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SURGERY

Radiation Exposure to the Surgeon During Percutaneous Endoscopic Lumbar Discectomy

A Prospective Study

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Study Design. A prospective study.

Objective. The purpose of this study was to determine the radiation dose to which the surgeons are exposed during percutaneous endoscopic lumbar discectomy (PELD) and to calculate the allowable number of cases per year.

Summary of Background Data. Transforaminal PELD is a minimally invasive technique for soft disc herniation. Minimal invasiveness can be achieved through the use of fluoroscopy and endoscopy. The radiation dose to the surgeon during PELD is unknown.

Methods. The occupational radiation dose absorbed by 3 spinal surgeons performing 30 consecutive PELDs (33 levels) during a 3-month period was evaluated. Transforaminal PELDs were performed according to the standard technique. The radiation exposure of the neck, chest, arm, and both hands of the surgeons was measured. Occupational exposure guidelines of National Council on Radiation Protection & Measurements were used to calculate the allowable number of procedures per year.

Results. The mean operation time was 49.8 minutes, and the mean fluoroscopy time was 2.5 minutes. No significant correlations were found between operation time and fluoroscopy time. The calculated radiation doses per operated level were as follows: neck, 0.0785 mSv; chest, 0.1718 mSv; right upper arm, 0.0461 mSv; left ring finger, 0.7318 mSv; and right ring finger, 0.6694 mSv. The protective effects of a lead collar and lead apron were demonstrated by the reduction of the radiation dose by 96.9% and 94.2%, respectively. Therefore, with regard to whole-body radiation, 5379 operations can be performed per year using a lead apron, whereas only 291 operations can be performed without using a lead apron. Moreover, 1910 operations can be performed within the occupational exposure limit for the eyes (150 mSv), and 683 operations can be performed within the occupational exposure limit for the hands (500 mSv).

Conclusion. Without radiation shielding, a surgeon performing 291 PELDs annually would be exposed to the maximum allowable radiation dose. Given the measurable lifetime radiation hazards to the surgeon, the use of adequate protective equipment is essential to reducing exposure during PELD.

Key words: radiation dosage, radiation risk, fluoroscopy, percutaneous, discectomy. **Spine 2013;38:617–625**

Current trends in spinal surgery are directed toward the development of minimally invasive surgery (MIS), image-guided procedures. In particular, most percutaneous spine procedures are performed with fluoroscopic guidance. Therefore, medical staff exposure to radiation has become an important issue.[1–4] In general, radiation has been linked to a number of stochastic and deterministic adverse events.[5–7] Tumor inductions are considered stochastic effects because they exhibit a linear/linear-quadratic, no-threshold radiation relationship. On the contrary, cataracts are thought to represent a deterministic radiation-related outcome.

Percutaneous endoscopic lumbar discectomy (PELD) is an emerging MIS spinal procedure made possible by the remarkable evolution in endoscopic technology.[8–10] A selective discectomy can be conducted *via* direct endoscopic visualization. Several randomized controlled trials have demonstrated the effectiveness of this technique.[8,11–13] In carefully selected patients, PELD offers favorable outcomes, while preserving healthy posterior lumbar structures.[10,14–18] However, fluoroscopy guidance is required for a safe percutaneous approach and accurate localization. Some publications have addressed the effect of radiation exposure in various percutaneous spine procedures, such as vertebroplasty, kyphoplasty, percutaneous pedicle screw insertion, and MIS transforaminal lumbar interbody fusion (TLIF).[19–29] To the best of our knowledge, there are no published clinical studies on the surgeon's radiation exposure during percutaneous endoscopic discectomy.

The objectives of this study were to measure the radiation dose to which the surgeons are exposed during PELD and to

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discuss the potential radiation risks for practitioners. We also describe preventive strategies to reduce the radiation dose.

MATERIALS AND METHODS

Study Design and Measurement of Radiation Dose

We performed a prospective study assessing the exposure of the surgeon to radiation during PELD. Thirty consecutive patients were enrolled in the study during 3 months. The inclusion criterion was presentation with radicular leg pain due to soft lumbar disc herniation. The exclusion criteria were segmental instability, lumbar spinal stenosis, calcified disc herniation, and painless weakness. From March 2008 through May 2008, 33 disc levels in 30 consecutive patients were treated with transforaminal PELD by 3 neurosurgeons. Two thermoluminescent whole-body dosimeters (Panasonic, Osaka, Japan) were placed outside the lead apron and thyroid shield. Two dosimeters were placed inside the lead apron and thyroid shield. Dosimeters inside the lead apron and thyroid shield were placed in a position identical to the dosimeters placed outside. One dosimeter was placed at the right upper arm. Two thermoluminescent finger dosimeters (Panasonic, Japan) were placed on the ring finger of each hand. The thermoluminescent dosimeters were placed as depicted in Figure 1. All dosimeters were marked and placed at the same location on the surgeon during each procedure. All dosimeters were stored in a radiation-free space between the procedures and read by an independent institute (Hanil Nuclear Co., Ltd, Anyang, Korea).

Surgical Technique

Transforaminal PELD was typically performed as described previously[14,18] and consisted of 2 parts: a transforaminal approach under fluoroscopic control followed by selective discectomy with endoscopic visualization. The patient was placed prone on a radiolucent table. The table consisted of a durable carbon frame and sponge pads. The skin entry point was approximately 8 to 12 cm from the midline, which was determined according to the body size and target point. A posterolateral transforaminal approach through the foraminal window was performed under fluoroscopic guidance. After insertion of the needle into the disc, a small amount of the mixture of contrast medium (6 mL) and indigo carmine (1 mL) was injected to stain the nucleus. The needle was replaced with a guide wire, and an obturator was introduced along the guide wire. After the obturator position was confirmed, a bevel-ended working sheath was placed near the disc herniation. For safe introduction of the spinal needle, obturator, and working sheath through the foraminal window, a real-time anteroposterior (AP) or lateral (LAT) view is essential. After a safe transforaminal approach, a 5.8 × 5.1 mm ellipsoidal working channel endoscope (YESS; Richard Wolf, Knittlingen, Germany) was inserted. Then, a selective discectomy using endoscopic forceps and a side-firing Holmium-YAG laser (Lumenis, Inc., New York, NY) was performed under direct endoscopic visualization. Epidural bleeding was controlled using a bipolar coagulator with a flexible tip (Trigger-Flex Bipolar System; Elliquence, New York, NY) under cold saline irrigation. The instrument position and working zone were checked with fluoroscopy as required during endoscopic discectomy.

Figure 1. Dosimeter placement during percutaneous endoscopic lumbar discectomy (PELD). Outside the apron/collar: thyroid, anterior chest wall, right arm, and left and right ring fingers. Inside the apron/collar: thyroid and anterior chest wall.

Data Collection

All procedures were performed using a biplane fluoroscope (Siremobil ISO-C; Siemens, Erlangen, Germany). The x-ray source was typically placed on the opposite side of the surgeon during lateral views and placed under the patient during AP views. We noted the exposure parameters during each procedure; the tube voltage was recorded in kilovolts (kV), and the tube current was recorded in milliamperes (mA). The x-ray tube exposure was under automatic control with the following ranges: 70 to 80 kV/3 to 4 mA at AP position and 100 to 110 kV/3 to 4 mA at LAT position. We also noted the operation time and fluoroscopy time in minutes. The cumulative radiation dose of each dosimeter was measured after the 3-month survey. The dose per case (level) was compared with the annual dose limits prescribed by the National Council on Radiation Protection & Measurements,[30] and the number of operations that can be performed annually by the surgeon was calculated. The dosimeter readings for the eyes (neck) and extremities were directly compared with the annual dose limits. Because of the difficulty of placing a dosimeter close to the eyes of medical staff during the procedure, the neck dosimeter was used to estimate the radiation dose to the eyes in this study.[31] The readings for the chest were used to calculate the whole-body effective dose for the surgeon according to the following formula[20,32]:

Surgeon's *effective* dose = (0.5 × dose for *chest below lead apron*) + (0.025 × dose for *chest above lead apron*)

The dosimeter placed on the right upper arm indicated the dose for the extremities, and both finger dosimeters indicated the dose for the hands.

Statistics

Statistical analysis was performed by an independent statistician using SPSS 14.0K (SPSS, Inc., Chicago, IL). Continuous variables were expressed as mean ± standard deviation. Spearman ρ correlation coefficient was used to determine the correlation between the operation time and the fluoroscopy time. The Kruskal-Wallis test was used to evaluate the differences between surgeons in operation time and fluoroscopy time.

RESULTS

The demographic data of patients and exposure parameters are presented in Table 1. The patients included 11 women and 19 men, and the mean age was 35.1 years (range, 17–79 yr). Three patients underwent PELD at 2 levels simultaneously: L3–L4 and L4–L5 in 2 patients and L4–L5 and L5–S1 in 1 patient. The mean tube voltage at the AP projection (TV_AP) was 72.63 ± 5.46 kV, and the mean tube voltage at the lateral projection (TV_LAT) was 105.90 ± 9.47 kV. The mean

TABLE 1. Demographics of the Patients and Exposure Parameters

Case No.	Sex	Age (yr)	BW (kg)	BMI (kg/m²)	PELD Level	Surgeon No.	Operative Time (min)	TV_AP (mVp)	TV_LAT (mVp)	TC_AP (mA)	TC_LAT (mA)	Fluoroscopy_ Time (min)
1	M	33	60.4	18.6	L34, L45 (Rt)	1	52	69	92	4.2	3.6	1.9
2	F	26	85	31.2	L45 (Lt)	2	60	78	110	4.2	3.1	2.3
3	F	32	56	21.1	L34 (Rt)	2	93	73	110	4.5	3.1	4.5
4	F	34	56.4	22.0	L56 (Lt)	1	32	79	110	4.2	3.0	2.0
5	M	30	93	30.4	L34 (Rt)	1	45	69	110	4.0	3.0	1.6
6	M	40	68.3	22.8	L5–S1 (Rt)	3	75	68	110	4.1	3.0	1.6
7	M	20	62.5	19.3	L45 (Rt)	3	44	74	110	4.5	3.0	5.5
8	M	18	102	30.1	L45 (Lt)	3	49	68	110	3.8	3.0	1.6
9	M	25	95.6	29.5	L5–S1 (Lt)	3	61	83	110	4.0	3.0	1.9
10	M	19	95	27.8	L45 (Rt)	2	40	72	110	4.6	3.0	1.7
11	M	57	63	21.8	L45 (Rt)	1	50	78	110	4.2	3.0	1.8
12	M	44	61	21.1	L45 (Lt)	1	27	76	110	4.4	3.0	3.8
13	M	23	95	29.0	L56 (Rt)	2	45	74	110	4.5	3.0	1.7
14	F	56	72	30.0	L34, L45 (Lt)	2	47	70	110	4.4	3.0	2.4
15	F	41	66.5	26.6	L45 (Lt)	2	60	85	110	3.9	3.0	3.0
16	M	22	67.1	21.2	L45 (Rt)	3	45	68	103	3.4	3.2	1.8
17	F	35	56	23.9	L45 (Lt)	2	27	71	110	4.7	3.0	1.8
18	M	28	70	21.0	L45 (Rt)	1	45	70	110	4.5	3.0	1.3
19	F	24	57.4	19.8	L45 (Rt)	1	60	64	80	2.2	4.1	3.5
20	M	33	80	23.6	L45 (Lt)	2	43	77	110	4.6	3.0	2.1
21	F	79	45	19.0	L45 (Rt)	2	83	67	80	3.4	2.9	2.3
22	F	49	59.5	23.5	L45 (Lt)	1	48	67	110	3.4	3.0	1.6
23	M	62	64	22.1	L45 (Rt)	2	44	78	110	4.2	3.0	2.3
24	M	33	69	23.9	L45 (Rt)	2	45	79	110	4.2	3.0	3.6
25	M	49	63.7	22.0	L45 (Lt)	2	46	70	105	4.5	3.2	4.2
26	M	22	71	21.2	L45 (Lt)	1	45	69	110	4.0	3.0	3.8
27	F	42	51	20.4	L45, L5, S1 (Lt)	2	57	68	107	3.3	3.1	2.2
28	M	17	62.9	21.8	L45 (Lt)	1	35	72	110	4.6	3.0	1.7
29	M	27	84	27.4	L45 (Lt)	3	30	79	110	4.2	3.0	2.0
30	F	32	47	18.1	L45 (Lt)	2	60	64	80	4.2	4.1	3.5

BW indicates body weight; BMI, body mass index; PELD, percutaneous endoscopic lumbar discectomy; TV_AP, tube voltage at the anteroposterior projection; TV_LAT, tube voltage at the lateral projection; TC_AP, tube current at the anteroposterior projection; TC_LAT, tube current at the lateral projection; M, male; F, female.

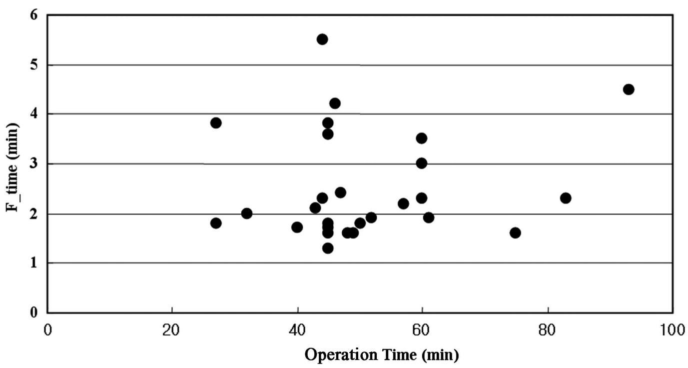

Figure 2. Relationship between the operation time and the fluoroscopy time. No significant correlation was detected. The correlation coefficient was 0.112 (*P* = 0.555).

tube current at the AP projection (TC_AP) was 4.097 ± 0.527 mA, and the mean tube current at the lateral projection (TC_LAT) was 3.113 ± 0.294 mA. The mean operation time was 49.8 minutes (range, 27–93 min). The mean fluoroscopy time was 2.5 minutes (range, 1.3–5.5 min). No significant correlations were found between the operation time and the fluoroscopy time (Figure 2). There were no intersurgeon differences in operation time or fluoroscopy time (Table 2).

The cumulative radiation doses and the calculated radiation doses per procedure are presented in Table 3. The radiation doses per disc level were slightly less than the doses per patient because 2-level PELDs were performed in 3 patients. The radiation doses per level were as follows: neck, 0.0785 mSv; chest, 0.1718 mSv; right upper arm, 0.0461 mSv; left ring finger, 0.7318 mSv; and right ring finger, 0.6694 mSv. The calculated surgeon's effective dose was 0.0093 mSv per level (Table 3).

The protective effects of the lead apron and thyroid shield were as follows. The unprotected radiation dose per level for the neck was 0.0785 mSv, whereas the protected radiation dose per level was 0.0024 mSv. Therefore, the protective effect of the thyroid shield was demonstrated by the reduction in radiation dose by 96.9%. The unprotected radiation dose per level for the chest was 0.1718 mSv, whereas the protected radiation dose per level was 0.01 mSv. Therefore, the protective effect of the lead apron was demonstrated through the reduction in radiation dose by 94.2%.

TABLE 2. Differences in Operation Time and Fluoroscopy Time Among 3 Surgeons

Surgeons	No. of Cases	Mean Operation Time (min)	Mean Fluoroscopy Time (min)
Surgeon 1	10	43.9 ± 9.9	2.3 ± 1.0
Surgeon 2	14	53.6 ± 17.3	2.7 ± 0.9
Surgeon 3	6	50.7 ± 15.5	2.4 ± 1.5
Total	30	49.8 ± 15.0	2.5 ± 1.1
P		0.579	0.164

By Kruskal-Wallis test.

TABLE 3. Cumulative Radiation Exposure to the Surgeon After 30 Consecutive Procedures (33 Levels)

Dosimeter Position	Cumulative Radiation Dose (mSv)	Radiation Dose per Patient (mSv)	Radiation Dose per Level (mSv)
Neck	2.59	0.0863	0.0785
Neck, protected	0.08	0.0026	0.0024
Chest	5.67	0.1890	0.1718
Chest, protected	0.33	0.0110	0.0100
Chest, effective		0.0102	0.0093
Upper arm, right	1.52	0.0506	0.0461
Ring finger, left	24.15	0.8050	0.7318
Ring finger, right	22.09	0.7363	0.6694

Dose effective = (0.5 × Dose below lead apron) + (0.025 × Dose above lead apron).[20,32]

DISCUSSION

The findings of this study may present standard data on radiation exposure associated with PELD technique. With this basic information, we can calculate the allowable annual number of PELDs and compare the radiation dose with those of other MIS spine procedures.

Occupational Exposure Limit (OEL) and the Number of Possible Operations per Year Within the Yearly OEL

According to the National Council on Radiation Protection & Measurements, the yearly OEL is 50 mSv for the body, 150 mSv for the eye, and 500 mSv for the skin (Table 4).[30] Therefore, 291 levels of PELD could be performed per year without using any shielding devices before exceeding the OEL for whole-body radiation. In real clinical settings, however, the surgeon and other medical personnel usually wear lead aprons and thyroid shields during the procedure. Therefore, a surgeon wearing a lead apron could perform 5379 levels of PELD per year without exceeding the OEL for whole-body radiation. With regard to the OELs for the eye and the hand,

TABLE 4. National Council on Radiation Protection & Measurements Annual Occupational Exposure Limits[30]

Exposure	Occupational Dose Limit
Effective dose limit	
Whole body	Annual: 50 mSv
	Cumulative: 10 mSv × age in years
Equivalent dose limit	
Lens of the eye	150 mSv
Skin, hands, feet	500 mSv

1910 procedures and 683 procedures, respectively, could be performed. Overall, the maximum number of PELD levels per year that can be performed without exceeding any of the OELs is 683 without hand protection. According to our data, the radiation doses for both hands were 4- to 10-fold higher than those for the other body sites, such as neck, eyes, chest, and upper arm. Recently, the International Commission on Radiological Protection suggested a new threshold for eye exposure, which was significantly reduced from 150 to 20 mSv.[33] If the new suggested threshold is applied, then only 254 levels of PELD can be performed per year without eye protection. Therefore, adequate protection of the hands and eyes is essential.

TABLE 5. Comparison of Radiation Dose Among Various Discectomy Techniques

	Open (mSv)*	MIS (mSv)*	PELD (mSv)†
Thyroid	0.0016	0.0172	0.0785
Chest	0.0021	0.0308	0.1718
Hand	0.0020	0.0445	0.7318

**Data from Mariscalco et al.[31]*

†Data from this study.

MIS indicates minimally invasive surgery; PELD, percutaneous endoscopic lumbar discectomy.

Radiation Risk

According to the literature, the baseline risk fraction of adults expected to die of cancer is approximately 20%.[6–7,34] Regarding the occurrence of solid cancer or leukemia, it is assumed that any dose above zero can increase the risk of radiation-induced cancer (stochastic effect). A linear model can be applied for solid cancer, and a linear quadratic model can be applied for leukemia.[5–6] Evidence in the literature has demonstrated that the estimated lifetime cancer mortality rate increases by 0.004% per millisievert of radiation to the whole body.[7,35] Some authors have mentioned an increased incidence of cancers among orthopedic surgeons or other physicians.[1–2,22,36] The effects of radiation on the lens of the eye are cumulative and deterministic. Therefore, cumulative radiation doses that exceed the threshold level, regardless of the period of exposure, can cause cataracts.[37] Mroz *et al*[26] commented that a surgeon performing kyphoplasties could easily exceed the eye OEL during the course of a career. This hypothesis can also be applied to PELD without eye protection. Furthermore, recent studies indicated that the threshold dose for cataract development is substantially less than previously thought.[33,38,39]

Effect of Lead Protection

Lead aprons are reported to reduce whole-body exposure during percutaneous vertebroplasty by 42.9% to 75%.[20,25] The radiation exposure with a thyroid shield and lead apron during kyphoplasty is reported to be less than the minimum reportable dose (<0.010 mSv).[26] The use of lead gloves for hand protection during percutaneous vertebroplasty reduces exposure by 33% to 86.1%.[25,27,28] Lead glasses are reported to reduce radiation absorption to the eyes by approximately 70% to 92%.[40,41] In this study, the use of a lead apron and thyroid shield decreased the radiation dose by 94.2% and 96.9%, respectively.

PELD *Versus* Microdiscectomy

Mariscalco *et al*[31] compared the radiation dose of open lumbar microdiscectomy with MIS microdiscectomy using a tubular retractor. The mean radiation dose of MIS microdiscectomy was greater than that of open microdiscectomy. The mean radiation dose of PELD was much greater than that of MIS microdiscectomy or open microdiscectomy (Table 5). This implies that a less invasive discectomy technique inevitably results in more radiation exposure for the surgeons and medical staff.

PELD *Versus* Other Percutaneous Spine Procedures

Researchers have evaluated radiation exposure during other MIS spinal procedures, such as percutaneous vertebroplasty, kyphoplasty, percutaneous pedicle screw insertion, and TLIF (Table 6). Our data indicated that the surgeon's exposure to radiation is similar during PELD, MIS pedicle screw insertion, and MIS TLIF, whereas the radiation dose in PELD is somewhat less than that in percutaneous vertebroplasty or kyphoplasty. However, there are limitations in directly comparing between studies because the radiation dose may be affected by differences in the surgical technique, fluoroscopy specifications, shielding devices, and other variables.

During the study period, we also performed other fluoroscopically guided procedures, including 47 vertebroplasties, 50 MIS pedicle screw insertions, and 30 MIS TLIFs. The calculated annual radiation exposure from other procedures for a single surgeon's hand was an average of 165.88 mSv. Therefore, the allowable levels of PELD per year were reduced from 683 to 455 in practice.

Parameters

Patient size may affect the automatically controlled fluoroscopy settings. Heavier patients generally require more penetrating x-rays, which may increase the dose to the skin at the entrance site.[42–44] A greater tube voltage or greater tube current may increase the radiation dose.[44,45] Although fluoroscopy settings (*i.e.*, tube voltage, tube current) used in this study were optimized by automatic parameter control, all patients received similar radiation doses regardless of body size. We postulate that technical limitations in fluoroscopic setting could account for this finding, but we were unable to clarify the effect of patient size on radiation dose. In addition, we did not detect a correlation between operation time and fluoroscopy time. Theoretically, PELD usually has 2 technical parts. The first part is the fluoroscopically guided transforaminal approach and the second part is the selective decompression under direct endoscopic visualization. Radiation exposure mainly occurs during the transforaminal

TABLE 6. Comparison of Radiation Exposure Among Various Fluoroscopically Guided Spine Procedures

Procedures	Citations	Radiation Doses	No. of Allowable Cases per Year	Comments
Vertebroplasty	Kruger and Faciszewski[25]	Whole body: 1.44 mSv/vertebrae	34 cases	The shielding used resulted in reductions ranging from 42.9% to 86.1%
		Hand: 2.04 mSv/vertebrae		
	Kallmes and Roy[23]	Hand, syringe: 1 mSv/case	500 injections (syringe)	Injection device decreased radiation dose
		Hand, injector: 0.55 mSv/case		
	Harstall *et al*[21]	Thyroid: 0.052 mSv/vertebrae	Extrapolated annual dose for:	The annual morbidity (0.025%) is small to medium, but the lifetime morbidity is high to very high
		Eye: 0.020 mSv/vertebrae	Eye: 8% of OEL	
		Hand: 0.107 mSv/vertebrae	Skin: 10% of OEL	
	Synowitz and Kiwit[28]	Hand, unprotected: 1.81 mSv	300 procedures (unprotected)	75% dose reduction with the use of lead gloves
		Hand, protected: 0.49 mSv	>1000 procedures (protected)	The lifetime risk for fatal cancer is high at 0.04%
	Fitousi *et al*[20]	Effective: 0.011 mGy/case	150 cases for the hand	Mobile shielding device reduces the effective dose by >75%
		Eye: 0.328 mGy/case	229 cases for the eye	
		Hand: 1.661 mGy/case		
Kyphoplasty	Mroz *et al*[26]	Whole body: 0.248 mSv/vertebrae	300 cases for the hand	Surgeons who perform kyphoplasty could easily exceed the OEL to the eye over the course of a career
		Eye: 0.271 mSv/vertebrae		
		Hand: 1.744 mSv/vertebrae		
Pedicle screw insertion	Jones *et al*[22]	In beam: 508 microGy/image	Not specified	The source-superior position is preferred with a minimal patient's dose and an acceptable surgeon's dose
		Eye: 0.56 microGy/image		
		Thyroid: 0.81 microGy/image		
	Rampersaud *et al*[27]	Thyroid: 0.083 mSv/min	Not specified	Fluoroscopically assisted pedicle screw placement results in 10–12 times greater exposure than other, nonspinal procedures
		Ventral waist: 0.533 mSv/min		
		Hand: 0.582 mSv/min		
	Ul Haque *et al*[29]	Thyroid and eye: 0.109 mSv/case	Spine surgeon would surpass the lifetime dose limit after <10 yr of exposure	The rate of thyroid malignancies is elevated among orthopedic surgeons
MIS TLIF	Bindal *et al*[19]	Waist (protected): 0.27 mSv/case	194 cases for the torso	Annual OEL could be exceeded if a large number of fluoroscopically guided procedures are performed
		Neck (unprotected): 0.32 mSv/case	166 cases for the thyroid	
		Hand: 0.76 mSv/case	664 cases for the hand	
	Kim *et al*[24]	Fluoro group: 0.124 mSv	Not specified	The use of navigation-assisted fluoroscopy decreases the radiation exposure to the patient and the surgical team
		NAV group: undetectable		
MIS MD *vs.* open MD	Mariscalco *et al*[31]	Open MD *vs.* MIS MD (mSv/case)	1623 cases for whole body	Radiation exposure to the surgeon during MIS MD is 10–20 times greater than open MD
		Whole body: 0.0021 *vs.* 0.0308	8720 cases for the eye	
		Thyroid: 0.0016 *vs.* 0.0172	11,235 cases for the hand	
		Hand: 0.0020 *vs.* 0.0445		
PELD	Present study	Whole body: 0.1718 mSv/level	683 cases for the hand	
		Thyroid: 0.0785 mSv/level		
		Hand: 0.7318 mSv/level		

OEL indicates occupational exposure limit; MIS, minimally invasive surgery; TLIF, transforaminal lumbar interbody fusion; NAV, navigation; MD, microdiscectomy; PELD, percutaneous endoscopic lumbar discectomy.

approach step. In contrast, radiation exposure during the longer decompression step is minor because most procedures can be performed endoscopically. However, in practice, the fluoroscopically guided procedure and endoscopic procedure are usually mixed. Fluoroscopy is also used during the endoscopic decompression step. Moreover, the beam-on time may be affected by the anatomical characteristics of the disc herniation. For decompression for complex cases, such as lateral recess syndrome or migrated disc herniation, more frequent fluoroscopic confirmation is needed. In contrast, cases of simple disc herniation may be treated with a longer endoscopic time and shorter beam-on time. Therefore, the operation time did not precisely reflect radiation exposure. No significant differences were found in operation time or fluoroscopy time among the 3 surgeons. However, we cannot conclude that the surgical techniques were similar among the surgeons because the number of cases was relatively small.

Measures to Minimize Radiation Exposure During Fluoroscopically Guided Procedures

Currently, many percutaneous or MIS procedures are performed under fluoroscopic guidance. Therefore, strategies to reduce radiation exposure are essential (Table 7).[42,44,46] First, for fluoroscopy, surgeons should make good use of the time-distance-shielding principle (minimize time, maximize distance as much as clinically possible, use shielding). They should also stand on the side of the transmitted beam (*i.e.*, by the detector), keep the x-ray tube under the patient table and not over it, and use the fluoroscope in automatic mode to minimize the radiation needed for image acquisition. Second, regarding technique, to minimize the beam-on time, correct operative technique and intermittent fluoroscopy technique (quick-check technique) are important.[47] Surgeons should also keep their hands outside the primary beam during the procedure (hands-off technique). Finally, surgeons and medical staff should use adequate protection, wearing devices, such as lead aprons, thyroid shields, lead glasses, and lead gloves. They should also wear dosimeters to monitor their annual exposure. Mobile shielding may also help attenuate radiation exposure. The hand dosimeter may be overlooked in real practice because of the strict hands-off technique, and the use of lead gloves is somewhat cumbersome. However, as described previously, the hand dosimeter revealed radiation doses that were greater than those of any other body sites. Therefore, hand protection may be the most important issue to reduce the radiation hazard to surgeons. Despite all efforts to reduce the radiation dose, however, cumulative radiation exposure, to some extent, is inevitable. Development of navigation technology[24] or a nonradiation image-guided (*e.g.*, ultrasound-guided) technique is necessary to minimize radiation exposure in the future.

TABLE 7. Seven Recommendations to Minimize Radiation Dose to the Surgeon and Medical Staff During Fluoroscopically Guided Minimally Invasive Spine Procedures[42,44,46]

1	Use protective devices (thyroid shields, leaded glasses, lead aprons, and lead gloves)
2	Make good use of the time-distance-shielding principle: minimize time; maximize distance as much as clinically possible; use shielding
3	Use the "hands-off" technique
4	Stand on the side of the transmitted beam (*i.e.*, by the detector)
5	Keep the x-ray tube under the patient table and not over it
6	All surgeons and medical staff should wear dosimeters to monitor annual exposure
7	Use the fluoroscope in the automatic mode to minimize the amount of radiation needed for image acquisition

This study had several limitations. First, although PELDs were performed under automated dose-control fluoroscopy, there was no correlation between exposure parameters and body size of the patient. Theoretically, the tube current or the tube voltage could be affected by body size. We postulate that a narrow window of fluoroscopy settings could explain the lack of a correlation. More sensitive parameter-setting controls and a wider range of exposure conditions may lead to the detection of a relationship between exposure parameters and patient body size. Second, we measured the effect of protective equipment using only a lead apron and a thyroid shield. We did not evaluate the potential of lead glasses and lead gloves to reduce radiation exposure to the hands and the eyes. Third, there were three 2-level PELD cases and single-level cases. This may impair the accuracy of the study to some extent. However, our cohort included consecutive cases, regardless of the number of operation levels, because it better reflects the real situation. To minimize bias, we calculated the radiation dose per level and per patient. Finally, our measurements of radiation dose were limited to the surgeon; additional members of the surgical team (*e.g.*, the scrub nurse, radiological technician, and other assistants) were not evaluated. These limitations will be addressed in our future studies.

CONCLUSION

Without using any shielding devices, a surgeon could perform 264 PELDs per year before exceeding the OEL. With adequate radiation shielding, more than 621 PELDs could be performed annually. The lifetime radiation hazards to a surgeon performing PELDs are not negligible. Therefore, proper protective techniques are essential to mitigate exposure.

➢ Key Points

- ❑ The surgeon's exposure to radiation during PELD is less than the exposure during percutaneous vertebroplasty or kyphoplasty, but it is greater than the exposure that occurs during open microdiscectomy.

- Without using any shielding devices, approximately 291 PELD procedures can be performed per year before exceeding the OEL for whole-body radiation.
- With a lead apron and thyroid shield, however, the maximum number of procedures that can be performed without exceeding any of the OELs is 683 because of the increased radiation dose to the surgeon's hands.
- With adequate shielding devices, including a lead apron, a thyroid shield, lead glasses, and lead gloves, the allowable annual number of PELD procedures can be increased.
- Radiation-induced morbidity associated with fluoroscopy-guided spinal procedures is not negligible over the course of a surgeon's career.

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