lateral to the table. Radiation exposure doses were measured at different points, such as the center of the radiation field on the cadaver as well as at the locations of the surgeon's hand and thyroid gland. In addition, Monte Carlo simulation (a physics equation to predict exposure) was performed to estimate the dose reduction and to confirm the experimental results.

Results: The radiation exposure doses associated with the use of pulsed fluoroscopy (8 times per second) were reduced by approximately 30% for the patient and by approximately 70% for the surgeon's hand and thyroid gland as compared with those associated with the use of continuous fluoroscopy. The radiation exposure doses associated with the use of collimated beams were reduced to approximately 65% for the surgeon's hand and thyroid gland as compared with those associated with the use of non-collimated fluoroscopy. These results were consistent with the simulation, and the phenomena could be appropriately explained by physics.

Conclusions: The present study revealed the effectiveness of pulsed and collimated x-ray beams in reducing radiation exposure doses resulting from C-arm fluoroscopy. Surgeons should consider using the techniques of pulsed fluoroscopy and collimation to protect patients and themselves from radiation.

Clinical Relevance: This study presents data regarding the reduction of radiation exposure provided by pulsed fluoroscopy and collimation.

Fluoroscopy is commonly used in many orthopaedic procedures. Image intensifiers have allowed orthopaedic surgeons to become more technically proficient and have decreased patient morbidity by decreasing operative time[1]. Intraoperative fluoroscopy is a necessity in orthopaedic procedures such as intramedullary nailing of long-bone fractures, insertion of pedicle screws, and kyphoplasty[2-8]. Consequently, we continue to be concerned about the exposure of the patient, surgeon, staff, and anesthetists[9-11]. The risk of radiation exposure appears to vary according to the surgical procedure and the anatomical location[12-14]. In particular, the surgeon's hands, thyroid gland, and eyes receive obvious exposure to radiation[15-19]. We previously reported on the measurement of radiation with use of cadavers, and the results of that study showed that the measurement of radiation was valid and reproducible[20].

The exposure dose received during fluoroscopy should be minimized in agreement with the well-known ALARA ("as low as reasonably achievable") principle[21]. It is well known that exposure time, distance from the radiation source, and barriers against radiation exposure are important factors for reducing
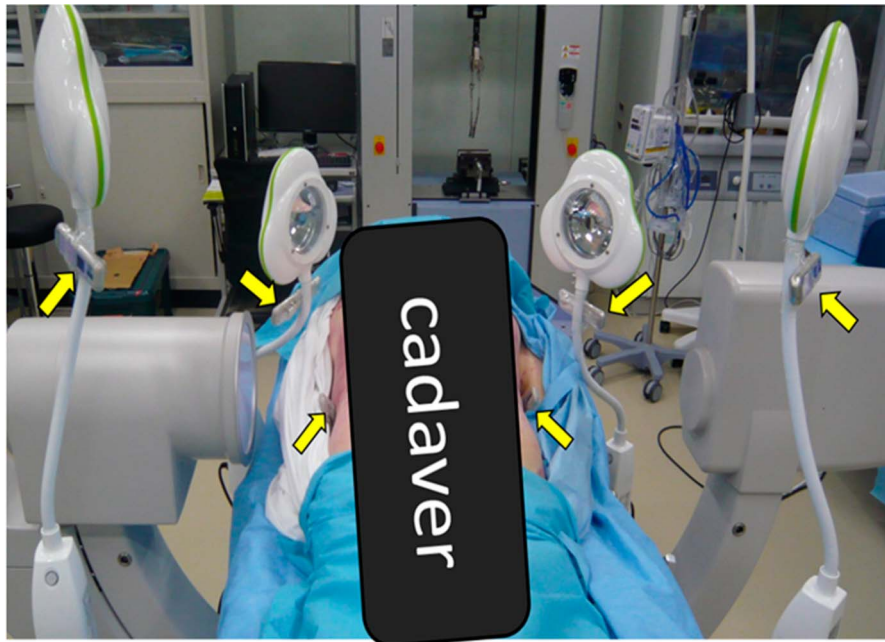
Fig. 1

Six real-time dosimeters (arrows) were mounted onto individual arrays that were fixed to an adjustable jig when the x-ray source was positioned lateral to the cadaver.

the radiation exposure dose[22]. In order to reduce radiation exposure during fluoroscopy, we have focused on techniques such as positioning of the C-arm, pulsed fluoroscopy, and collimation[1,23-26]. Although some studies have examined the effects of reducing the radiation exposure dose by using pulsed fluoroscopy and collimation[27,28], we are not aware of any comprehensive studies that have accurately replicated clinical situations to evaluate the reduction in the radiation exposure

dose associated with different fluoroscopic procedures. The purpose of the present study was to evaluate the reduction of radiation exposure dose resulting from C-arm fluoroscopy when using pulsed and collimated x-ray beams.

Materials and Methods

We performed a cadaver study that was designed to replicate operative situations accurately. In this study,
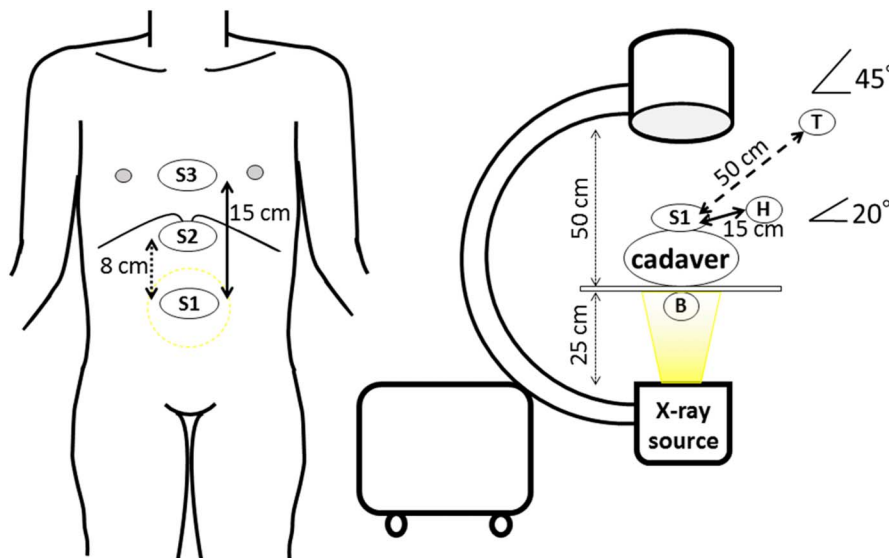

Fig. 2-A

Figs. 2-A, 2-B, and 2-C Positions of the x-ray source and dosimeters during testing. **Fig. 2-A** The positions of the dosimeters when the x-ray source is under the radiolucent table.
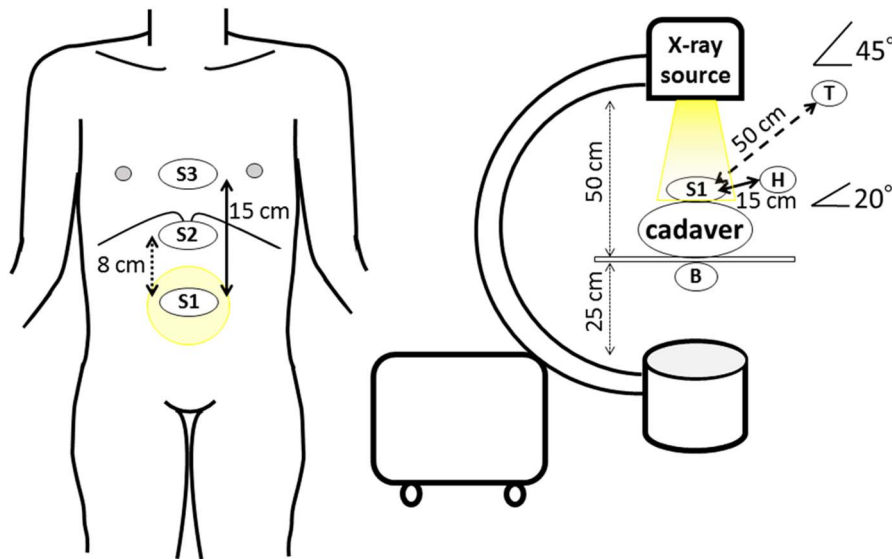
Fig. 2-B

The positions of the dosimeters when the x-ray source is over the radiolucent table.

we replicated a common method for intraoperative navigation with use of a C-arm fluoroscopic system on defrosted fresh cadavers that were not preserved in formalin. Real-time dosimeters were used to measure the radiation exposure doses. Seven fresh cadavers (5 male and 2 female) were used. The mean height was 160 cm (range, 140 to 172 cm), the mean body weight was 57.9 kg (range, 45.5 to 71.0 kg), and the mean body mass index (BMI) was 22.6 kg/m^2 (range, 18.2 to 24.5 kg/m^2). The mean lateral width of the trunk was 30 cm (range, 23 to 40 cm), and the mean anteroposterior width of the trunk was 15 cm (range, 12 to 22 cm). The present study was approved by the ethics committee of our university hospital.

Instrumentation

All radiation exposures were performed with use of a C-arm fluoroscopic system (Clearscope1000 [SXT-1000A]; Toshiba Medical Systems). The machine was manufactured in 2014.

The distance from the x-ray source to the image receptor was 75 cm. An adjustable radiolucent surgical table (MOT-1700; Mizuho Medical) was used to position the cadavers. Six real-time dosimeters (MY DOSE mini; Hitachi) with identical settings were mounted onto individual arrays that were fixed to an adjustable jig (Fig. 1). This type of dosimeter can accurately detect exposures ranging from 1 μSv to 999 mSv.

C-Arm Settings and Fluoroscopy Techniques

The C-arm fluoroscopic system was set to automatic mode so that technical factors (i.e., kilovolt peak [kV] and milliampere [mA] values) were adjusted automatically to optimize image quality. The C-arm fluoroscopic system was tested in 3 different configurations: under the table (Fig. 2-A), over the table (Fig. 2-B), and lateral (Fig. 2-C). The distance between the x-ray source and the table was set to 25, 50, and 20 cm, respectively, for these positions. For each position, the cadavers were
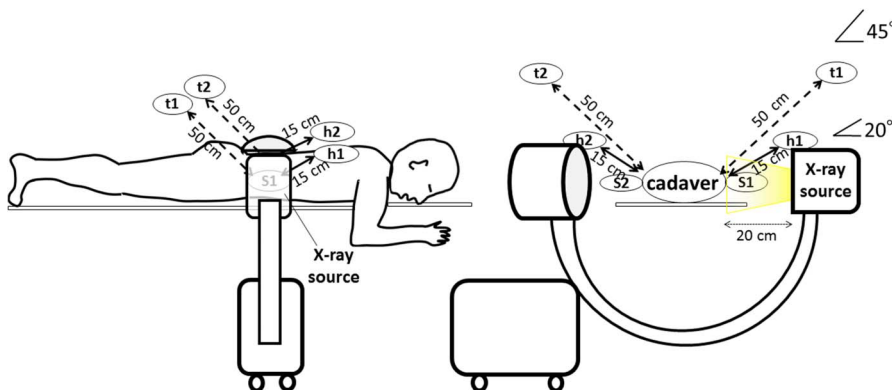
Fig. 2-C

The positions of the dosimeters when the x-ray source is at the side of the cadaver.
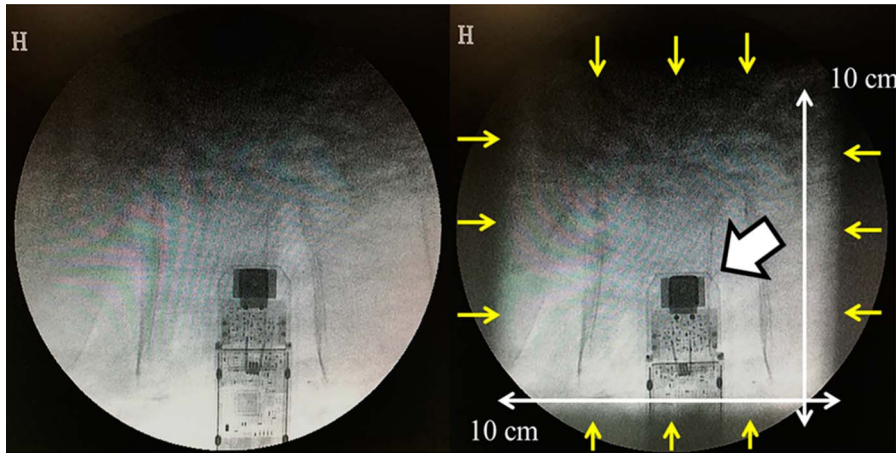
Fig. 3

Fluoroscopic images of the L3 vertebra and dosimeters when the x-ray source is at the side of the cadaver; the large white arrow in the right image indicates dosimeter S. The left panel is a lateral fluoroscopic image without collimation. The right panel is a lateral fluoroscopic image with collimation, with the field of view being 10 × 10 cm; the small short arrows indicate the line of collimation.

irradiated for 5 minutes, and the beam was centered on the L3 vertebra.

The C-arm fluoroscopic system was operated with a continuous x-ray beam or a pulsed x-ray beam. In addition, we examined the use of collimation. To evaluate the effect of pulsed fluoroscopy, we tested 3 different configurations: continuous irradiation (not pulsed), pulsed at a frequency of 8 times per second (hereafter referred to as *8-pulse fluoroscopy*), and pulsed at a frequency of 4 times per second (hereafter referred to as *4-pulse fluoroscopy*). All 3 configurations were tested without collimation. Then, to assess the effect of collimation, we measured the radiation exposure doses with and without collimation under continuous fluoroscopy (Fig. 3). The size of the collimated radiation field was set to 10 × 10 cm so as not to interfere with the field of view.

Dosimeter Positioning

Six real-time dosimeters with identical settings were mounted onto individual arrays as follows.

X-Ray Source Position: Under or Over Table

When the x-ray source was located under or over the radiolucent table (Figs. 2-A and 2-B), the first dosimeter was placed on the body surface at the center of the image (S1). The second and third dosimeters were placed on the body surface at 8 cm and 15 cm from the center of the image, respectively (S2 and S3). The fourth dosimeter was fixed at 15 cm from the center of the
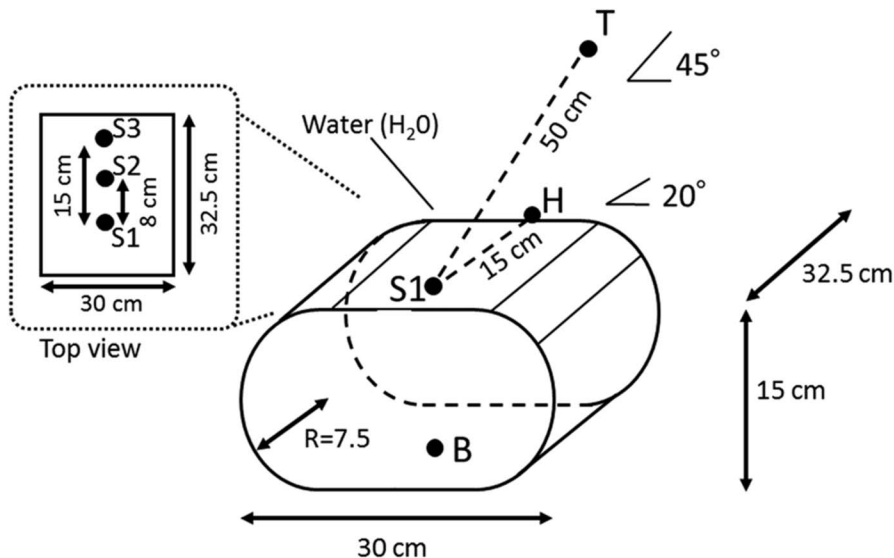

Fig. 4-A

Figures 4-A and 4-B Schematic drawings of the geometries used in the Monte Carlo simulation. **Fig. 4-A** Over and under-the-table settings.
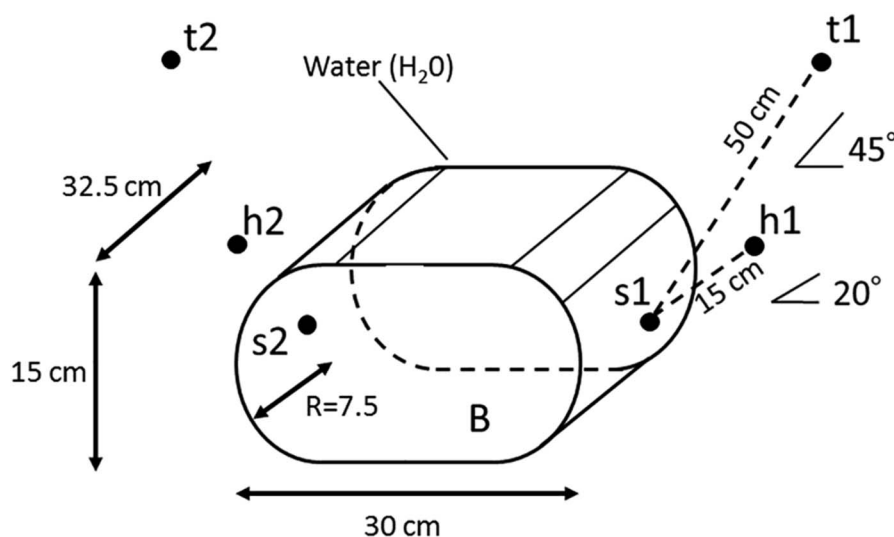
Fig. 4-B
Lateral setting.

image, in the air at an angle of 20°, and was used to simulate the surgeon's hand (H). The fifth dosimeter was fixed at 50 cm from the center of the image, in the air at an angle of 45°, and was used to simulate the surgeon's thyroid gland (T). The sixth dosimeter was fixed beneath the table under the cadaver (B). When the x-ray source was under the table, the B dosimeter measured the direct radiation exposure of the patient, and the other 5 dosimeters measured the scatter radiation exposure of the surgeon. When the x-ray source was over the table, the S1 dosimeter measured the direct radiation exposure of the patient, and the other 5 dosimeters measured the scatter radiation exposure of the surgeon.

X-Ray Source Position: Lateral Position
When the x-ray source was placed at the lateral position (Fig. 2-C), the first dosimeter was placed on the body surface at the center of the image of the side of the x-ray source (s1). The second dosimeter was placed on the body surface at the center of the image on the intensifier side (contralateral body surface) (s2). The third and fourth dosimeters were fixed at 15 cm and 50 cm in the air at angles of 20° and 45° on the x-ray source side, respectively, and were used to simulate the areas of the operator's hand and thyroid gland (h1 and t1), respectively. The fifth and sixth dosimeters were fixed at 15 cm and 50 cm in the air at angles of 20° and 45° on the intensifier side (contralateral body surface), respectively, and were used to simulate the areas of the assistant surgeon's hand and thyroid gland (h2 and t2), respectively. The s1 dosimeter measured the direct radiation exposure of the patient, and the other dosimeters measured the scatter radiation exposure of the operator and the assistant surgeon.

	Dose (μSv)					
	No Collimation			Collimation		
		Pulsed			Pulsed	
Positions	Continuous	8 Pulses/s	4 Pulses/s	Continuous	8 Pulses/s	4 Pulses/s
S1	756 ± 168	415.3 ± 74.2	212.4 ± 52.4	633.7 ± 173.8	474.4 ± 209.9	214.4 ± 81.7
S2	116.7 ± 63.4	75.6 ± 38.1	33.9 ± 16.3	80.6 ± 40.8	51.6 ± 27.7	30.1 ± 22.2
S3	33.4 ± 20.1	20.9 ± 13.6	9.3 ± 5.5	21.9 ± 14.5	14.7 ± 12.1	8.3 ± 7
B	109,524.3 ± 24,284.6†‡	4,1040 ± 4,008.5†	24,443 ± 3,001.3‡	125,331.9 ± 22,226.3	44,577.1 ± 6,571.8	25,032.9 ± 4,898.5
H	61.7 ± 24.9§ # **	41.7 ± 19**	19.6 ± 7.7§	45.4 ± 16.5#	27.9 ± 14.6	13.0 ± 6.5
T	12.7 ± 4†† ‡‡ §§	8.3 ± 2.7††	3.7 ± 1.7‡‡	9.6 ± 2.4§§	5.9 ± 1.6	2.6 ± 0.5

TABLE I Average of 5-Minute Radiation Exposure Doses When X-Ray Source Was Under Table*

*The values are given as the average and the standard deviation. B indicates the direct radiation exposure dose to the patient's skin. S1, S2, S3, H, and T indicate the scatter radiation exposure doses to the surface of the body with the dosimeters in different locations on the patient, the surgeon's hand, and the surgeon's thyroid gland, respectively. †8-pulse/continuous = 37.5%. ‡4-pulse/continuous = 22.3%. §4-pulse/continuous = 31.8%. #Collimation/no collimation = 73.6%. **8-pulse/continuous = 67.6%. ††8-pulse/continuous = 65.4%. ‡‡4-pulse/continuous = 29.1%. §§Collimation/no collimation = 75.6%.

TABLE II Average of 5-Minute Radiation Exposure Doses When X-Ray Source Was Over Table*

	Dose (μSv)					
	No Collimation			Collimation		
		Pulsed			Pulsed	
Positions	Continuous	8 Pulses/s	4 Pulses/s	Continuous	8 Pulses/s	4 Pulses/s
S1	84,223 ± 25,653.9† ‡	33,291 ± 7,857.4†	18,669 ± 4,005.4‡	87,343 ± 27,484.4	34,397 ± 6,851.4	18,500 ± 4,535.5
S2	700.9 ± 576.4	453.6 ± 336	179.7 ± 146.8	535.7 ± 551	318.7 ± 306.2	134.7 ± 120
S3	50.7 ± 19.7	31.3 ± 11.7	14.9 ± 7.3	33 ± 13	21.3 ± 9.1	10.1 ± 4.4
B	477.3 ± 76	294.7 ± 61	135.6 ± 36.1	403.1 ± 36.8	272.4 ± 47	129.6 ± 31.5
H	360.7 ± 158.6§ # **	296.7 ± 157.7§	111.7 ± 57.6#	246.3 ± 84.5**	163.9 ± 55.8	78 ± 34.5
T	72.4 ± 26.5†† ‡‡ §§	51.3 ± 18.8††	21.1 ± 9.4‡‡	52.3 ± 23.1§§	34.9 ± 12.9	16.1 ± 7.4

*The values are given as the average and the standard deviation. S1 indicates the direct radiation exposure dose to the patient's skin. S2, S3, B, H, and T indicate the scatter radiation exposure doses to the surface of the body with the dosimeters in different locations on the patient's skin, the surgeon's hand, and the surgeon's thyroid gland, respectively. †8-pulse/continuous = 39.5%. ‡4-pulse/continuous = 22.2%. §8-pulse/continuous = 82.3%. #4-pulse/continuous = 31.0%. **Collimation/no collimation = 68.3%. ††8-pulse/continuous = 70.9%. ‡‡4-pulse/continuous = 29.1%. §§Collimation/no collimation = 72.2%.

Monte Carlo Simulation

To evaluate the experimental results of collimation, we performed a Monte Carlo simulation (code EGS5)[29]. The patient was simulated with use of a water phantom, which is usually used in phantom studies for computed tomography (CT) examination[30]. The simulation was performed with the over and under-the-table settings (Fig. 4-A) as well as the lateral setting (Fig. 4-B). The same dosimeter positions represented in Figures 2-A, 2-B, and 2-C were adopted. Theoretical x-ray spectra[31] were used, and areas of radiation fields were set to be the same as those in the experiment. Our simulation was performed so as to obtain statistical uncertainty of <1%. In the simulation, we derived the photon fluence φ(E) for the beam incident on the analysis regions (spherical regions). Then, air kerma, which is equivalent to the dose measured in the experiment, was calculated[32] according to the formula

$$ \mathrm{kerma} = \int \varphi(E) \times E \times (\mu_{tr}/p) dE, $$

where E and μ_{tr}/p indicate energy and the mass energy transfer coefficient, respectively.

Results

We measured the radiation exposure doses with and without pulsed fluoroscopy and with and without collimation for each x-ray source position. Tables I, II, and III show results concerning the radiation exposure doses when the x-ray source was set under the table, over the table, and at the side of the cadaver (lateral). The mean tube voltages with the source under the table, over the table, and lateral to the table were 78.0, 74.4, and 103.9 kV, respectively.

TABLE III Average of 5-Minute Radiation Exposure Doses When X-Ray Source Was at Side of Cadaver*

	Dose (μSv)					
	No Collimation			Collimation		
		Pulsed			Pulsed	
Positions	Continuous	8 Pulses/s	4 Pulses/s	Continuous	8 Pulses/s	4 Pulses/s
s1	171,543 ± 28,475† ‡	52,380 ± 3,432.9†	31,640 ± 1,497.5‡	174,129 ± 27,330.4	51,493 ± 4,167.8	31,324 ± 3,177.5
s2	450.7 ± 224.2	295.1 ± 164.6	143.7 ± 72.8	428.4 ± 279.1	271.1 ± 181	126.4 ± 79.3
h1	2,104.3 ± 603.6§ # **	1,329.9 ± 430.1§	652.4 ± 192.9#	1,542.9 ± 553.6**	1,028.7 ± 305.5	469.4 ± 119
h2	143.9 ± 78.8	98.1 ± 68.5	49.7 ± 37.3	114 ± 86.1	72.9 ± 55.3	34.4 ± 25
t1	448.9 ± 125.5†† ‡‡ §§	281.6 ± 65.5††	134.7 ± 25.6‡‡	314 ± 87.8§§	202.9 ± 52.3	96.7 ± 23.8
t2	135 ± 63.9	87.7 ± 48.1	43.9 ± 21.5	96 ± 52.4	57 ± 31	26.9 ± 14.6

*The values are given as the average and the standard deviation. s1 and s2 indicate the direct radiation exposure dose to the patient's skin. h1, h2, t1, and t2 indicate the scatter radiation exposure doses to the surgeon's and assistant's hands and thyroid glands, respectively. †8-pulse/continuous = 30.5%. ‡4-pulse/continuous = 18.4%. §8-pulse/continuous = 63.2%. #4-pulse/continuous = 31.0%. **Collimation/no collimation = 73.3%. ††8-pulse/continuous = 62.7%. ‡‡4-pulse/continuous = 30.0%. §§Collimation/no collimation = 69.9%.
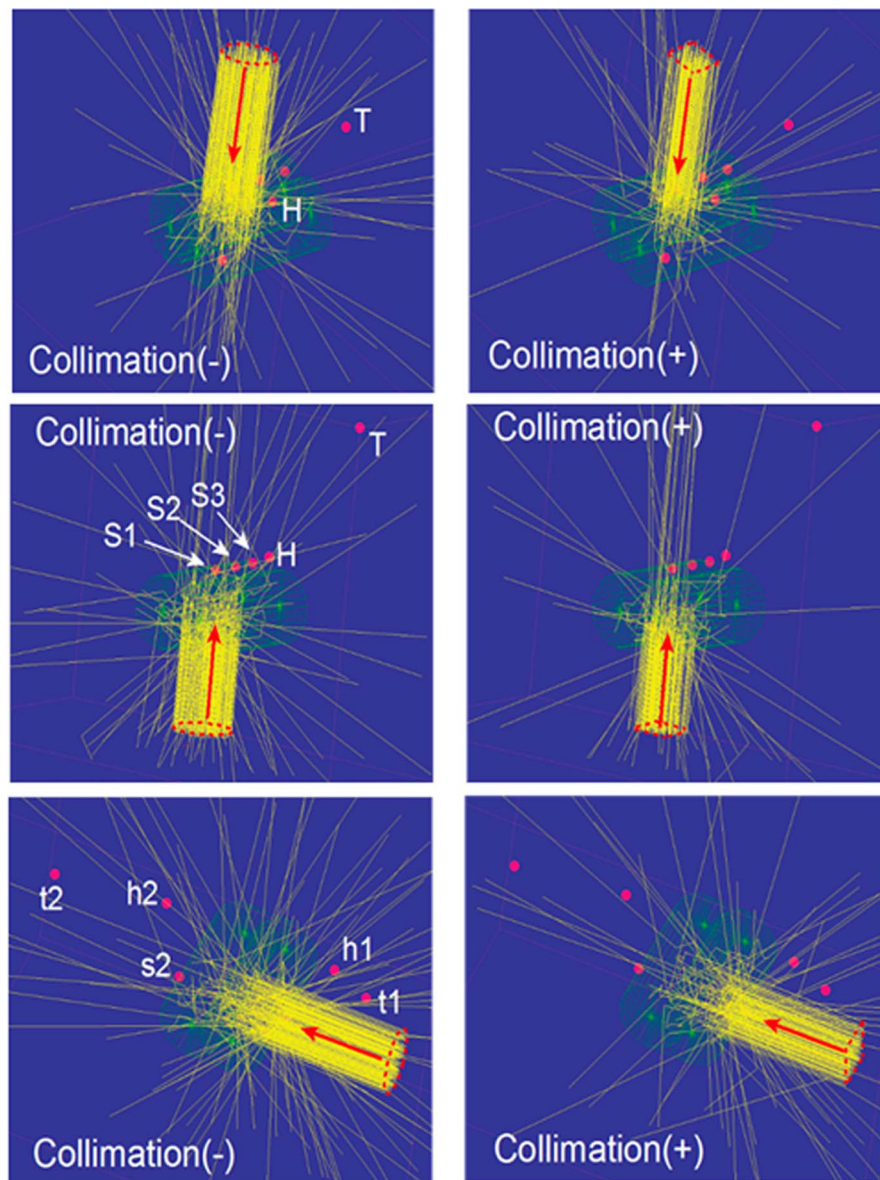
Fig. 5

Computer graphics of the x-ray paths. The red arrows indicate the incident direction. The yellow lines show trajectories of incident and scattered x-rays. The top panels, middle panels, and bottom panels indicate the results for over-the-table, under-the-table, and lateral settings, respectively. The left and right panels show the simulation without collimation (−) and with collimation (+), respectively.

The mean electrical currents with the source under the table, over the table, and lateral to the table were 1.6, 1.5, and 2.8 mA, respectively.

Radiation Exposure Doses with and without Pulsed Fluoroscopy (Not Collimated Fluoroscopy)
Source Under the Table
The direct radiation dose of the B dosimeter was substantially lower with pulsed fluoroscopy than with continuous fluoroscopy, and the dose ratio when 8-pulse fluoroscopy was compared with continuous fluoroscopy was 37.5% (Table I [†]). Furthermore, the scatter radiation doses of the H and T

dosimeters were substantially lower with pulsed fluoroscopy than with continuous fluoroscopy. The dose ratios when 8-pulse fluoroscopy was compared with continuous fluoroscopy for the H and T dosimeters were estimated to be 67.6% and 65.4%, respectively (Table I [**, ††]). Similar trends were observed for the dose ratios when 4-pulse fluoroscopy was compared with continuous fluoroscopy (Table I [‡, §, ‡‡]).

Source Over the Table
The direct radiation dose of the S1 dosimeter was substantially lower with pulsed fluoroscopy than with continuous

TABLE IV Doses Calculated Using the Monte Carlo Simulation			
	Relative Dose		Ratio *(%)*
X-Ray Source and Positions	No Collimation	Collimation	Collimation /No Collimation
Over table*			
S1	0.9997	1.0000†	100%‡
S2	0.0704	0.0355	50%
S3	0.0083	0.005	61%
B	0.0385	0.034	88%
H	0.0179	0.0114	64%§
T	0.0021	0.0014	66%§
Under table*			
S1	1.1337	1.0000†	88%
S2	0.3468	0.2168	63%
S3	0.0773	0.0482	62%
B	27.3316	27.3108	100%‡
H	0.1147	0.0744	65%§
T	0.0148	0.0096	65%§
Lateral#			
s1	0.9938	1.0000†	101%‡
s2	0.0108	0.009	84%
h1	0.0212	0.0146	69%§
h2	0.0023	0.0014	61%§
t1	0.0022	0.0015	68%§
t2	0.0007	0.0004	58%§

*S1 indicates the direct radiation exposure dose to the patient's skin. S2, S3, H, and T indicate the scatter radiation exposure doses to the surface of the body with the dosimeters in different locations on the patient, the surgeon's hand, and the surgeon's thyroid gland, respectively. †These values are used as the standard values. ‡These measurement points are just within the radiation fields (see Discussion). §These measurement points are far away from the phantom (see Discussion). #s1 and s2 indicate the direct radiation exposure dose to the patient's skin. h1, h2, t1, and t2 indicate the scatter radiation exposure doses to the surgeon's and assistant's hands and thyroid glands, respectively.

fluoroscopy. The dose ratio when 8-pulse fluoroscopy was compared with continuous fluoroscopy for the S1 dosimeter was 39.5% (Table II [†]). Furthermore, the radiation doses for the H and T dosimeters were substantially lower, with dose ratios of 82.3% and 70.9%, respectively (Table II [§, ††]). A similar trend in dose ratios was observed when 4-pulse fluoroscopy was compared with continuous fluoroscopy (Table II [‡, #, ‡‡]).

Source Lateral
The direct radiation dose of the s1 dosimeter was substantially lower with pulsed fluoroscopy than with continuous fluoroscopy, and the dose ratio when 8-pulse fluoroscopy was compared with continuous fluoroscopy was 30.5% (Table III [†]). Furthermore, the scatter radiation exposure doses of the h1 and t1 dosimeters with pulsed fluoroscopy were substantially lower than those with continuous fluoroscopy, and the dose ratios when 8-pulse fluoroscopy was compared with continuous fluoroscopy for the h1 and t1 dosimeters were estimated to be 63.2% and 62.7%, respectively (Table III [§, ††]). Similar trends in dose ratios were

observed when 4-pulse fluoroscopy was compared with continuous fluoroscopy (Table III [‡, #, ‡‡]).

Radiation Exposure Doses with and without Collimation (Continuous Fluoroscopy)
Source Under the Table
The doses of the H and T dosimeters were substantially lower with collimation than without collimation; the dose ratios when collimated fluoroscopy was compared with non-collimated fluoroscopy for the H and T dosimeters were estimated to be 73.6% and 75.6%, respectively (Table I [#, §§]).

The same trends were observed for the H and T dosimeters with the source over the table and for the h1 and t1 dosimeters with the source in the lateral position.

Source Over the Table
The dose ratios when collimated fluoroscopy was compared with non-collimated fluoroscopy for the H and T dosimeters were estimated to be 68.3% and 72.2%, respectively (Table II [**, §§]).

Source Lateral

The dose ratios when collimated fluoroscopy was compared with non-collimated fluoroscopy for the h1 and t1 dosimeters were estimated to be 73.3% and 69.9%, respectively (Table III [**, §§]).

Simulated Doses Using Monte Carlo Methods

Figure 5 shows the computer graphical representation of the simulated x-rays. Many scattered x-rays were outside the field of view, and those for non-collimated fluoroscopy were obviously more numerous than those for collimated fluoroscopy. The numerical values of the simulated absorbed dose are summarized in Table IV. The dose ratios when collimated fluoroscopy was compared with non-collimated fluoroscopy for S1, S2, S3, s1, and s2 were estimated to range from 50% to 101%; that is, a large difference was noted. The dose ratios when collimated fluoroscopy was compared with non-collimated fluoroscopy for B were estimated to be 88% and 100%, with no significant difference, while those for H, T, h1, h2, t1, and t2 were estimated to range from 58% to 68%, indicating seemingly constant values. The model confirms that there was lower exposure when collimation was used.

Discussion

When intraoperative fluoroscopy is used in orthopaedic procedures, the surgeon has the highest radiation risk among all personnel in the operating room because of his or her proximity to the exposure area[33,34]. The radiation exposure for the surgeon is primarily due to scattered x-rays, although the hands often suffer direct exposure[35]. The biological effects of radiation exposure at higher doses are well known to include cataracts, thyroid cancer, and skin cancer[36]. It is recommended that orthopaedic surgeons endeavor to limit cumulative per-procedure exposure to radiation[37].

Measurements directly in the beam (including the over-the-table S1, under-the-table B, and lateral s1 locations) showed no difference with collimation. Collimation typically decreases scatter to the periphery. The experimental results were consistent with the simulated results for both non-collimated and collimated fluoroscopy. This result is explained by a consideration of the physics involved; in the radiation field, the exposure dose caused by the direct x-rays was much higher than that caused by the scattered x-rays. On the other hand, some measurement points—H and T for the over and under-the-table settings and h1, h2, t1, and t2 for the lateral setting—were not located in the radiation fields and were far away from the cadaver. Although the disadvantage of collimation is a fractional reduction in the field of view, the exposure doses to surgeons are reduced by approximately 35%, as shown in Table IV. Therefore, we strongly suggest that the surgeons limit the field of view by using a collimator installed in the fluoroscopic equipment.

It can be assumed that the exposure dose rate for a pulse rate of 8 times per second is likely to be double the dose rate of 4 times per second. Most of the experimental results indeed showed such doubling, although the values were not exactly double. The inconsistencies between the above assumption and the experimental results may arise from the realistic configurations used for x-ray irradiations. The pulsed x-ray beam can be created with use of a complicated electrical circuit. Control of the rise time, irradiation time, and fall time for the x-ray irradiation affects the measured exposure doses. However, these 3 times are difficult to measure, and direct measurement of the exposure doses is therefore important. As Tables I, II, and III clearly show, the use of pulsed fluoroscopy indeed reduced the exposure doses. We recommended that surgeons assess image quality with use of phantoms before operating on patients with use of the C-arm fluoroscopic system; when surgeons are satisfied with the image rendered by pulsed fluoroscopy, they can use pulsed x-ray fluoroscopy for reducing exposure doses. Continuous fluoroscopy typically records at least 30 images per second, which allows the surgeons to view the images without perceived flickering between the images. Pulsed fluoroscopy decreases the frequency at which these images are obtained to a few frames per second[38]. Therefore, the radiation dose is decreased by reducing the time during which the x-rays are generated.

In the present study, we systematically quantified the reduction in radiation exposure sustained by patients and surgeons during the use of a C-arm fluoroscopic system. Our results indicated that radiation exposure doses from the C-arm equipment in the lateral position were dramatically reduced in association with the use of pulsed fluoroscopy and collimation. With use of pulsed fluoroscopy, direct radiation exposure doses to the patient's skin as well as the scatter radiation exposure doses to the surgeon's hand and thyroid gland were reduced to about 30% (8-pulse/s) and 70% (4-pulse/s), respectively, as compared with continuous fluoroscopy (Tables I, II, and III). Similarly, with use of collimation, the scatter radiation exposure dose to the surgeon's hand and thyroid gland were reduced by approximately 65% (Tables I, II, and III). Both pulsing and collimation are under the control of the surgeon and have the potential to reduce the radiation exposure of surgeons, patients, and staff.

The present study had some limitations. First, the sizes of the cadavers were relatively small. When larger patients are irradiated with use of fluoroscopy in the automatic mode, the tube voltages are automatically adjusted to higher values to achieve adequate penetration and thereby acceptable images. However, the reduction in the exposure dose caused by altered fluoroscopic techniques is expected to occur irrespective of patient size. Second, in the present study, we did not investigate the resolution of the images when using pulsed fluoroscopy. In essence, continuous fluoroscopic images offer better spatial resolution than pulsed fluoroscopic images[39]. However, for most orthopaedic procedures, pulsed fluoroscopy should be adequate to confirm fracture reduction and to guide implant placement. Despite its limitations, the present study provides data regarding the reduction in radiation exposure by using altered fluoroscopic techniques.

In summary, surgeons can minimize radiation exposure by understanding the physics of radiation and maximizing the use of safety techniques offered by their specific fluoroscopy units. In particular, the use of pulsed fluoroscopy and collimation can reduce radiation exposure to the hands and the thyroid. ∎

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