

Usefulness of an Additional Shielding Sheet for Reducing Radiation Exposure to Patients and Medical Staff during Interventional Radiology

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Abstract

Background: Interventional radiology (IR) procedures often require prolonged fluoroscopic imaging, resulting in substantial radiation exposure to both patients and medical staff. Although conventional protective devices are widely used, the scattered radiation beneath the procedural table remains inadequately shielded. **Materials and Methods:** An additional shielding sheet, fabricated from a discarded 0.25 mmPb lead apron, was developed to block the open space between the interventional table and lead curtain. Phantom-based simulations of bronchial artery embolization (BAE) and transarterial chemoembolization (TACE) have been performed. Optically stimulated luminescence dosimeters were used to measure the radiation doses in the radiosensitive organs of the patient and operator phantoms, both with and without an additional shielding sheet. This study also evaluated dose reduction in the presence or absence of personal protective devices (PPD). Statistical significance was determined using the Wilcoxon signed-rank test ($P < 0.05$). **Results:** When an additional shielding sheet was used, the patient dose was significantly reduced by 20.5% and 20.6% during BAE and TACE, respectively (both $P < 0.05$). For operators, dose reductions were 68.1% and 43.3% during BAE and TACE with PPD, respectively. Without PPD, the dose was also significantly reduced in both BAE and TACE procedures ($P < 0.05$). **Conclusions:** Additional shielding sheets significantly decreased radiation exposure in both patients and operators during IR procedures. This simple and cost-effective device complements existing shielding tools and enhances radiation safety in clinical practice.

Keywords: Additional shielding sheet, interventional radiology, optically stimulated luminescence dosimeters, radiation exposure

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INTRODUCTION

With advancements in medical imaging and interventional treatment technologies, interventional radiology (IR) has become an essential tool for the diagnosis and treatment of various conditions, including cardiovascular diseases, tumors, and hemorrhagic disorders.^[1,2] In particular, owing to their minimally invasive nature and quicker recovery than surgical interventions, their applications are continuously expanding. However, as these procedures are performed under real-time image guidance, prolonged fluoroscopic imaging is essential, resulting in significant radiation exposure by patients and medical staff.^[3]

As the complexity and frequency of IR increase, the cumulative radiation exposure to operators and assistants also increases. This exposure has been associated with various long-term adverse effects, such as cataracts, thyroid dysfunction,

decreased reproductive function, and skin damage.^[4,5] The primary source of radiation exposure for medical personnel in interventional settings is scattered radiation, which arises from the patient, table, and surrounding structures. Although this type of radiation tends to be overlooked compared to primary radiation, it accounts for the majority of the cumulative exposure.^[6]

Accordingly, institutions such as the United States' National Institutes of Health and Food and Drug Administration have emphasized the importance of minimizing radiation exposure during interventional fluoroscopy through issued

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guidelines. The International Commission on Radiological Protection (ICRP) has also released recommendations in Publications 85 and 139 to prevent radiation exposure during IR.^[7,8] In South Korea, the Nuclear Safety and Security Commission and the Ministry of Health and Welfare limit the annual radiation doses for healthcare workers to below 50 mSv, with a 5-year cumulative limit of 100 mSv, an additional annual limit of 20 mSv for the eyeball lens, and 500 mSv for the skin, hands, and feet.^[9]

In actual procedures, repeated use of Digital Subtraction Angiography (DSA) is required to accurately identify the location of lesions and anatomical conditions. Long fluoroscopy durations are also used to guide catheters or therapeutic devices to target sites.

During DSA, both patients and medical staff are increasingly exposed to scattered radiation originating from tables, detectors, and other components. To mitigate such exposure, protective devices such as ceiling-suspended shields, lead curtains, and personal protective devices (PPD) (including lead glasses, thyroid shields, and lead aprons) are commonly employed.^[10,11] Among these, lead curtains are particularly effective at shielding the scattered radiation generated beneath the patient table. However, a structural gap exists between the table and lead curtain, thereby creating a blind spot that contributes to increased radiation doses to both patients and staff.^[12] Consequently, the operator's radiosensitive organs, such as the gonads, lower extremities, thyroid, and eyes, are at risk of concentrated exposure, emphasizing the need for more proactive supplementary shielding devices.

Therefore, in this study, we designed and fabricated an additional shielding sheet to physically block the open space beneath the intervention table and the existing lead curtain. We aimed to quantitatively compare the radiation doses received by patients and operators to assess the effectiveness and usefulness of this device. This study is expected to supplement existing shielding methods and contribute to the establishment of a more effective radiation protection strategy.

MATERIALS AND METHODS

Patient dose with and without an additional shielding sheet

The Siemens system was used as the interventional equipment (Model: Artis zee biplane, SIEMENS, Germany). The Source-to-Image Receptor Distance was set to 120 cm, with the irradiation field area matching a flat detector size of 48 cm × 48 cm. The height of the procedure table was fixed at 90 cm.

To shield the scattered radiation generated in the space between the patient table and lead curtain, an additional shielding sheet (25 cm × 110 cm) was fabricated using a 0.25 mmPb lead apron scheduled for disposal [Figure 1].

Radiation dose measurements were performed using an optically stimulated luminescence dosimeter (OSLD; MicroStar reader, LANDAUER Co., France), with background values measured in advance after erasing the dosimeters.



Figure 1: Images of radiation dose measurement with (a) and without (b) the additional shielding sheet placed between the interventional table and lead curtain

A human phantom (Model CTU-41, Kyoto Kagaku, Japan) was used. To measure radiation exposure during IR, six NanoDot dosimeters were placed on radiosensitive sites: One on each eyeball, two on the thyroid, and two on the gonads.

The IR techniques used for simulation were transarterial chemoembolization (TACE) and bronchial artery embolization (BAE), which typically involve prolonged fluoroscopy and multiple image acquisition.^[13] According to the protocol of Hospital A, fluoroscopy was conducted at 15 pulses/s for 300 s, and DSA was performed at 4 frames/s for 10 s. All dose measurements were conducted five times, and the mean values were used in the analysis. The radiation doses for both the patients and operators were calculated by converting the measured dose values according to the average procedure time for each examination (1212 s for BAE and 1097 s for TACE).^[13]

Operator dose with and without an additional shielding sheet

The experimental conditions were identical to those used for measuring the patient dose. The Rando phantom (Model RAN110, Churchill Associate LTD., USA) was used to measure the operator dose, adjusted to the average height of adult Korean males (172 cm),^[14] and positioned 20 cm away from the procedure table. The operator phantom was aligned with the femoral artery puncture site of the phantom.

Dosimeters were attached to both eyeballs, the thyroid (2), and the gonads (2), for a total of six OSLDs.

In addition, to compare radiation doses with and without the PPD, measurements were conducted under both conditions

using lead glasses (Toray XR-700 0.07 mmPb, Japan), a thyroid shield (INFAB 0.25 mmPb, USA), and a lead apron (INFAB 0.5 mmPb).

Statistics

To evaluate the change in dose before and after using the additional shielding sheet, and verify its statistical significance, the Wilcoxon signed-rank test was performed using SPSS version 29.0.0.0 (IBM Corporation, NY, USA). Statistical significance was set at $P < 0.05$.

RESULTS

Patient doses with and without an additional shielding sheet

During BAE, the patient dose without the additional shielding sheet was 5.025 ± 6.969 mGy, whereas that with the shielding sheet was reduced to 3.995 ± 5.544 mGy, indicating a significant dose reduction of 20.5% ($P < 0.05$). During TACE, the patient dose without the shielding sheet was 1.838 ± 1.180 mGy, whereas that with the shielding sheet was 1.459 ± 0.948 mGy, resulting in a significant reduction of 20.6% ($P < 0.05$) [Table 1].

Operator doses with and without additional shielding sheet With personal protective devices

In the BAE procedures, when the PPD was worn, the operator dose without the additional shielding sheet was 0.066 ± 0.068 mGy, which reduced to 0.021 ± 0.029 mGy with the shielding sheet. Although this represented a 68.1% reduction, the difference was not statistically significant. For TACE, the operator dose without the additional shielding sheet was 0.143 ± 0.147 mGy, whereas it was 0.081 ± 0.100 mGy with the shielding sheet, resulting in a significant reduction of 43.3% ($P < 0.05$) [Table 2].

Without the personal protective devices

During the BAE procedure, the use of an additional shielding sheet resulted in a significant reduction in the operator dose of 64.7% ($P < 0.05$). Similarly, for TACE, the operator dose was significantly reduced by 71.5% with the application of a shielding sheet ($P < 0.05$) [Table 3].

DISCUSSION

IR is actively utilized in various fields, such as vascular disease, cancer treatment, and hemorrhage control, owing to its minimally invasive nature. However, as these procedures commonly require prolonged fluoroscopy under image guidance, radiation exposure is inevitable, necessitating ongoing research and regulatory attention to ensure radiation safety for both patients and healthcare workers.^[15]

This study focuses on scattered radiation that is insufficiently blocked by conventional ceiling-mounted shields or lead curtains. In particular, scattered radiation arising from the open space beneath the patient table can lead to cumulative exposure of radiosensitive areas, such as the lower body,

Table 1: Patient doses according to the use of the additional shielding sheet

Measurement	Without shield	With shield	P
BAE (mGy)			
Left eyeball	0.139	0.125	0.028
Right eyeball	0.180	0.136	
Left thyroid	14.161	11.785	
Right thyroid	15.568	11.884	
Left gonad	0.054	0.024	
Right gonad	0.049	0.015	
Mean±SD (95% CI)	5.025±6.969 (0.000–12.340)	3.995±5.544 (0.000–9.814)	
TACE (mGy)			
Left eyeball	0.180	0.131	0.028
Right eyeball	0.164	0.110	
Left thyroid	2.564	2.193	
Right thyroid	2.684	2.130	
Left gonad	2.815	2.030	
Right gonad	2.620	2.159	
Mean±SD (95% CI)	1.838±1.180 (0.599–3.077)	1.459±0.948 (0.464–2.454)	

BAE: Bronchial artery embolization, TACE: Transarterial chemoembolization, SD: Standard deviation, CI: Confidence interval

Table 2: Operator doses with a personal protective device with and without the additional shielding sheet

Measurement	Without shield	With shield	P
BAE (mGy)			
Left eyeball	0.138	0.046	0.068
Right eyeball	0.172	0.073	
Left thyroid	0.050	0.005	
Right thyroid	0.035	0.000	
Left gonad	0.000	0.000	
Right gonad	0.000	0.000	
Mean±SD (95% CI)	0.066±0.068 (0.000–0.137)	0.021±0.029 (0.000–0.051)	
TACE (mGy)			
Left eyeball	0.358	0.244	0.027
Right eyeball	0.344	0.198	
Left thyroid	0.029	0.000	
Right thyroid	0.028	0.004	
Left gonad	0.049	0.017	
Right gonad	0.050	0.021	
Mean±SD (95% CI)	0.143±0.147 (0.000–0.297)	0.081±0.100 (0.000–0.186)	

BAE: Bronchial artery embolization, TACE: Transarterial chemoembolization, SD: Standard deviation, CI: Confidence interval

gonads, thyroid, and eyeballs of the operator. Such exposure may result in chronic effects, including cataracts, thyroid dysfunction, and decreased fertility; therefore, preventive measures are essential.^[2,4]

The shielding sheet used in this study was fabricated by repurposing a discarded lead apron. Despite its simple structure, this apron has demonstrated high efficacy. In IR, such as BAE and TACE, which involve long fluoroscopic

Table 3: The operator doses without a personal protective device with and without the additional shielding sheet

Measurement	Without shield	With shield	P
BAE (mGy)			
Left eyeball	0.543	0.385	0.028
Right eyeball	0.438	0.362	
Left thyroid	0.250	0.131	
Right thyroid	0.230	0.126	
Left gonad	1.408	0.236	
Right gonad	1.217	0.197	
Mean±SD (95% CI)	0.681±0.462 (0.196–1.166)	0.240±0.102 (0.133–0.347)	
TACE (mGy)			
Left eyeball	1.078	0.650	0.028
Right eyeball	0.992	0.615	
Left thyroid	1.315	0.229	
Right thyroid	1.418	0.318	
Left gonad	5.651	1.340	
Right gonad	4.704	1.160	
Mean±SD (95% CI)	2.526±1.900 (0.532–4.520)	0.719±0.408 (0.291–1.147)	

BAE: Bronchial artery embolization, TACE: Transarterial chemoembolization, SD: Standard deviation, CI: Confidence interval

durations and frequent imaging, the device reduced the patient dose by an average of 20.5% and the operator dose by up to 71.5%, achieving a significant dose reduction ($P < 0.05$). These findings are consistent with those of previous studies on radiation dose reduction.^[16]

Kim *et al.*^[17] reported that shielding devices placed between the patient table and operator significantly reduced the doses to the eyeballs, thyroid, and gonads. ICRP Publication 139 also emphasizes the importance of a multilayered shielding system, highlighting the critical need to block scattered radiation from open spaces.^[8]

This study also confirmed the importance of a combined protection strategy by comparing the dose-reduction effects with and without PPD, such as lead glasses, thyroid shields, and aprons. Even with PPD in use, adding the shielding sheet resulted in further dose reductions, illustrating the concept of “redundancy” in protection. The simultaneous use of multiple protective tools ensures more stable radiation mitigation.^[18]

Although a 68.1% reduction was observed with the additional shielding sheet in the PPD-wearing condition, the difference was not significant. This is likely because the overall exposure was already reduced to levels below the detection limits of the OSLD dosimeter owing to PPD.^[19]

In the absence of PPD, the shielding sheet exhibited a more pronounced effect, suggesting that in real-world scenarios, where the PPD may not be worn owing to emergencies, training, or lack of availability, the shielding sheet can serve as a final line of defense.

For clinical applications, the proposed shielding sheet is easy to use and can be conveniently attached or placed in existing

procedural settings, thereby enhancing its field usability. Moreover, its fabrication using repurposed lead aprons offers benefits such as cost efficiency and environmental sustainability.

Nonetheless, this study has certain limitations because it was based on phantom experiments. Specifically, phantom experiments cannot fully replicate the variations in patient anatomical structures, operator movements, or fluoroscopic angles encountered in daily clinical practice. Therefore, further prospective clinical studies are required to validate the shielding performance under real-world conditions. In a clinical setting, the use of excessively large or heavy shielding devices may hinder catheter manipulation, operator mobility, and patient access. Such limitations can also influence operator workload, procedural time, and fatigue, thereby underscoring the need to quantify related ergonomic outcomes. Moreover, additional investigations are required to assess the long-term durability of repurposed shielding, as well as the environmental implications and changes in shielding effectiveness over time.

Furthermore, analyzing the operational characteristics of existing lead curtains and applying optimized additional shielding sheets could contribute to further reductions in radiation exposure for both operators and patients.

CONCLUSIONS

In this study, an additional shielding sheet was designed and evaluated to reduce the radiation exposure of patients and operators during IR. The results showed that its use led to an approximately 20% reduction in the patient radiation dose and a 71% reduction in the operator dose. Notably, these reductions were significant, regardless of whether the PPD was worn.

These findings suggest that the additional shielding sheet can provide a practical enhancement to existing radiation protection equipment. Further studies are necessary to validate its long-term effectiveness and clinical applicability under diverse procedural conditions and to develop shielding designs tailored to different interventional environments.

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Conflicts of interest

There are no conflicts of interest.

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