Korean J Pain 2022;35(2):129-139
https://doi.org/10.3344/kjp.2022.35.2.129
pISSN 2005-9159 eISSN 2093-0569

KJP

Review Article

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Radiation safety for pain physicians: principles and recommendations

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Received November 23, 2021
Revised February 12, 2022
Accepted February 13, 2022

Handling Editor: Kyung Hoon Kim

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C-arm fluoroscopy is a useful tool for interventional pain management. However, with the increasing use of C-arm fluoroscopy, the risk of accumulated radiation exposure is a significant concern for pain physicians. Therefore, efforts are needed to reduce radiation exposure. There are three types of radiation exposure sources: (1) the primary X-ray beam, (2) scattered radiation, and (3) leakage from the X-ray tube. The major radiation exposure risk for most medical staff members is scattered radiation, the amount of which is affected by many factors. Pain physicians can reduce their radiation exposure by use of several effective methods, which utilize the following main principles: reducing the exposure time, increasing the distance from the radiation source, and radiation shielding. Some methods reduce not only the pain physician's but also the patient's radiation exposure. Taking images with collimation and minimal use of magnification are ways to reduce the intensity of the primary X-ray beam and the amount of scattered radiation. It is also important to carefully select the C-arm fluoroscopy mode, such as pulsed mode or low-dose mode, for ensuring the physician's and patient's radiation safety. Pain physicians should practice these principles and also be aware of the annual permissible radiation dose as well as checking their radiation exposure. This article aimed to review the literature on radiation safety in relation to C-arm fluoroscopy and provide recommendations to pain physicians during C-arm fluoroscopy-guided interventional pain management.

Key Words: Fluoroscopy; Pain, Procedural; Radiation; Radiation Dosage; Radiation Effects; Radiation Exposure; Radiation, Ionizing; Radiography, Interventional; Radiology, Interventional; Safety; Scattering, Radiation; X-Rays.

INTRODUCTION

Various imaging devices are used to treat pain patients. Although the use of ultrasound has gradually been increasing in recent years, procedures using C-arm fluoroscopic machines are still widely used in the treatment of pain. C-arm fluoroscopy has several advantages, such as the ability to assess the patient's bone structure or shape, ease of assessing intravascular injection compared to that associated with using ultrasound, and ease of discerning the needle's location regardless of the needle's gauge or insertion angle.

However, C-arm fluoroscopy may expose patients and medical staff to radiation [1–4]. Small, cumulative doses over a long time period can produce adverse effects in health workers in the ionizing radiation zone. In one study [5], a more significant incidence of cataract was found in medical staff who work in the ionizing radiation zone,

Author contributions: Sewon Park: Writing/manuscript preparation; Minjung Kim: Resources; Jae Hun Kim: Supervision.

where the relative risk was 4.6, when compared with the medical staff who work in the non-radiation zone. According to a report in 2005 [6], the average cumulative radiation dose (35.2 mSv) and cancer incidence (29%) are both higher in orthopedic surgeons than in other medical specialties. Orthopedic surgeons using X-ray equipment had a significantly higher risk of tumors compared to unexposed medical workers ($P = 0.002$).

In another study [7], they reported cases of brain and neck tumors that occurred in physicians performing interventional procedures. The study included data from 31 interventional physicians with brain and neck cancer. A striking finding was the disproportionate occurrence of tumors on the left side of the brain (85% of cases). This reflects the effect of a differential dose distribution of radiation exposure in interventionists who typically work with the left side of the head in closest proximity to the primary X-ray beam and scattered radiation. Of the reported cases, 87.1% were brain tumors and the remainder were neck tumors. The relatively low incidence of neck tumors may be due to the thyroid shield effect.

Therefore, radiation safety awareness and practice by medical staff are important for reducing the risk of radiation exposure and its potential negative biological effects [8]. In this review, radiation safety among pain physicians who use C-arm fluoroscopic machines is discussed.

MAIN BODY

1. Radiation exposure

1) Three main causes of radiation exposure

When medical X-ray equipment is used, radiation exposure may occur through three major sources: primary X-ray beams, scattered X-rays, and leakage X-rays. Radiation exposure is the highest with primary X-rays, followed by scattered X-rays, and leakage X-rays (**Fig. 1**). During fluoroscopy, the dose rates of the primary X-ray beam, scattered X-rays, and leakage X-rays are 5–20 mGy/hr at the surface of the patient's body, 1–10 mGy/hr at the operator's position, and 0.001–0.01 mGy/hr at the operator's position, respectively [9].

(1) Primary X-ray beam

Primary X-rays from a machine are the primary source of radiation exposure [10]. However, the major source of radiation exposure to the patient is the beam during irradiation. Generally, pain physicians and medical staff are not exposed to direct X-ray beams unless their hands or body parts are directly placed in the X-ray irradiation area [11]. Therefore, the primary X-ray beam is not a major source of radiation exposure for pain physicians and medical staff.

(2) Scattered X-ray

The second source of radiation exposure is scattered radiation [10]. Scattered radiation refers to the radiation primarily generated by the irradiated radiation bouncing around the patient's body or table after it hits the patient's body or table. When using a fluoroscopic machine, the patient directly receives an X-ray; however, the pain physician and medical staff usually remain at a certain distance. Exposure to scattered radiation is primarily less than that in irradiation during fluoroscopy; however, scattered radiation spreads in almost all directions from the patient's body and table, making it the largest source of radiation exposure for physicians and medical staff [12].

(3) Leakage X-ray

Leakage radiation refers to radiation that leaks to other places while generating radiation from the machine [10]. In fluoroscopy, X-rays are irradiated towards the image intensifier, and the remainder of the fluoroscopy machine is shielded; however, some radiation leaks in a direction other than the image intensifier. Nevertheless, the amount of leakage radiation is smaller than that of primary X-rays and scattered X-rays.

2) Factors affecting the amount of scattered X-ray

The scattered radiation dose is proportional to the primary X-ray dose [13]. Therefore, in situations where the primary X-ray dose is high, the scattered radiation dose is also

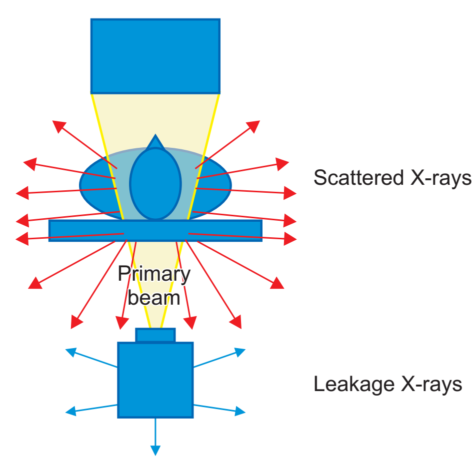

Fig. 1. Three major causes of radiation exposure: primary X-ray beams (yellow), scattered X-rays (red), and leakage X-rays (blue).

high. Even for the same primary X-ray dose, the scattered radiation dose varies depending on the distance from the X-ray generator to the table and patient [14].

(1) Thickness of the area

The amount of scattered radiation is proportional to the thickness of the area or body part of which the image is captured [13,15]. The thicker the body part to be captured, the more difficult it is for X-rays to pass through the patient's body. Therefore, a higher X-ray dose is used to penetrate the thicker body part and reach the image intensifier to form an image. For example, even if an X-ray of the same area of the lumbar spine is taken, obese patients are irradiated with more X-rays than are lean patients. Therefore, in obese patients, the primary X-ray and scattered radiation doses to physicians or medical staff are higher than those associated with lean patients. In the same patients, the radiation exposure per shot for a lumbar or thoracic spine intervention is higher than that for an upper and lower extremity or cervical spine intervention.

(2) X-ray generator location

As X-rays are projected from the X-ray generator towards the image intensifier, a higher concentration of scattered radiation is generated near the X-ray generator [16,17]. When an image is taken with the X-ray generator positioned underneath (**Fig. 2A**), more scattered radiation reaches the lower extremities of the physician and medical staff [9]. When a lateral view is taken (**Fig. 2B**), more scattered radiation is generated on the side where the X-ray generator is located [14]. Thus, the staff on the side of the X-ray generator will have a higher radiation exposure than will the staff on the opposite side. The latest C-arm fluoroscopic machine is usually equipped with a flat panel detector instead of an image intensifier. If the flat panel detector is positioned downwards to obtain an image (**Fig. 2C**), a large amount of scattered radiation reaches the upper body, neck, and head.

This results in more radiation exposure to the eye or thyroid, which are relatively sensitive to radiation [18,19]. In a report on brain tumors among physicians, such as cardiologists performing interventional procedures involving ionizing radiation, brain tumors occurred more frequently on the side that was highly exposed to radiation, implying that the occurrence of brain tumors was related to radiation exposure [7]. Therefore, it is necessary to avoid taking pictures with the image intensifier located underneath.

3) Radiation exposure allowance

(1) Annual maximum permissible dose

Medical staff using a C-arm fluoroscopic machine are exposed to radiation for a long period of time, even if the amount of radiation exposure per procedure is not large. There is an annual maximum permissible dose for people occupationally exposed to radiation. **Table 1** shows the annual maximum permissible dose from the National Council on Radiation Protection (NCRP) and Measurements [20]. In the recommendations of the NCRP, the exposure allowance of the lens of the eye was lower than that of other body parts. However, accumulating data on radiation exposure has revealed that the lens is considerably more sensitive to radiation than was previously known [21–24]. Even a small amount of radiation exposure can cause abnormalities, such as radiation cataracts [25]. In 2011, the International Commission on Radiological Protection (ICRP) announced a significantly lower radiation dose to the lens ('150 mSv/year' to '20 mSv/year for over 5 years with no annual dose in a single year exceeding 50 mSv'),

Fig. 2. Depending on the location of the X-ray generator, the parts of the body exposed to scattered X-rays vary. When an image is taken with the X-ray generator (red circle) positioned below (A), more scattered radiation is generated in the lower extremities of the physician and medical staff [9]. When a lateral view is taken (B), more scattered radiation is generated on the side where the X-ray generator is located [14]. If the flat panel detector is positioned downwards to obtain an image (C), a large amount of scattered radiation is generated to the upper body, neck, and head. The red circle is X-ray generator.

Table 1. Annual maximum permissible dose according to the National Council on Radiation Protection (NCRP) and measurements for occupational radiation exposure [20] and the International Commission on Radiological Protection (ICRP) [22]

Area/Organ	NCRP annual maximum permissible dose	ICRP annual maximum permissible dose
Thyroid	50 rem (500 mSv)	
Extremities	50 rem (500 mSv)	
Gonads	50 rem (500 mSv)	
Lens of the eye	15 rem (150 mSv) in 1993 50 mGy (50 mSv) : change in 2018[b]	20 mSv, averaged over 5 years[a]
Whole body	5 rem (50 mSv)	
Pregnant women	0.5 rem (5 mSv)	

Adapted from National Council on Radiation Protection and Measurements (Limitation of exposure to ionizing radiation: recommendations of the National Council on Radiation Protection and Measurements; 1993. pp 1-86) [20].
[a]In 2011, the ICRP reduced this dose to 20 mSv per year, averaged over 5 years, with no single year exceeding 50 mSv [22].
[b]In 2018, NCRP reduced the annual maximum permissible dose of occupational exposure in the lens of the eye from 150 mSv to 50 mSv [26].

as shown in **Table 1** [22]. Although 50 mSv for 1 year can be the permissible radiation exposure of ICRP, exposure of the lens should not exceed 20 mSv per year for a period of 5 years or more when there is long-term exposure. After the ICRP's announcement, the maximum permissible dose to the lens was adopted in European and by International Basic Safety Standards [24]. In 2018, NCRP also reduced the annual maximum permissible dose of occupational exposure in the lens of the eye from 150 mSv to 50 mSv [26]. The European Union Council Directive enabled the application of the principle of "as low as reasonably practicable" (ALARP) to limit the exposure to the eye by those who perform therapeutic procedures using radiation [27]. Consequently, in the UK, the annual maximum permissible radiation dose to the eye was limited to 15 mSv [28].

(2) Use of a dosimeter

If a radiation device is used, a dosimeter is used to regularly assess the radiation exposure [29], monthly, yearly, and in the long-term at 5 years or more to maintain radiation doses within acceptable limits [22]. Radiation exposure is usually measured when radiation is shielded by lead aprons or thyroid shields during a procedure. However, in many cases, the upper/lower extremity or face is not properly shielded, and the resultant exposure is not measured. Therefore, it is important to determine radiation exposure both within and beyond the coverage of protective devices [12,30].

2. Principles of reducing radiation exposure

The basic concept for reducing radiation exposure is "as low as reasonably achievable" (ALARA) [31]. This term is similar to the ALARP principle mentioned above. Generally, the ALARA principle remains consistent with the ICRP's recommendations and is focused on those exposures that can reasonably be controlled. In the UK, the ALARA principle was incorporated into the regulatory regime in the form of ALARP [32]. A key difference between ALARP and ALARA is the principle's application to risks from all hazards in totality, rather than being applied solely to radiological hazards.

There are several ways to reduce radiation exposure; however, the three major principles for radiation safety are time, distance, and shielding [33]. This is to minimize the radiation exposure time, stay as far away from the radiation source as possible, and wear sufficient and appropriate shielding to protect the body from radiation. Ways to reduce radiation exposure by changing the C-arm fluoroscopy mode are also explored.

1) Time

A method for reducing the radiation exposure time corresponds to a method of reducing radiation exposure for both patients and medical staff. Resultantly, efforts should be made to reduce the irradiation time and the number of images taken. First, the higher the physician's skill level, the fewer fluoroscopy images will be required, and the same procedure can be completed with a lower radiation exposure [33]. In a recent study [25], the radiation exposure time of a professor was shorter than that of a fellow. Moreover, if possible, rather than continuous images with high radiation exposure, utilizing still images, and obtaining continuous images only when necessary, is recommended [29].

To reduce the fluoroscopy time, the radiographer needs to check the C-arm at the correct location and at the right moment to avoid blurred images [33]. Recently, C-arm fluoroscopic machines have been equipped with laser aiming lines, so that the area to be captured can be examined in advance [34].

2) Distance

Radiation decreases as the distance from the radiation source increases and is inversely proportional to the "square" of the distance [33]. This also applies to scattered radiation. Compared to medical staff situated 1 m away from the radiation source, medical staff situated 2 m away are only exposed to 1/4 of the radiation. Therefore, the operator is exposed to a smaller amount of radiation as the distance from the table and the patient is increased when taking a radiographic image after inserting the needle. It takes effort to move backwards every time an image is taken; however, it is an effective way to reduce your radiation exposure at no cost.

Kim et al. [35] showed that a distance of 20 cm from the table reduced scattered radiation by 73.3% compared to that on the side of the table. In a study on radiation exposure of radiographers performing radiography [16], the effective dose of the radiographer standing next to the operator panel was 53.3% lower than that of the radiographer standing in front of the fluoroscopy operator panel. The radiographer standing behind the operator panel had a 79.5% less effective dose than that of the radiographer standing in front of the control panel. In another study [36], it was found that the physician's distance from the radiation source and the position of the hand correlated with the radiation dose during complicated procedures such as transforaminal epidural block.

3) Shielding

Shielding has the disadvantage of being expensive and having to prepare equipment compared to the two methods mentioned above. However, an advantage is that radiation exposure can be reduced without making any effort other than wearing the device [33]. In a recent study [25], radiation exposure was measured during a cervical epidural block according to the operator. The results of the study confirmed that radiation exposure was minimized when appropriate equipment (thyroid protector, leaded apron, and eye gear) were used, even if the distance between the X-ray field and the physician was different depending on the operator.

(1) Degree of attenuation

Protective devices are made of vinyl or rubber, impregnated with lead or other shielding material composites, for which their thickness is reported in terms of protective lead or lead-equivalent (Pb_{eq}) thickness in millimeters [37]. The lead equivalent is a unit that indicates the thickness of lead (in millimeters) having the same degree of attenuation when converted to lead. The degree of attenuation depends on the material used rather than the weight or thickness of the device [38].

(2) Personal protective devices

Protective devices must be as fully equipped as possible. In addition to the lead apron and thyroid shield, it is necessary to equip for radiation protection, to the extent possible, the hat, ceiling suspended shield, portable barrier drape, gloves, face shield, goggles, glasses, *etc*. [39].

① Lead aprons

Lead aprons are the primary protective devices against radiation. Three types of lead aprons are commercially available: the front type (**Fig. 3A**), wraparound type (**Fig. 3B**), and skirt and vest type (**Fig. 3C**). In the case of a one-piece product, there is a front type that protects the anterior side of the body; however, it has a hole in the back. The wraparound and skirt and vest types can protect both the anterior and posterior sides of the body [11]. It is recommended that these aprons be worn, if possible. If it is made of a material with the same degree of attenuation, the front part of the wraparound-type apron as well as the skirt and vest type, is worn in two layers, so radiation is blocked twice compared to that of the front-type apron [29].

A recent study [40] compared radiation exposure to the back (occurring when the medical workers were standing with their back toward the fluoroscopy equipment) in three groups: no lead apron, front type apron, and wraparound type apron. The radiation exposure with a front type apron is higher than that when a wraparound type is used, and is also higher than that in the group with no apron protecting the neck or thyroid. Scattered radiation from the back may be retained in the front type apron, increasing the radiation exposure to the upper region. In the front type group, the mean radiation dose to the neck or thyroid was four times higher than that in the group without an apron. Therefore, even when using lead aprons, medical workers should not stand with their back towards the radiation source with a front coverage apron during fluoroscopy.

In one study [41], approximately 47% of the interventionists reported that among the three types of aprons, they experienced body aches due to wearing only front-type aprons. This is probably because the weight of the front-type apron is not evenly distributed on the body, although the weight is lighter than that of other types of aprons. Therefore, when considering radiation protection or body

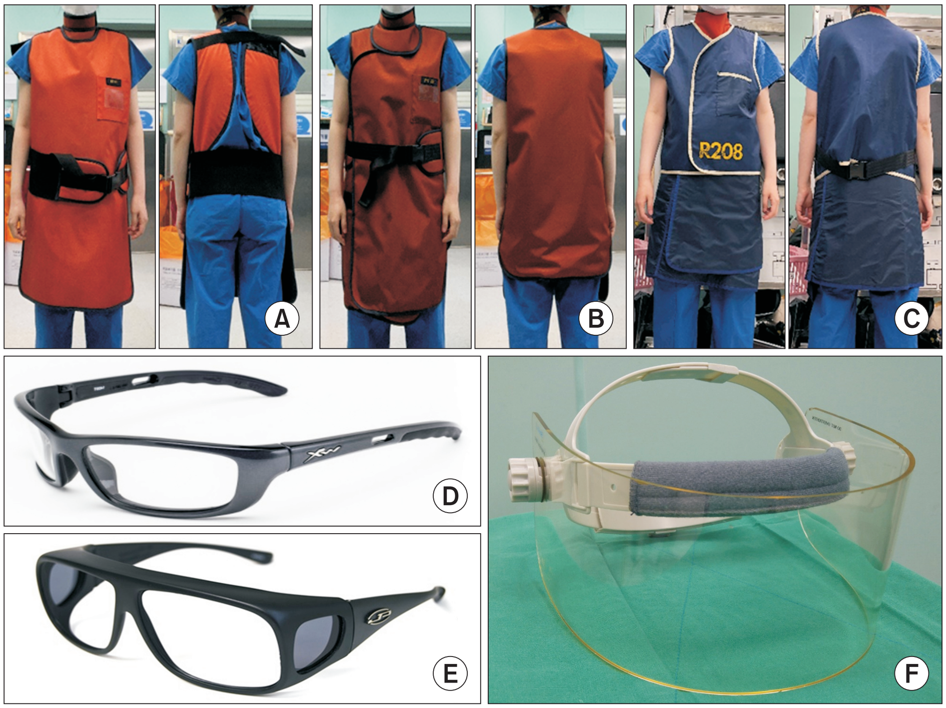

Fig. 3. Personal protective devices. Three types of commercially available lead aprons: (A) front type, (B) wraparound type, and (C) skirt and vest type. Various types of eye shields: (D) wraparound type, (E) side shield type, and (F) face shield.

ache caused by wearing aprons, the wraparound-type aprons or skirt-and-vest-type aprons are recommended. The skirt-and-vest-type apron weighs the most when the same material is used, but compared to the one-piece type, the weight is distributed over the shoulder and waist, reducing the burden on the spine [11].

The International Atomic Energy Agency recommends wearing an apron with a lead equivalent of 0.35 mm or more [30]. In general, there are many aprons equivalent to 0.25 mm lead; however, when using a wraparound-type apron, the degree of attenuation is equivalent to 0.5 mm lead on the anterior side of the body, which corresponds to a thickness that can block more than 90% of scattered radiation [9].

However, more important than the design is a lead apron that fits the neckline and armhole [9]. Especially in female staff, radiation exposure of breast tissue can be dangerous when a large gap between the lead apron and the body exists. Chou et al. [42] reported a 1.9-fold increased prevalence of cancer and a 2.9-fold increased prevalence of breast cancer in female orthopedic surgeons compared with American women of similar ages and races. Therefore, each physician should be provided with an apron of appropriate size and fit [11].

② Thyroid shields

The thyroid gland is vulnerable to radiation [10]. Thyroid shields are the best way to minimize the risk of thyroid cancer from radiation exposure [11]. Thyroid shields can reduce the effective dose by 2.5 times and the total exposure by almost 50% [43]. Wearing a thyroid shield with a lead equivalent thickness of at least 0.5 mm is recommended [11].

Thyroid shields must be worn to sufficiently cover the thyroid gland. If worn loosely because of feeling hot and sweaty, thyroid shields may not sufficiently cover the thyroid gland, and thus, the protector may be ineffective [11]. One study [44] reported that wearing a shield tight against the throat led to lower radiation exposure levels compared to wearing the shield loosely ($P \leq 0.001$).

③ Radiation-reducing gloves

Gloves can be used to reduce radiation exposure to a part of the body that is close to the X-rays during procedures that use a C-arm fluoroscopic machine. Radiation-reducing gloves have a less shielding effect than the apron; however, the results show that it was effective in reducing scattered radiation by approximately 26% [35]. There are cases where some medical staff put their hands in the X-ray area while wearing these gloves and perform the procedure while taking images in real time. Because higher-energy X-rays are emitted to penetrate the gloved hand, the shielding effect of the glove is almost nonexistent; therefore, putting your hand in the X-ray area when taking X-rays should be avoided [45].

④ Eye shield

As described above, since the lens is the most sensitive organ to radiation, medical staff who use a fluoroscopic machine for long periods of time should wear radiation-shielding goggles or glasses (**Fig. 3D–F**) [24]. Products that only have radiation-protective glass lenses should be avoided, and products that have radiation-protective frames should be acquired [29]. In addition, the larger the gap between the radiation shielding glasses and the face, the more scattered radiation enters the eyes through the gap; therefore, it is recommended to wear wraparound-type glasses (**Fig. 3D**) with less of a gap between the glasses and the face [46]. In a recent study [47], lead glasses modified with lateral and lower lead shielding significantly reduced eye radiation exposure and improved safety compared to standard lead glasses.

In one study [28], the dose reduction factors (the ratio of the dose with no eyewear divided by that when lead glasses are worn) were calculated for various lead glasses and recommended high radiation-shielding glasses. Wrap-around-type glasses or those with large front lenses and side shielding provide a reasonable level of protection. The results of this study indicate that both the size of the lenses and the degree to which the glasses fit the contours of the face, especially under the eyes, are important. If you wear glasses because of poor eyesight, it is difficult to use wrap-around-type glasses; therefore, goggles or face shields (**Fig. 3F**) can be chosen. Regarding face shields, there is a lot of empty space between the face and the shield; however, compared to the glass-type product, the radiation shielding degree does not decrease significantly due to its wider coverage of the face [24]. The face shield has a lead equivalent thickness of 0.1 mm, which is lower than the glass-type product, but has a dose reduction factor of 4. Since the dose reduction factor of the glass-type product is 3.2 to 7.6, the radiation shielding degree of the face shield is not significantly lowered [28].

Koukorava's [48] simulation proved that beam quality and lead thickness have little influence on the eye dose, whereas X-ray beam projection, the position and head orientation of the operator, and the distance between the image intensifier and the patient are key parameters affecting eye and whole-body radiation doses. Moreover, a report revealed that if the lead equivalent thickness of glasses was ≥ 0.5 mm, no significant difference in the effect of the protection for the lens of the eye was observed. In fact, most lead glasses have a lead equivalent thickness of 0.5 or 0.75 mm, which can reduce more than 95% of the scattered radiation coming through the spectacle lens [24].

Another device to protect the eyes from radiation is the ceiling-suspended screen [49]. This device is effective when it is close to the patient. The use of a ceiling screen can result in the same dose reduction to both eyes while protecting the operator's upper body (50%–80%) from radiation exposure. However, it may be ineffective in clinical practice because the position of the screen placement must be changed throughout the procedure [28].

(3) Maintenance of protective devices

It is important to check if the protective device is not damaged and is functioning properly [9]. Visual inspection of radiation-reducing gloves can be directly carried out; however, the apron or thyroid protector is covered with a cloth, so it is impossible to visually check whether the inner protector is damaged. In a study conducted at Rwandan Public Hospital [50], 59% of participants never checked the integrity of their lead-rubber apron. In a study conducted at two university hospitals in Korea [51], 42.3% of 7-yr-old lead aprons were damaged, as seen through fluoroscopic images. The older the protective device, the more likely it is to be damaged. Therefore, it is essential to regularly check protective devices through fluoroscopic or X-ray examinations every year [52].

According to a study, the most damaged part of the lead apron is the middle part, accounting for 51% [51] (**Fig. 4**). This area needs to be checked more carefully because it wrinkles when walking or sitting. In addition, to reduce damage to the apron or thyroid protector, it is important to store them appropriately [11]. It should not be stored folded and hung on a hanger.

Fig. 4. Defects in the shields are found using fluoroscopic images. The most common site of damage to the radiation-protective shields was at the waist of the aprons (51%) [51]. (A) One-piece-type apron and (B) skirt-type apron. Adapted from the article of Ryu et al. (Korean J Pain 2013; 26: 142-7) [51].

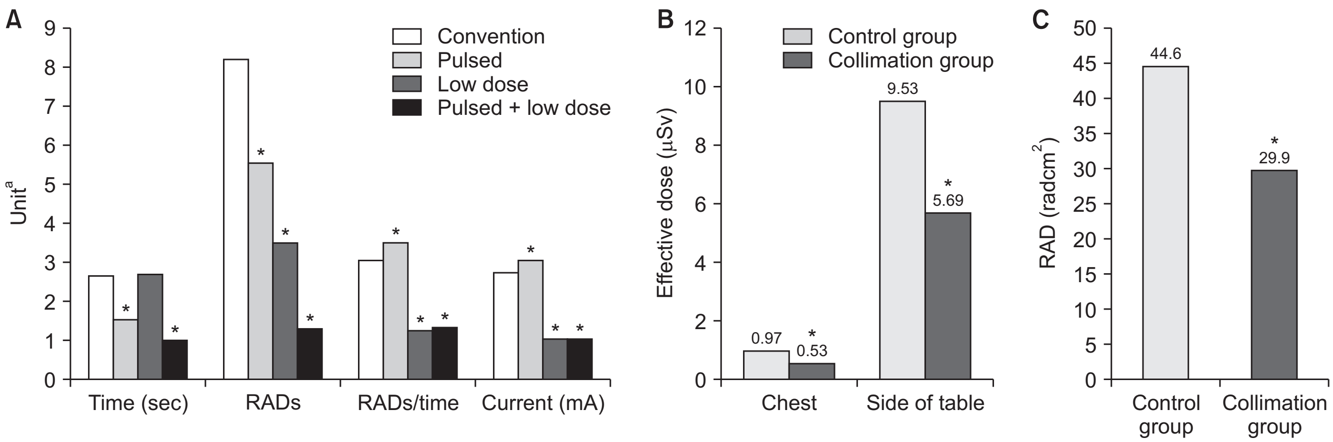

Fig. 5. Reduce radiation exposure by changing the C-arm fluoroscopy mode. (A) Comparison of the radiation absorbed dose (RAD) in the C-arm fluoroscopic mode [54]. The graph shows the time, RADs, mean RADs/mean time, and current (mA) according to the C-arm modes. The pulsed fluoroscopic mode of 15 frames per second is used. **P* < 0.050. [a]Unit is expressed as second for time, mRADs/cm^2 for RADs, mRADs/cm^2 • second for RADs/Time, and mA for current. (B) The differences in radiation exposure in relation to collimation in the medial branch block [56]. Comparison between the effective dose on left chest of the operator and the side of the table among groups. Chest, **P* = 0.042; table, **P* = 0.025. (C) Comparison of RAD between the control and collimation groups, **P* = 0.001. Adapted from the article of Cho et al. (Korean J Pain 2011; 24: 199-204) [54]; Baek et al. (Korean J Pain 2013; 26: 148-53) [56].

4) Fluoroscopy mode and collimation

(1) Pulsed mode

Typically, in C-arm fluoroscopy, images are captured at 30 frames per second. The pulsed mode lowers this frame [53] and decreases the irradiation time [54]. Therefore, the pulsed mode reduces the primary X-rays [54] and scattered X-rays. Research shows that average dose savings of 22%, 38%, and 49% are found for the pulsed mode at 15, 10, and 7.5 frames, respectively [55]. If the “pulse” button on the fluoroscopy operator panel is pressed and a picture is taken, an image can be captured in pulsed mode.

(2) Low-dose mode

The low-dose mode captures images in the same frame; however, the amount of radiation is reduced [29,54]. If the button labeled “low dose” on the fluoroscopy operator panel is pressed, a picture can be captured in the low-dose mode. If the “pulse” and “low-dose” buttons are pressed together, the pulsed mode and low-dose mode can be used together to capture an image with a smaller amount of radiation exposure. If both modes are used simultaneously, a slight reduction in image quality can be observed; however, it is sufficiently usable in the medial branch block [54].

Compared to the general imaging method, one study [54] showed that the pulsed mode (15 frames per second) reduced the radiation absorbed dose (RAD) of primary X-rays by 32%, the low-dose mode reduced the RAD by 57%, and the combined pulsed mode and low-dose mode reduced the RAD by 83% (**Fig. 5A**). Regarding the use of only one mode, radiation exposure can be reduced more effectively using the low-dose mode than in the pulsed mode, with less reduction in image quality [54].

(3) Collimation

Collimation is a method that can reduce the amount of irradiated and scattered radiation by reducing the radiographic area without changing the radiographic mode [29]. A randomized controlled trial in patients who underwent the medial branch block [56] compared the general imaging method and image area reduction using collimation. When the imaging area was reduced by 33%, the RAD decreased by 40.3%, the effective dose measured on the table decreased by 41%, and the effective dose measured outside the chest of the operator decreased by 46% (**Fig. 5B, C**).

3. Reducing patients’ radiation exposure

The abovementioned contents focused on reducing the radiation exposure of physicians and the medical staff during C-arm fluoroscopy interventions. Here, we will discuss how to reduce the patient’s exposure to radiation using methods of reducing the primary X-ray beam. They are methods with many benefits for both patients and pain physicians.

1) Time

Reducing radiation exposure time using one of the three

Table 2. Key points for radiation safety

Minimize the fluoroscopy time.
Minimize the number of images taken.
Use a C-arm fluoroscopic machine with a laser aiming line.
Do not take images with an image intensifier (or flat panel detector) underneath.
Use available patient dose reduction technologies (*e.g.*, pulsed mode or low-dose mode).
Use collimation.
Use all available information (*e.g.*, MRI, CT) to plan the interventional procedure.
Position yourself in a low-scatter area.
Use shielding devices.
For a lead apron, wear a wraparound type rather than a front type.
Once a year, lead aprons and thyroid protectors should be checked for damage.
Keep the lead apron and thyroid protector on a hanger, ensuring they do not get wrinkled.
Wear your dosimeter and know your own dose.
Use eye shields to protect the lens.
Obtain appropriate training.

MRI: magnetic resonance imaging, CT: computed tomography.

principles of radiation safety (time, distance, and shielding) is important for both patients and staff, which is similar to the principles and methods of reducing radiation exposure time mentioned above.

2) Decreasing magnification

Minimizing magnification can reduce radiation exposure in patients. There are two basic ways to magnify images in fluoroscopy: geometric and electronic [57]. The geometric method involves positioning the X-ray generator close to the patient. Geometric magnification increases the radiation dose of the patient's skin per area as the patient gets closer to the X-ray source. Electronic magnification can be done by pressing the "magnification" button on the fluoroscopy operator panel. This method increases the radiation exposure by irradiating a narrower area of the patient's skin with the same intensity of X-rays. Therefore, both methods increase the patient's radiation exposure and scattered radiation in the same area [57].

3) Using C-arm fluoroscopy modes and collimation

The pulsed mode, low-dose mode, and collimation, mentioned above, should be used as often as possible. These methods reduce the radiation exposure of patients, physicians, and medical staff.

4) Laser aiming line

Recently, C-arm fluoroscopic machines have been equipped with a laser aiming line. As the number of images taken is reduced with the laser aiming line, the patient's exposure to radiation can be reduced [34].

4. Education

While using a C-arm fluoroscopic machine, one should know how to protect your body from radiation and reduce radiation exposure, not just focus on the procedure. A Korean study conducted in 2016 [58] found that only 39% of pain physicians had radiation safety training and that training did not lead to practice. Through education, the devices and methods used to reduce radiation exposure can be learned and applied [29]. **Table 2** summarizes the main points of radiation safety.

CONCLUSIONS

It is important to manage time, distance, and shielding, which are the basic principles of radiation safety according to the ALARA principle. In addition, the use of an appropriate fluoroscopic mode (pulsed mode, low dose mode) and collimation, as well as the use of a laser aiming line are helpful in reducing the exposure of patients, as well as the physician and medical staff, to the primary X-ray beam and scattered radiation. Improving procedural skills will help reduce radiation exposure; moreover, acquiring and practicing basic knowledge about radiation safety and the use and management of protective devices is essential.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

FUNDING

No funding to declare.

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