学　術
Arts and Sciences

原　著

Effects of radioprotective equipment on radiation exposure to the operator's eye lens during computed tomography fluoroscopy-guided procedure

CT透視下治療における術者の水晶体被ばくに対する放射線防護器具使用の影響

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Key words: radiation exposure, CT fluoroscopy, radioprotective equipment, eye lens

【Abstract】
Purpose: To evaluate whether radiation exposure to the operator's eye lens is reduced by radioprotective equipment of shield and lead drape during computed tomography (CT) fluoroscopy-guided procedures.
Materials and Methods: Radiation doses were measured using small optically stimulated luminescence dosimeters outside and inside radioprotective glasses of the operator during 16 lung nodule localizations. Measurements were performed under four settings: A) with radioprotective shield and lead drape; B) with radioprotective shield, without lead drape; C) without radioprotective shield, with lead drape; and D) without radioprotective shield or lead drape. The fluoroscopy duration was compared between settings, with and without a shield, using Welch's t-test. Radiation doses per procedure were compared among the four settings of radioprotective equipment using the one-way analysis of variance.
Results: Mean duration of fluoroscopy was significantly longer in settings with shield (53.8 ± 5.5 s for settings of A and B) than in those without shield (45.6 ± 2.6 s for settings of C and D) ($p=0.005$). Mean radiation doses were 26.0 ± 4.9 μGy, 43.1 ± 3.5 μGy, 66.4 ± 3.5 μGy, and 79.1 ± 7.0 μGy outside the glasses, for settings A, B, C, and D, respectively, and 11.9 ± 4.2 μGy, 20.9 ± 3.4 μGy, 30.9 ± 2.7 μGy, and 34.2 ± 3.6 μGy inside the glasses, for settings A, B, C, and D, respectively. Significant differences were detected among the four settings for the radiation dose both outside ($p<0.001$) and inside ($p<0.001$).
Conclusion: Radioprotective equipment reduces radiation doses to the operator's eye lens during CT fluoroscopy-guided procedures.

【要 旨】
目的：CT透視下手技における放射線被ばく防護具の使用による術者の水晶体被ばく線量の低減効果を検討する.
対象と方法：16件のCT透視下術前肺マーキングにおいて,（A）遮蔽板あり, 鉛ドレープあり（B）遮蔽板あり, 鉛ドレープなし（C）遮蔽板なし, 鉛ドレープあり（D）遮蔽板なし, 鉛ドレープなしの４つの条件で, 術者防護眼鏡部の被ばく線量の平均値を比較した.
結果：被ばく線量平均値は, 防護眼鏡外側で（A）26.0μGy,（B）43.1μGy,（C）66.4μGy,（D）79.1μGy, 内側で（A）11.9μGy,（B）20.9μGy,（C）30.9μGy,（D）34.2μGyであった.
結語：遮蔽板および鉛ドレープは, CT透視下手技における術者の水晶体被ばく低減に有効であった.

INTRODUCTION

The importance of reducing radiation exposure in medical staff has recently increased. The International Commission on Radiological Protection has recommended an annual dose limit to the eye lens of 20 mSv averaged over a defined period of five years, with doses not exceeding 50 mSv in any single year[1]. The International Atomic Energy Agency has adopted this new dose limit[2]. Thus, we must consider radiation exposure to the eye lens during interventional radiology procedures.

Computed tomography (CT) fluoroscopy is one of imaging modality used during interventional radiology. It offers the advantage of rapid and objective visualization of the puncture target[3, 4] and is widely used in performing procedures such as biopsy, ablation, and pre-

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Received September 2, 2022; accepted June 23, 2023

operative lung nodule localization[5-11]. However, this procedure has the strong drawback of radiation exposure to both patients and medical staff[3, 9-12]. In particular, the eye lens of operators are exposed to relatively high radiation doses[11, 12].

Several methods to reduce operator radiation exposure during CT fluoroscopy-guided procedures have been reported. For example, the installation of a radioprotective shield in front of the scan plane has been reported to reduce the radiation exposure to the operator[13, 14]. Placement of a lead drape over the patient to block scattered radiation reaching the operator has been shown to be an effective option[15-17]. However, such results have been derived from experimental studies using phantoms; therefore, the extent to which radiation exposure could be reduced by these methods has not been evaluated in clinical settings. In this study, we measured doses to the eye lens received by the operator during CT fluoroscopy-guided procedures and evaluated the clinical reduction in radiation doses to the operator using shields and lead drapes as radioprotective equipment.

METHODS

Study design

Radiation doses were measured during preoperative localization of the lung nodules. This procedure was chosen for the analysis because the fluoroscopy time was relatively short and did not vary between sessions.

This study was approved by our institutional review board as a survey for operator radiation exposure. Written informed consent was obtained from the operator performing the procedure before measuring the radiation dose. Informed consent to perform lung nodule localization under CT fluoroscopy, which provides medical exposure, was obtained from each patient.

Measurement of radiation doses

Radiation doses were measured during 16 sessions of lung nodule localization between November 2020 and January 2021. The procedure was performed percutaneously using real-time CT fluoroscopy (Aquilion LB; Canon Medical Systems Corp., Otawara, Japan). Local anesthesia was performed with 1% lidocaine (Xilocaine Injection Polyamp 1%; Aspen Japan K.K., Tokyo, Japan) using a 6 cm 23-G needle (Terumo Cattelan Needle; Terumo Corp., Tokyo, Japan). Subsequently, the needle was advanced to the target nodule and a mixture of indigo carmine (Indigo Carmine; Daiichi Sankyo Co. Ltd., Tokyo, Japan) and lipiodol (Lipiodol; Fuji Pharma Co. Ltd., Tokyo, Japan) was injected into the lung parenchyma while withdrawing the needle until lipiodol accumulation reached the pleural surface on CT fluoroscopy images. A real-time 3 slices CT image was displayed by treading on the foot panel of the operator. The fluoroscopic images were obtained with a tube voltage of 120 kV and a tube current of 10 mA, and the duration of fluoroscopy was recorded. The procedures were performed by an interventional radiologist (T.H., with approximately 10 years of experience in interventional radiology). Measurements were performed with four settings of radioprotective

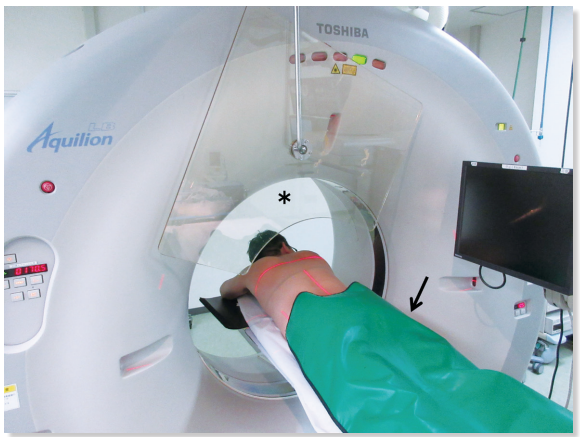

Fig.1 A radioprotective shield (asterisk) was set in front of the scan plane at settings A and B, and a lead drape (arrow) was placed on the patient outside the computed tomography gantry at settings A and C.

Table 1 Detail and result of the procedure of each radiation dose measurement setting

Case	Age	Sex	Body weight (kg)	BMI	Tumor location	Tumor size (mm)	Body position	Duration of CT fluoroscopy (sec)	Radiation dose outside the glasses (μGy)	Radiation dose inside the glasses (μGy)
Setting A										
1	76	M	56.3	21.1	Right lower	8	Prone	54.4	25.6	11.9
2	75	M	62.7	22.9	Right upper	5	Prone	57.0	27.3	11.9
3	73	F	57.4	24.5	Right upper	8	Prone	55.7	32.4	17.9
4	71	F	52.5	22.5	Right lower	6	Left decubitus	50.8	18.8	6.0
Setting B										
1	69	M	51.8	20.2	Right upper	3	Left decubitus	58.4	43.5	25.6
2	64	M	63.7	21.5	Right upper	18	Prone	42.5	40.1	19.6
3	30	F	72.6	29.2	Left lower	6	Right decubitus	50.3	48.6	22.2
4	65	F	69.8	25.4	Right lower	7	Prone	61.4	40.1	16.2
Setting C										
1	48	F	59.8	19.8	Right lower	3	Prone	47.9	70.8	33.3
2	65	F	49.3	22.8	Right upper	13	Left decubitus	41.9	63.1	28.1
3	61	F	55.6	23.2	Left upper	4	Supine	44.3	69.1	34.1
4	71	F	42.8	19.4	Right upper	10	Prone	48.0	62.8	28.3
Setting D										
1	65	M	62.4	22.1	Left upper	9	Prone	44.3	78.4	30.7
2	71	F	42.8	19.4	Right upper	8	Prone	47.9	80.1	36.7
3	68	F	61.0	26.3	Right lower	11	Left decubitus	42.3	69.1	30.7
4	66	F	54.6	21.5	Right lower	7	Prone	48.6	88.7	38.9

BMI: body mass index

equipment using a 0.5-mm lead shield (KYOWAGLAS XA; KURARAY Trading Co., Tokyo, Japan) and a 0.25-mm lead drape (Smart light; HOSHINA Co., Tokyo, Japan): A) with shield and lead drape; B) with shield, without lead drape; C) without shield, with lead drape; and D) without shield or lead drape. No significant differences on body weight and body mass index of patients ($p=0.58$) and tumor size ($p=0.90$) were detected by the one-way analysis of variance (ANOVA) between settings. The radioprotective shield was set in front of the scan plane, and a lead drape was placed on the patient outside the CT gantry. Each setting comprised four sessions of localization procedure.

The radiation dose was measured using small optically stimulated luminescence dosimeters (OSLDs) (NanoDot; Nagase Landauer, Tsukuba, Japan). These small OSLDs were taped outside and inside the left surface of the

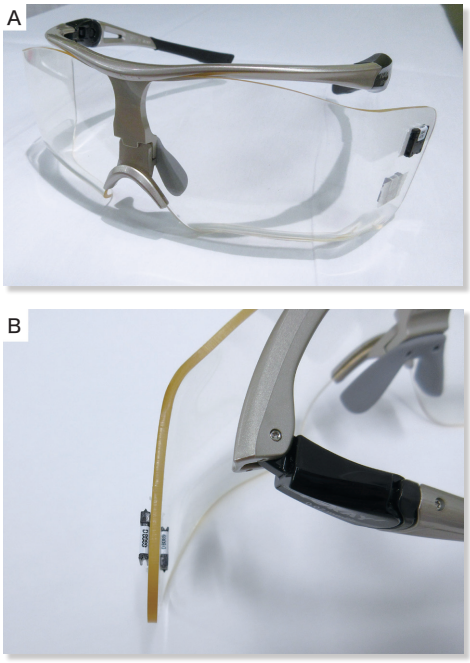

Fig.2 A) Locations of small optically stimulated luminescence dosimeters (OSLDs) on the radioprotective glasses.
B) Small OSLDs were taped outside and inside the left surface of the radioprotective glasses.

radioprotective glasses, with the plane of the dosimeters facing the CT scan plane (Panoramashield; TORAY Industries, Tokyo, Japan). Taped OSLDs were removed from the radioprotective glasses and the data were read using a microSTAR reader (Nagase Landauer) immediately after each session.

Assessment

The duration of fluoroscopy and the radiation dose of CT fluoroscopy outside and inside the radioprotective glasses were measured. Data are expressed as mean ± standard deviation. To evaluate the influence of the usage of radioprotective shield on the fluoroscopy duration, the duration was compared between settings with and without a shield using Welch's t-test. The radiation doses per procedure among the four radioprotective equipment settings were evaluated using the one-way ANOVA, and the difference between each setting was compared using Tukey's multiple comparison test. Statistical significance was set at $p<0.05$. Statistical analyses were performed using a commercially available software (SPSS for Windows, version 24; IBM, Armonk, NY, USA).

RESULTS

Duration of fluoroscopy

Durations of fluoroscopy were 54.5 ± 2.3 s, 53.1 ± 7.4 s, 45.5 ± 2.6 s, and 45.8 ± 2.6 s for settings A, B, C, and D, respectively. Mean duration of fluoroscopy was significantly longer in settings with shield (53.8 ± 5.5 s at settings A and B) than in those without shield (45.6 ± 2.6 s at settings C and D) ($p=0.005$).

Radiation dose

Radiation doses were 26.0 ± 4.9 μGy, 43.1 ± 3.5 μGy, 66.4 ± 3.5 μGy, and 79.1 ± 7.0 μGy, outside the radioprotective glasses, for settings A, B, C, and D, respectively, and 11.9 ± 4.2 μGy, 20.9 ± 3.4 μGy, 30.9 ± 2.7 μGy, and 34.2 ± 3.6 μGy, inside the radioprotective glasses, for settings A, B, C, and D, respectively. Significant differences were detected among the four settings for the radiation dose both outside ($p<0.001$) and inside ($p<0.001$) the radioprotective glasses by one-way ANOVA. In the following Tukey's multiple comparison test, significant differences were seen between all settings at outside the glasses (A vs B: $p=0.005$, A vs C: $p<0.001$, A vs D: $p<0.001$, B vs C: $p<0.001$, B vs D: $p<0.001$, C vs D: $p=0.04$) and all settings except between Settings C and D at inside (A vs B: $p=0.04$, A vs C: $p<0.001$, A vs D: $p<0.001$, B vs C: $p=0.02$, B vs D: $p=0.003$, C vs D: $p=0.68$).

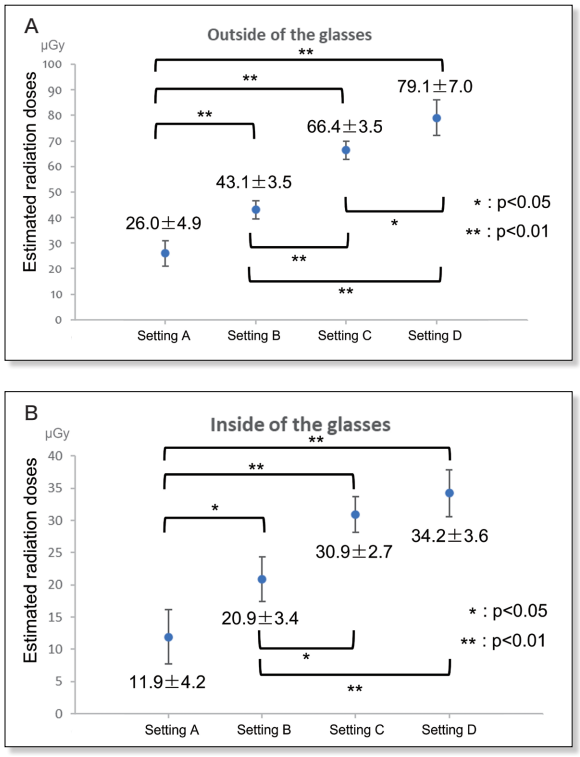

Fig.3 A) Estimated radiation doses outside the radioprotective glasses. Radiation doses were: A) 26.0 ± 4.9 μGy; B) 43.1 ± 3.5 μGy; C) 66.4 ± 3.5 μGy; and D) 79.1 ± 7.0 μGy. The one-way analysis of variance revealed significant differences among settings ($P<0.001$).
B) Estimated radiation dose inside the radioprotective glasses. Radiation doses were: A) 11.9 ± 4.2 μGy; B) 20.9 ± 3.4 μGy; C) 30.9 ± 2.7 μGy; and D) 34.2 ± 3.6 μGy. The one-way analysis of variance revealed significant differences among settings ($P<0.001$).

DISCUSSION

This study showed that radioprotective equipment comprising a shield and a lead drape was effective in reducing radiation exposure to the eye lens of the operator during clinical CT fluoroscopy-guided procedures. These results support the concept that radioprotective equipment should be used during CT fluoroscopy-guided procedures, as suggested in previously reported experimental studies[13-17].

It has been reported that the occupational radiation dose could be reduced by 71–97% with a radioprotective shield or lead drape[14-17] in a phantom study. However, radiation dose was reduced up to 67% (1-26.0 μGy/79.1 μGy) in this study, even though both shield and lead drape were used. This suggests that the theoretical maximum dose reduction could not be achieved in a clinical setting. The reason for this is unclear; however, the measurement point might be one explanation. The measurement points close to the scan plane are associated with more scattered radiation[16]. If the measurement point of the phantom study is closer to the scan plane than the eye position in clinical settings, the reduction in radiation dose by radioprotective equipment might be overestimated. The reduced sensitivity of OSLDs to the higher X-ray energy may be another explanation[18]. Nonetheless, we must pay attention to reducing the occupational dose as much as possible by using radioprotective equipment during CT fluoroscopy-guided procedures.

The fluoroscopy duration was significantly longer when a radioprotective shield was used. The movement of the operator's arm was interfered with by the shield set in front of the scan plane, which might have prolonged the fluoroscopy time. Despite the longer fluoroscopy time, the radiation dose was reduced using a shield. However, shortening the duration of fluoroscopy is important to reduce occupational exposure doses to medical staff and exposure to patients[19, 20]. The use of curtain-type radioprotective equipment might also be effective as a less obstructive option[17]; however, comparisons of whether and how such equipment might shorten the duration of fluoroscopy and reduce radiation doses have yet to be performed. Further investigations are required to determine which type of equipment is better.

This study has several limitations. First, radiation doses measured using small OSLDs were environmental radiation doses; therefore, the results did not entirely match the dose to the eye lens. However, the OSLDs were placed near the eye, and the results were thought to represent doses close to the actual dose to the eye lens. Second, the sample size was small. Third, tumor location was not matched between the groups. This may affect fluoroscopy duration and the distances between the scan plane and the operator. Further investigation to evaluate the relation of them may help to validate the result of this study.

Conclusion

We measured the radiation doses to the operator's eye lens during CT fluoroscopy guided procedures and showed that radioprotective equipment of glasses, shield, and lead drape reduces the radiation doses to the operator's eye lens during CT fluoroscopy-guided procedures. In particular, using both a shield and lead drape might be effective in maximizing the full benefit of all equipment.

Statement and Declarations

This work was supported by the Aichi Cancer Research Foundation.

The authors declare that they have no conflict of interest.

表の説明

Table 1　各放射線被ばく測定セッティングにおける手技の詳細と結果

図の説明

Fig.1　セッティングAおよびBでは放射線防護板（アスタリスク）をCTガントリーの前に設置し，セッティングおよびCでは鉛ドレープ（矢印）を患者の上に敷いた．

Fig.2　A）放射線防護ゴーグル上の小型光刺激発光線量計の位置．
B）小型光刺激発光線量計は放射線防護ゴーグル左側の外と内に両面テープで貼りつけた．

Fig.3　A）各セッティングにおける放射線防護ゴーグルの外側の被ばく線量は，A）26.0±4.9 μGy; B）43.1±3.5 μGy; C）66.4±3.5 μGy; D）79.1±7.0 μGyであった．一元配置分散分析で各セッティングの平均値の間に有意な差があることが示された（P < 0.001）．
B）各セッティングにおける放射線防護ゴーグルの内側の被ばく線量は，A）11.9±4.2 μGy; B）20.9±3.4 μGy; C）30.9±2.7 μGy; D）34.2±3.6 μGyであった．一元配置分散分析で各セッティングの平均値の間に有意な差があることが示された（P < 0.001）．

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