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Evaluation and management of radiation exposure for patients and medical staff during fluoroscopy-guided spinal injection procedures

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► ***Original article***

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ABSTRACT

Background: The number of fluoroscopy-guided pain procedures using C-arm devices has risen in parallel with the increasing prevalence of spine-related disorders. Although these procedures reduce complications and discomfort for patients, they also increase radiation exposure for patients and medical staff. ***Materials and Methods:*** The primary radiation dose received by patients and the secondary radiation dose received by medical staff when a C-arm device used were measured using a variety of dosimeters (XR multidetector, ion chamber gamma survey meter, thermoluminescent dosimeter (TLD). Doses absorbed by patient organs were calculated using MCNP based ALARA-F (mathematical stylized geometry phantom based software). Utilizing the data obtained, permissible daily numbers of procedures were estimated based on radiation dose limits for medical staff and general public. ***Results:*** The primary radiation dose directly absorbed by the patient during the C-arm procedure was, on average, 1.5 times higher than the secondary dose measured 30 cm away from the patient. From these observations, the permissible number of procedures per day was calculated to be one for medical staff and zero for the general public without protective gear. However, wearing lead goggles or a lead apron would allow medical staff to conduct up to 28 and 1,000 procedures, respectively, while general public wearing this equipment could attend 6 and 200 procedures, respectively. ***Conclusion:*** This study determines radiation exposure levels during C-arm -guided pain relief procedures and advocates for the adoption of protective measures such as lead goggles and an apron to protect medical staff.

INTRODUCTION

As the prevalence of spine disc pain increases, the use of fluoroscopy-guided procedures, involving C-arm devices for administering drug injections into spinal nerve branches, is becoming more widespread [1-6]. These procedures are used to alleviate inflammation caused by compression and to treat pain-sensitive nerves, thereby minimizing complications and patient discomfort [1]. However, their use has increased the overall number of procedures performed. According to the Health Insurance Review and Assessment Service department of the Republic of Korea, the installation of C-arm devices is steadily increasing across various regions in the country, with more than 57% installed in orthopedic clinics [7]. Actually, over the past decade, the registrations of general X-ray and C-arm machines have increased by 34% and 74%, respectively [7].

The ability to accurately identify a treatment site and perform drug injections with C-arm devices has proven to relieve pain within 10 minutes [1, 8, 9]. These procedures are commonly recommended in general hospitals and orthopedic clinics for treating conditions such as neck and lumbar disc pain, spinal stenosis, degenerative arthritis, sciatica, and other pain-related syndromes [5, 10]. However, despite the increasing use of C-arm devices, evaluations of effective and absorbed radiation doses by patients and medical staff (defined as those directly involved in the procedure) are limited.

The increasing use of non-invasive procedures in radiology departments is aimed at reducing hospital stays and surgical complications and has resulted in an increase in the number of medical professionals involved, the number of procedures performed, patient volumes, and associated costs [11]. However, prolonged and frequent exposure to radiation increases the risk of radiation-related injury for both patients and medical staff [5, 10]. In particular, while fluoroscopy radiology offers many benefits, it also exposes medical staff to higher radiation doses than standard diagnostic radiography, which underscores

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the need to mitigate the risks associated with low-dose radiation.

Although studies on radiation dose evaluation for procedures like computed tomography (CT) and interventional radiography, which involve frequent, high doses, have been undertaken, dose evaluations for the increasingly utilized C-arm imaging systems are limited [12]. This limitation highlights to need to assess and analyze the radiation exposure associated with C-arm-guided spinal injection procedures to protect patients and medical staff. Thus, this study was performed to determine radiation doses, the daily allowable number of procedures based on dose limits, and propose management strategies to minimize radiation exposure. These strategies, including estimates of the allowable number of daily procedures within occupational limits, aim to inform future regulatory standards that minimize radiation exposure to medical staff.

MATERIALS AND METHODS

C-arm equipment and experiment setup

The C-arm (OEC 9800 Plus, GE Healthcare, USA) equipment used in this study is employed for pain-reduction in orthopedic clinics and hospital-based orthopedic procedures, particularly in general hospitals or larger medical facilities. To establish the conditions for fluoroscopy-guided pain procedures using the C-arm, a chest phantom (Opaque Chest Rando Phantom 76-683, Cardinal Health, USA) was exposed prone. To measure the primary radiation dose delivered directly, a (A) radiation dosimeter (XR Multidetector, IBA Worldwide, USA) was accurately placed on the lumbar spine 1 (L1) of the phantom to measure the radiation dose and exposure duration.

Measurement of secondary radiation exposure

To assess the secondary radiation dose to which medical staff are exposed, an (B) ion chamber gamma survey meter (2026C, Radcal Corporation, USA) was placed 30 cm from the phantom's L1 location. This setup enabled the measurement of secondary radiation doses potentially received by medical staff (hospital staff not directly involved in the procedure) (figure 1). Furthermore, to evaluate radiation exposure by body part, a thermoluminescent dosimeter (TLD) (UD-802, Panasonic Corporation, Japan) was affixed at 12 sites on the phantom including the eyes, neck (above the shoulders), chest internal/external (relative to the lead apron), gonads internal/external (relative to the lead apron), hands, and feet (figure 1).

Radiation exposure conditions

Under automatic exposure control (AEC) and in a prone setting, tube voltage, tube current, and exposure time were set at 97 kVp and 4.3 mAs. For oblique conditions, the tube voltage, tube current, and exposure time loading used were 107 kVp and 4.8 mAs, respectively.

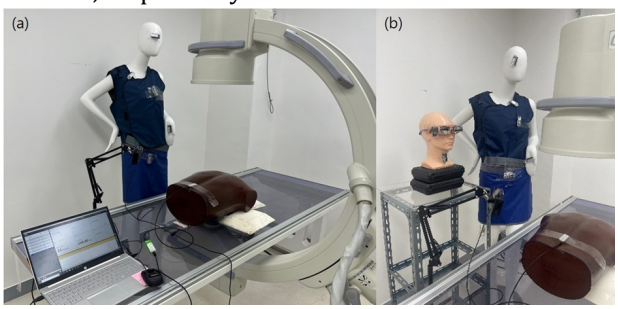


Figure 1. Experimental setup for assessing radiation exposure to patients and medical staff using three dosimeters: **(a)** The IBA radiation dose multidetector was located in the L1 of the phantom to measure exposure doses, a 2026C ion chamber gamma survey meter was located 30 cm away from the phantom to measure the radiation dose to medical staff, and a thermoluminescent dosimeter (TLD) was located at the phantom to measure the radiation dose to medical staff; **(b)** mannequin head was included to measure the radiation doses to the eyes and thyroid gland with and without protective goggles using TLDs.

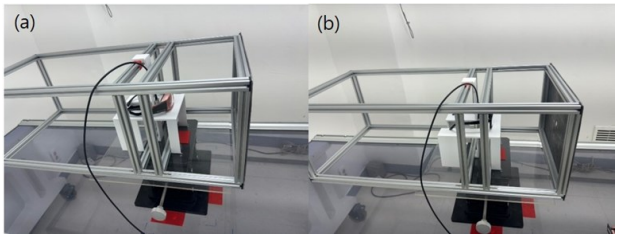


Figure 2. Measurements of radiation dose attenuation rates for lead glass of various thicknesses. All were conducted in accordance with the IEC 61331-1 standard. The experiment was designed to evaluate how different lead-equivalent thicknesses affect the shielding performance of goggles against scattered radiation. Distances, exposure conditions, and position measurements were performed as specified by the IEC guidelines: **(a)** the image represents the experimental setting, **(b)** the image represents actual settings according to the IEC guidelines and includes a 20 mm hole to narrow the beam width.

Evaluation of the shielding effectiveness of lead goggles

In addition, to evaluate the effectiveness of lead goggles (Italian Red, X-guard Armor, Japan), the attenuation of radiation dose was determined using the (A) XR Multidetector dosimeter with and without goggles (figure 2). The arrangement used complied with International Electrotechnical Commission (IEC) 61331-1 standards: the distance from the X-ray tube focus to the lead goggles was 150 cm, from the goggles to the dosimeter was 5 cm, and from the dosimeter to the rear wall was 120 cm [13-15]. Dose settings, using the narrow beam measurement method, were 100 kVp, 200 mA, and 0.1 sec. Measured values were analyzed using SPSS Version 27.0. Multiple regression analysis was used to determine differences between radiation shielding rates at various lead glass thicknesses. Statistical significance was accepted for P values <0.05.

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Organ dose assessment using MCNP based software (ALARA-F)

The mathematical stylized geometry phantom and Monte Carlo N-Particle (MCNP) based As Low As Reasonably Achievable-Fluoroscopy (ALARA-F) software (Korea Disease Control and Prevention Agency, Republic of Korea) was employed to determine organ doses absorbed during fluoroscopic imaging [16]. Based on the experimental conditions (e.g., tube voltage, tube current, exposure time, inherent filter, additional filter, filter type, Focus-to-Skin Distance (FSD), examination site, imaging direction, and examination range) dose evaluations were performed on male and female patients.

RESULTS

The primary radiation doses directly impacting patients were determined by positioning the (A) XR Multidetector dosimeter at the L1 location. When measured using the (B) 2026C Surveymeter positioned 30 cm from the phantom's L1 location, the average dose recorded by the (A) XR Multidetector dosimeter was 24.75 uGy, which was 1.5 times higher than the 16.04 uGy displayed by the (B) 2026C Surveymeter at the same distance. The average exposure time was 3 seconds per exposure, and the actual average exposure time was 2.9 seconds.

A TLD was attached to 12 body locations to determine direct exposure doses. Greatest exposure was observed in the foot area, though exposures to hands and neck were significant (figure 3). Readings obtained from TLDs positioned inside and outside the lead apron and lead goggles were below the detectable limit.

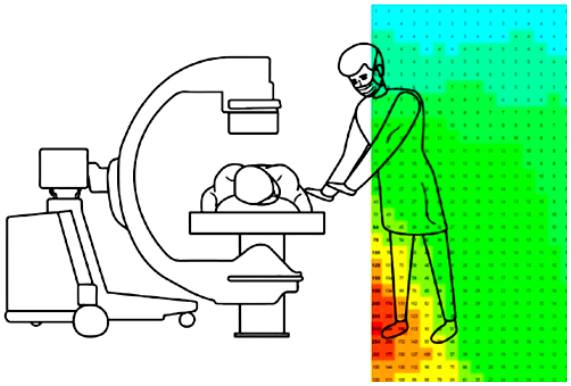


Figure 3. Assessment of effective radiation exposure to medical staff during fluoroscopy-guided pain procedures based on TLD results. Thermoluminescent dosimeters were placed at multiple body sites including the eyes, neck, chest, gonads, hands, and feet to measure site-specific radiation doses. The data reflected the exposure levels encountered during simulated procedures and provided insight into occupational dose distribution and potential risk areas for medical staff.

Calculations were performed to determine the number of procedures that could be performed daily by assuming a medical staff and general public to patient distance of 30 cm. The results showed that when medical staff wore lead goggles during procedures, radiation exposure was reduced by up to 95%, allowing a maximum of 28 procedures per day for medical staff and 6 procedures per day for general public (table 1). Furthermore, wearing a lead apron decreased radiation exposure by 99.86%, enabling up to 1,000 procedures per day for medical staff and 200 procedures per day for the general public (table 1). In contrast, without such protective equipment, the number of permissible procedures would have been limited to one per day for medical staff and 0.27 per day for general public (table 1).

Table 1. Daily permissible number of procedures based on radiation exposure limits for medical staff and general public.

	30 cm from the phantom*	Lead goggles**	Lead apron**
1 Set (10 Exposures) Irradiation Equivalent Dose (uSv)	16.04	0.72	0.02
Radiation-Related Medical staff Limit Per Day	1	28	1000
General Public Irradiation Limit Per Day	0.27	6	200

*Medical staff were located 30 cm away from the phantom during the procedure. **When medical staff or general public wore lead goggles or a lead apron during the procedure.

To evaluate the absorbed radiation dose to the eye lens with and without the use of lead goggles, an (A) XR Multidetector dosimeter was positioned in front of and behind the lead goggles. Multiple regression analysis was performed to examine the effect of goggle glass thickness on radiation shielding efficiency. The analysis revealed a coefficient of determination of R^2=0.998, indicating that the shielding rate increased by an average of 3.47% for every 1 mm increase in goggle glass thickness (Table 2). Furthermore, for thicknesses of greater than 0.6 mm, the shielding rate was consistently above 99% ($p < 0.001$) (table 2).

Table 2. Attenuation rate of lead goggles based on lead thickness.

Lead Thickness (mm)	Irradiation Dose (uGy)	Attenuation Rate	Attenuation %
0	86.25	1	0
0.5	2.056	0.0238	97.62
0.6	1.392	0.0161	98.39
0.7	0.956	0.0111	98.89
0.8	0.649	0.0075	99.25
0.9	0.458	0.0083	99.47

Dose assessment was performed using ALARA-F software and preferred conditions for males and females. Although no significant difference in effective doses was observed between the sexes, doses were higher in female organs, including lungs, breasts, ovaries, uterus, thyroid, liver, brain, salivary glands, skin, bone surface, spleen, and muscles. This discrepancy was attributed to slight variations in the organ positions of men and women.

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DISCUSSION

The use of C-arm equipment for accurately identifying the locations for pain relief procedures is on the rise, particularly for conditions like neck and lumbar disc disorders, spinal stenosis, degenerative arthritis, sciatica, and paresthesia of shoulders, elbows, fingers, and toes [6, 17]. C-arm equipment facilitates the confirmation of treatment areas and medication administration, and procedures are typically completed in under 10 minutes. However, due to the increased frequency of procedures (e.g., to three treatments per week), radiation exposure risk to patients and medical staff has become a major concern. Despite exposure to high levels of radiation, many medical staff are unaware of the radiation doses they receive during fluoroscopic procedures or safe exposure limits [18-20].

The study measured the radiation dose received by medical staff 30 cm from the phantom at an average 16.04 uGy for a 30-second procedure, which is two thirds of that received by a patient. Increased distance from the radiation source further lowered exposure [5, 18]. Some studies have reported that scattered radiation exposure to radiology and medical staff is 2 to 3 times lower than the dose absorbed by a patient's skin during 685 intervention procedures [5, 21, 22]. Nonetheless, medical staff still face continuous radiation exposure.

By calculating radiation exposures and determining the maximum number of procedures medical staff can safely perform daily monitoring based on exposure limits; the study found that medical staff could only conduct one procedure per day without protective equipment but that with a lead apron and goggles could perform up to 1,000 or 28 procedures per day, respectively (table 1). These findings underscore the ability of protective equipment to significantly reducing radiation exposure to critical organs.

Continuous radiation exposure to the same area increases the risk of erythema and skin necrosis and also increases operator exposure to scattered radiation [5, 10, 18]. According to the ICRP 85, the risk of cataracts and cancer escalates when cumulative radiation doses reach 50-200 mSv [10, 23, 24]. Given the varying thicknesses of lead goggles on the market, selecting the appropriate goggles based on the frequency of procedures and total exposure time is crucial. Experiments conducted in accord with IEC 61331-1 standards have revealed that glass with lead equivalent thicknesses of 0.5- and 0.7-mm attenuate exposure by 97.6% and greater than 99%, respectively [13]. Hence, using lead goggles with a lead equivalent thickness of at least 0.7 mm can block greater than 99% of radiation (table 2).

According to the Regulation on the Safety Management of Diagnostic Radiation-Generating Equipment, each medical institution is required to have at least one radiation-protective apron and a minimum of two radiation-protective devices [11]. These protective devices include radiation-protective aprons, thyroid protectors, lead goggles, lead curtains, radiation-protective partitions, and lead gloves, all of which must be readily accessible to medical staff. Under the Regulation on Medical Device Items and Item-specific Classifications, these devices fall into 13 categories of radiation hazard protection equipment [11, 25]. The wearing of protective aprons and other shielding devices is an essential habit that should be consistently practiced to minimize radiation exposure [26, 27]. Moreover, wearing two or more radiation protection devices, as mandated by the Ministry of Food and Drug Safety (KFDA), and the use of equipment with suitable lead content are also recommended. Approximately 30% of medical staff in hospitals have received training on the use of radiation protective equipment. However, the absence of lead goggles and lead gloves in diagnostic radiography rooms has been reported to be as high as 96% [28]. To address such issues, it is essential that relevant legislation be passed and that systematic radiation safety training programs be implemented to enhance individual awareness and promote social awareness and institutional commitment to radiation safety.

CONCLUSION

This study focuses on the knowledge gap that exists concerning radiation doses and their impacts on patients and medical staff conducting fluoroscopy-guided pain relief procedures using C-arm equipment. The study provides information on the radiation doses medical staff and patients are exposed to during these procedures, and on the use of protective equipment, such as lead aprons and lead goggles. Notably, it emphasizes the importance of the thickness of the glass in lead goggles. By proposing management measures to minimize radiation exposure, this study is anticipated to play a crucial role in safeguarding the safety of medical staff during procedures.

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