Original Article

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Comparison of the Radiation Protection Effectiveness between Lead and Antimony-Tungsten Bed Skirt in Fluoroscopic-guided Simulated Urological Surgery

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Abstract:

Objective: This study aimed to develop a new shielding device, a bed skirt, and compare the radiation protection effectiveness between lead and antimony-tungsten (Sb-W) bed skirts in fluoroscopic-guided urological surgery.

Material and Methods: The simulated surgery of ureteroscopy (URS) and percutaneous nephrolithotomy (PCNL), using the phantoms, was set. The lead and Sb-W skirts were mounted around the operating table. The fluoroscopy time was 120 seconds, and the experiment was repeated 10 times. The radiation dose to the body parts of the patient, surgeon, and anesthesiologist was measured with optically stimulated luminescent dosimeters and compared in the following conditions: conventional operating table, Sb-W bed skirt, and lead bed skirt.

Results: By installing a bed skirt, the radiation dose was decreased, with lead being dominant in all areas. The lead bed skirt reduced the radiation dose by 20% to the patient, 66% to the surgeon, and 91% to the anesthesiologist. The absorbed radiation dose of the lead bed skirt was lower than the Sb-W bed skirt in URS settings (23.3±1.8 µGy vs 32.0±1.9 µGy, p-value<0.001) as well as PCNL settings (257.2±15.6 µGy vs 296.5±24.6 µGy, p-value<0.001). There was no statistically significant difference between the conventional operating table and the Sb-W bed skirt in both URS settings (p-value=0.066) and PCNL settings (p-value=0.153).

Conclusion: The lead bed skirt significantly reduced the radiation exposure and provided superior radiation protection compared with the Sb-W bed skirt. This shielding technique is practical to minimize the harmful effects of radiation from fluoroscopy.

Keywords: fluoroscopy, percutaneous nephrolithotomy, radiation exposure, radiation protection, ureteroscopy

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Introduction

The prevalence of urolithiasis has been increasing globally. The mainstay of definite treatment for upper urinary tract calculi is presently minimal invasive surgery[1]. Currently, the preferred technique is endourology including ureteroscopy (URS), retrograde intrarenal surgery (RIRS) and percutaneous nephrolithotomy (PCNL). Fluoroscopy is an important tool in many steps of these procedures. Radiation emitted during fluoroscopic imaging is responsible for the greatest radiation dose in the medical field, leading to inescapable radiation exposure to both patients and surgical teams alike. Additionally, the cumulative dose of lifetime radiation carries a potential risk of detrimental biologic effects; especially carcinogenesis[2–4]. Moreover, ionizing radiation can cause long-lasting damage to the eye lens and induces cataracts[5–7]. Therefore, radiation safety awareness and the implementation of strategies among healthcare workers are necessary.

The International Commission on Radiological Protection (ICRP) has proposed the: “as low as reasonably achievable (ALARA) principle” to minimize the harmful effects of radiation[8]. The key facets of reducing exposure are duration of radiation exposure, distance from the radiation source, and physical shielding. Personnel radiation protection devices, such as lead aprons, thyroid shields, lead-lined glasses, and gloves, are unquestionably effective in reducting radiation dose[2,8]. However, this has been replaced by lead-free aprons containing antimony, bismuth, tin, aluminum, tungsten, titanium, and barium due to its lightweight and non-toxic features.

Recent studies have created innovative devices to enhance radiation protection; for instance, a lead bed skirt[9], a lead sheet[10,11] and a lead bedspread[12]. To date, a lead-free bed skirt and its efficacy of radiation protection has not been published. This study aimed to determine whether lead or antimony-tungsten (Sb-W) bed skirts are more effective for radiation protection in fluoroscopic-guided urological surgery.

Material and Methods

This experiment was a phantom study and did not utilize human participants or patient information. It was exempted by the Human Research Ethics Committee (COE-RBHEC002/2024).

Phantoms

A phantom was used to simulate the density and scatter properties of the human body. The phantom surgeon was a half-body phantom made of poly methyl methacrylate (PMMA) material, which included a 30x30x15 cm slab phantom as a surgeon’s trunk and a 7x30 cm pillar phantom as a surgeon’s upper extremity. It was dressed with a wrap-around type vest and a thyroid shield (Figure 1). A 30x30x15 cm water phantom was used as a patient’s trunk.

1. eye 2. thyroid (outside the thyroid shield) 3. chest (one is outside the vest and the other is under the vest) 4. wrist

Figure 1 The phantom surgeon and the dosimeter’s position

Simulated surgery

An operating room was simulated to perform URS or RIRS in the lithotomy position and PCNL in either the prone or supine position. It used the operating table (MOT-5081S, Mizuho Medical Co., Ltd. Tokyo, Japan), with a height of 90 cm from the floor. The lead skirts (Burlington Medical Supplies, Inc., VA, USA) and the Sb-W skirts, with 0.25-mm lead-equivalent thickness (Xenolite®, Lite Tech Inc., PA, USA) were applied as a bed skirt by circumferential mounting around the operating table (Figure 2A, 2B). In the URS setting, the phantom surgeon was placed between the leg holders, 30 cm away from the table edge, while in the PCNL setting, it was positioned opposite to the fluoroscopy; 10 cm away from the table edge. A hanger with a front coverage type apron represented an anesthesiologist, which was located at the bedhead 50 cm away from the table edge. It was assumed that both surgeons and anesthesiologists were 160 cm tall and worked in a standing position. The phantom patient was placed on the table at the center of the image receptor. The positions of the phantoms and the fluoroscopy were marked with tape to ensure reproducibility.

Fluoroscopy protocol

A mobile C-arm fluoroscopy (BV Pulsera, Philips Medical Systems, Inc., Amsterdam, The Netherlands) was located to the left of the operating table. The X-ray tube was 25 cm under the table, and the image receptor was 30 cm above the table. The fluoroscopy with an automatic brightness control mode was used; the optimal tube voltage and current were automatically set. One hundred and twenty-second continuous stopwatch-timed fluoroscopy exposure was performed, and each experiment was repeated 10 times. This is based on our hospital, in that the estimated fluoroscopic time for PCNL was 120 seconds and the average number of cases per month was 10 cases. Hence, the cumulative radiation doses were representative of the radiation exposure in one month.

Radiation measurements

The nanoDots™ optically stimulated luminescent dosimeters (OSLD) (Landauer Inc., Glenwood, IL, USA) were attached to the phantoms to measure the cumulative radiation doses at the patient's abdomen, the surgeon's body, including eyes, thyroid, chest, and wrist (Figure 1),

URS=ureteroscopy, PCNL=percutaneous nephrolithotomy

Figure 2 Installing the bed skirts in both URS setting (A) and PCNL setting (B) and the anesthesiologist's thyroid and chest. The absorbed doses of scatter radiation at the surgeon's chest were also recorded by a radiation dosimeter. The OSLD has an accuracy of +/- 5.5% at the 95% confidence level, and they were calibrated by the Thailand Institute of Nuclear Technology (TINT), an accredited calibration provider. Measurements were read out by a microSTAR® mobile reader (Landauer Inc., Glenwood, IL, USA) and analyzed by two radiation physicists who did not involve in the study. The calibration of the microSTAR® reader at TINT was traceable to the National Institute of Standards and Technology (NIST), USA. The exposed OSLD was stored under appropriate conditions, not exposed to bright light or sunlight, to minimize the fading of the OSLD before readout. In order to remove background radiation, two OSLD were placed in the locker room and the radiation dose shown by these chips was deducted from the dosage received during the experiment. The cumulative radiation exposures were reported as an equivalent dose and an effective dose, which were calculated to represent whole-body radiation dose. Radiation exposure was then compared to the different parts of the phantoms in the following three conditions: a conventional operating table without a bed skirt, an Sb-W bed skirt, and a lead bed skirt. The effectiveness of radiation protection was reported by the radiation attenuation and given as a percentage.

$$\text{radiation attenuation (\%)} = \frac{\text{dose with bed skirt (mSv)} \times 100}{\text{dose without bed skirt (mSv)}}$$

Statistical analysis

The Statistics Package for Social Science version 21.0 (SPSS Inc., Chicago, IL, USA) was used. Continuous variables were described as mean with standard deviation. The comparison between the three groups was performed using one-way ANOVA. A post-hoc test was performed to determine which groups were different from each other. P-values<0.05 were considered statistically significant.

Results

Throughout the study, the kilovoltage (kV) remained constant at 60 and the current was 5.07 to 5.38 mA. Table 1 shows the mean absorbed dose of scatter radiation at the surgeon's chest. The radiation exposure in the PCNL setting was approximately 10 times higher than the URS setting, and there was a statistically significant difference in radiation dose among the three conditions (p-value<0.001). Post-hog analysis revealed the difference between the lead bed skirt and the conventional operating table (p-value<0.001) as well as the lead bed skirt and the Sb-W bed skirt. The absorbed radiation dose of the lead bed skirt was lower than the Sb-W bed skirt in both URS (23.3±1.8 μGy vs 32.0±1.9 μGy, p-value<0.001) and PCNL settings (257.2±15.6 μGy vs 296.5±24.6 μGy, p-value<0.001). There was no statistically significant difference in radiation dose between the conventional operating table and the Sb-W bed skirt in both URS (34.2±2.4 μGy vs 32.0±1.9 μGy, p-value=0.066) and PCNL settings (312.4±13.5 μGy vs 296.5±24.6 μGy, p-value=0.153).

Table 2 demonstrates the cumulative radiation dose over one month. Without the bed skirt, the highest amount of radiation exposure was to the patient's abdomen

Table 1 The absorbed dose of scatter radiation at the surgeon's chest

Setting	Absorbed radiation dose (μGy)			p-value
	Without bed skirt	Sb-W bed skirt	Lead bed skirt	
URS	34.2±2.4	32.0±1.9	23.3±1.8	<.001
PCNL	312.4±13.5	296.5±24.6	257.2±15.6	<.001

μGy=microgray, Sb-W=antimony-tungsten, URS=ureteroscopy, PCNL=percutaneous nephrolithotomy
Values are presented as mean±standard deviation
p-values are derived from one-way ANOVA

(7.84 mSv), followed by the surgeon's chest (0.48 mSv), wrist (0.33 mSv), thyroid (0.29 mSv), and eyes (0.10 mSv), respectively. The anesthesiologist received the least amount of radiation dose: 0.03 mSv at the chest and 0.02 mSv at the thyroid. By installing a bed skirt, the radiation dose was decreased, with lead being superior in all parts of the body. On the assumption that the approximate effective radiation dose for a chest X-ray was 0.1 mSv, the lead bed skirt reduced radiation exposure to the patient from 7.84 mSv to 6.26 mSv, which was comparable to 15 chest X-rays.

The effectiveness of radiation protection is shown in Figure 3. A bed skirt reduced approximately 20% of the radiation dose to the patient's abdomen. For surgeons, the whole-body radiation dose was decreased by 40% with the Sb-W bed skirt and 66% with the lead bed skirt. The greatest radiation attenuation was about 70% to the thyroid and the chest, whereas the lowest radiation reduction was to the eyes and the wrist. The radiation dose to the anesthesiologist dropped by 27% to 50% with the Sb-W bed skirt and 91% to 100% with the lead bed skirt.

Table 2 The cumulative radiation dose in one month

Position	**Location**	**Cumulative radiation dose (mSv)**		
		Without bed skirt	**Sb-W bed skirt**	**Lead bed skirt**
Patient	Abdomen[a]	7.840	6.450	6.260
Surgeon	Eyes[b]	0.100	0.100	0.090
	Thyroid[c]	0.290	0.130	0.080
	Chest[a]	0.480	0.280	0.130
	Wrist[c]	0.330	0.320	0.280
	Whole body[d]	0.020	0.013	0.008
Anesthesiologist	Thyroid[c]	0.020	0.010	0.000
	Chest[a]	0.030	0.020	0.000
	Whole body[d]	0.011	0.008	0.001

mSv=millisievert, Sb-W=antimony-tungsten, a=equivalent dose at a 10-mm depth from the skin, Hp (10), b=equivalent dose at a 3-mm depth from the skin, Hp (3), c=equivalent dose at a 0.07-mm depth from the skin, Hp (0.07), d=effective dose (E) which is calculated from the equation E=0.5HW+0.025HN; wherein, HW is personal dose equivalent, Hp (10) at chest under the apron and HN is the personal dose equivalent, Hp (10) at neck outside the thyroid shield.

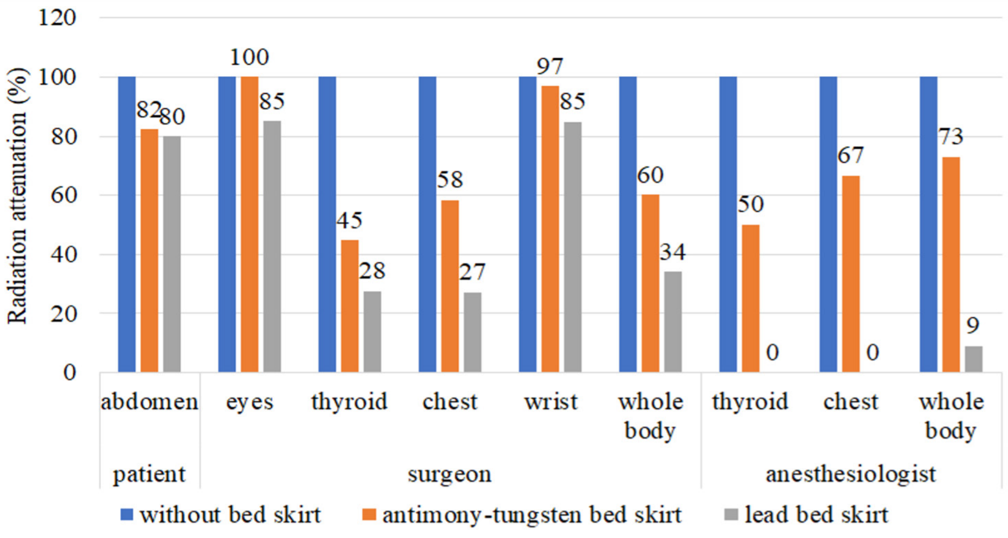

Figure 3 The effectiveness of radiation protection

Discussion

In this study, the fluoroscopic time was 2 minutes at 60 kV. The average radiation dose for each fluoroscopy exposure without a bed skirt was 0.784 mSv to the patient's abdomen and 0.033 mSv to the surgeon's wrist. This is comparable to the study by Kumari, in which they described radiation exposure to the patient and operating room personnel during PCNL and reported the mean fluoroscopy screening time during the procedures as ranging from 1.8 to 12.16 minutes, with a mean fluoroscopy tube potential of 68 kV. The mean radiation exposure dose to the patient and the urologist's finger was 0.56 mSv and 0.28 mSv, respectively[13].

By installing a bed skirt, the radiation dose was decreased, with lead being dominant in all parts of the body. This demonstrated that the lead bed skirt significantly reduced radiation exposure in simulated urological surgery as well as provided superior radiation protection compared with the Sb-W bed skirt. This shielding technique is most effective for the anesthesiologist, wherein the radiation dose was reduced by almost 100%. On the other hand, less than 15% of the radiation dose to the surgeon's eyes and wrist was reduced. Therefore, lead-lined glasses and gloves are necessary to protect the eye lens and hands from scatter radiation. Thatcher studied the reduction in radiation when placing a lead skirt circumferentially around the operating room table. They found that the most notable radiation attenuation was to the eyes: a nearly 500% reduction in radiation, from 8.42 to 1.46 μGy[9]. The mentioned study used real time Geiger counters to measure radiation dose, and the highest amount of radiation received was to the surgeon's eyes. In contrast, this study focused on the cumulative radiation exposure recorded by OSLD and the equivalent dose to the eyes was lowest compared with other organs.

In early studies, Giblin introduced a newly designed fluoroscopic drape, using a 0.5-mm lead-equivalent vinyl-coated lead sheet during URS and cystoscopy. This reduced the scatter radiation dose to the urologist by nearly 70-fold. This study was collected through only 5 clinical cases, and the radiation dose was measured just at the level of the physician's chest[10]. In 2002, Yang proposed a new radiation shield constructed from a 0.5-mm lead-equivalent vinyl-coated lead sheet placed between the surgeon and the patient during PCNL. The radiation doses received by the chest and the forehead of the surgeon were measured before and after shielding. The average reduction in radiation was 96% at a distance of 25 cm and 71% at a distance of 50 cm from the radiation source when the shield was utilized. This study was performed on 6 patients in each group and only two points on the surgeon's body were considered[11]. These two studies focused solely on reducing the radiation dose received by the surgeon and the shielding devices may limit surgical activity. This study expanded that concept by assessing the radiation exposure to various body parts of the patient, surgeon and anesthesiologist. Additionally, the bed skirt was of an adaptable design and did not interfere with the surgical procedure.

In a recent study by Amirhasani, a new shielding method was created to perform PCNL. At a thickness of 0.5 mm, a lead layer bedspread with a 30x30 cm square hole was placed to cover the operating table and a 15 cm height lead cone was mounted around the fluoroscopic tube. They reported a 37% reduction in the dose exposure as compared to the conventional shielding method. The maximum reduction in radiation dose was to the surgeon's hands, while the lowest reduction was to the surgeon's thyroid[12]. This study found better radiation attenuation at 66%. Conversely, the high radiation reduction was specified to the surgeon's thyroid, whereas low radiation attenuation was related to the surgeon's wrist.

All the previous literature applied shielding devices made from lead, which has been traditionally used in radiation protection apparel and shields across the range of radiation energies. Lead is particularly suitable for radiation protection due to its high absorption and attenuation of

X-ray photons as well as its relatively inexpensive cost to manufacture. Despite its advantages, lead is a heavy material, leading to chronic musculoskeletal disorders by prolonged wearing. Additionally, the major concern is lead poisoning due to lead-dust contamination on radiation protective garments[14,15]. To be specific, a study by Sweilum revealed that the hair and blood lead levels of radiologists wearing lead aprons were significantly higher than those of the control group[16]. The alternative is a lead-free composite, which is lightweight and provides a level of radiation protection equivalent to lead, as stated by the manufacturers. Lu reviewed 15 lead-containing and lead-free composite garments currently used in multicenters. The study discovered that these garments provided less radiation protection than what the manufacturers had stated. Moreover, lead-free composites had worsening outcomes[17]. Similarly, König examined the performance of new-generation protection aprons from a total of 7 companies containing both lead and lead-free composites as alternatives to conventional lead aprons. They observed a similar radiation protection effectiveness between conventional lead aprons and new generation aprons at low intensity radiation workplaces (less than 90 kV), with lead aprons being dominant for all energies[18]. Correspondingly, the results from this study demonstrated that the lead bed skirt had a better shielding effect compared with the Sb-W bed skirt. Therefore, the possibility of lightweight aprons usage is limited for healthy radiation protection.

The potential mechanism underlying the disparity between lead and Sb-W bed skirts is the difference in the attenuation coefficient of the materials, which is an important parameter to indicate the fraction of radiation scattered or absorbed. A linear attenuation coefficient depends on the thickness, atomic number, and density of the materials. Lead has a high atomic number and a relatively high density; thus, its attenuation coefficient is higher than Sb-W for the same energy of the photon. Even though manufacturers stated that Sb-W has a lead equivalence, the lack of compatibility between nominal and actual lead equivalent values is possible to modify the radiation transmission.

ICRP issued guidelines on safe occupational radiation exposure for healthcare workers, stating that the annual effective dose limit is 20 mSv, averaged over 5 years, with no single year exceeding 50 mSv. On an annual basis, this study revealed that the effective dose to the surgeon was 0.24 mSv, and no one in the simulated operating room was exposed to an excessive amount of radiation. Nevertheless, many urologists perform more than 200 fluoroscopic-guided surgeries annually over several consecutive years. On the other hand, patients with urolithiasis, which is a recurrent disease, may require multiple radiation exposures throughout their lives for diagnosis, treatment and follow-up. Although the risks of chronic exposure to low-level radiation have been inconclusive, the cumulative dose is of concern due to stochastic effects, which are regarded as having no threshold dose to induce cancer and hereditary genetic mutations. Consequently, the concept "ALARA" should be highlighted in response to radiation risks.

This study has potential limitations. The measured amount of radiation was based on a simulated surgery. First, although the phantom can cause radiation scattering its properties are not the same as a real body. Second, the position of the phantom was stationary and the C-arm fluoroscopy was set at a zero degree, whereas the surgeon's movement and fluoroscopic angulation occurrs during procedures in actual circumstances. Finally, the standard dose protocol used in this study was based on PCNL cases in our hospital and may not represent fluoroscopic-guided surgery for every urologist. Further investigation should test a lead bed skirt during real fluoroscopy procedures in a prospective randomized trial throughout multicenters. Expanding the study design to include conventional lead, lead composites, and lead-free composite bed skirts, as well as low and high intensities of radiation, would further corroborate the results.

Conclusion

The lead bed skirt significantly reduced the radiation exposure during fluoroscopic-guided simulated urological surgery in addition to providing superior radiation protection compared with the Sb-W bed skirt. This is a practical method without incurring additional costs to protect all operating room personnel. Therefore, it is recommended that urologist that encounter high volumes of fluoroscopic procedures should adopt this shielding device so as to minimize the harmful effects of radiation. For future research, it is challenging to clarify how much protection the "lead equivalence" actually provides.

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Conflict of interest

The authors declare no conflict of interest.

References

1. Geraghty RM, Davis NF, Tzelves L, Lombardo R, Yuan C, Thomas K, et al. Best practice in interventional management of urolithiasis: an update from the European association of urology guidelines panel for urolithiasis 2022. Eur Urol Focus 2023;9:199–208.
2. Vanzant D, Mukhdomi J. StatPearls. Trasure Island: StatPearls; 2023.
3. Gogos S, Touzell A, Lerner LB. What we know about intra-operative radiation exposure and hazards to operating theatre staff: a systematic review. ANZ J Surg 2022;92:51–6.
4. Stahl CM, Meisinger QC, Andre MP, Kinney TB, Newton IG. Radiation risk to the fluoroscopy operator and staff. AJR Am J Roentgenol 2016;207:737–44.
5. Vano E, Kleiman NJ, Duran A, Romano MM, Rehani MM. Radiation-associated lens opacities in catheterization personnel: results of a survey and direct assessments. J Vasc Interv Radiol 2013;24:197–204.
6. Jacob S, Boveda S, Bar O, Brézin A, Maccia C, Laurier D, et al. Interventional cardiologists and risk of radiation-induced cataract: results of a French multicenter observational study. Int J Cardiol 2013;167:1843–7.
7. Jacob S, Michel M, Spaulding C, Boveda S, Bar O, Brézin AP, et al. Occupational cataracts and lens opacities in interventional cardiology (O'CLOC study): are X-rays involved? radiation-induced cataracts and lens opacities. BMC Public Health 2010;10:537.
8. Bhanot R, Hameed ZBM, Shah M, Juliebø-Jones P, Skolarikos A, Somani B. ALARA in urology: steps to minimise radiation exposure during all parts of the endourological journey. Curr Urol Rep 2022;23:255–9.
9. Thatcher J, Mueller T, Klimowich K. Don't skirt the question: lead bed skirts in the operating room, an intervention. J Urol 2021;206:e130-1.
10. Giblin JG, Rubenstein J, Taylor A, Pahira J. Radiation risk to the urologist during endourologic procedures, and a new shield that reduces exposure. Urology 1996;48:624–7.
11. Yang RM, Morgan T, Bellman GC. Radiation protection during percutaneous nephrolithotomy: a new urologic surgery radiation shield. J Endourol 2002;16:727–31.
12. Amirhasani S, Daneshdoost R, Mousavibahar S, Ghazikhanlou-Sani K, Raeisi R. Reduction of radiation dose received by surgeons and patients during percutaneous nephrolithotomy: a new shielding method. Urol J 2021;18:271–6.
13. Kumari G, Kumar P, Wadhwa P, Aron M, Gupta NP, Dogra PN. Radiation exposure to the patient and operating room personnel during percutaneous nephrolithotomy. Int Urol Nephrol 2006;38:207–10.
14. Burns KM, Shoag JM, Kahlon SS, Parsons PJ, Bijur PE, Taragin BH, et al. Lead aprons are a lead exposure hazard. J Am Coll Radiol 2017;14:641–7.
15. Manocchio F, Ni T, Pron G, Jaffer H, Murphy K. Lead-dust contamination on radiation protection apparel. J Vasc Interv Radiol 2023;34:563–7.
16. Sweilum O, El-Badry A, El-Agamy S. Risk assessment of lead exposure in radiology personnel in Menoufia hospitals, Egypt. Toxicol Ind Health 2023;39:281–9.
17. Lu H, Boyd C, Dawson J. Lightweight lead aprons: the emperor's new clothes in the Angiography Suite? Eur J Vasc Endovasc Surg 2019;57:730–9.
18. König AM, Verbe Zoum J, Fiebich M, Abissi PW, Mahnken AH. Comparison of the radiation protection effect of different radiation protection aprons made of different materials. Eur J Radiol 2023;164:110862.