Practical Protective Tools for Occupational Exposure:

- 1) *Double Focus Spectacles for the Aged with Highly Refracted Glass Lens*
- 2) *Remodeled Barrier for Radiation Protection*

S. KUROKAWA, S. YABE, A. TAKAMURA, H. ISHIZAKI, S. AIZAWA

Department of Radiology, Koshigaya Municipal Hospital; Higashi-koshigaya, Koshigaya City, Saitama, Japan

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Summary

Two practical protective tools for occupational exposure for neurointerventional radiologists are presented. The first purpose of this study was to investigate the effectiveness of double focus spectacles for the aged with a highly refracted glass lens (special spectacles for the aged) for radiation protection of the crystalline lens of the eye in comparison with other spectacles on the market, based on the measurement of film density which was obtained by exposure of X-ray through those spectacles. As a result of the film densitometry mentioned above, the effectiveness of special spectacles for the aged in radiation protection was nearly equal to the effectiveness of a goggle type shield which is made with a 0.07 mm lead-equivalent plastic lens.

The second purpose of this study was to investigate the effectiveness of the protective barrier, which we remodeled for cerebral angiography or neuroendovascular therapy, for radiation exposure, based on the measurement in a simulated study with a head phantom, and on the measurement of radiation exposure in operators during procedures of clinical cases. In the experimental study radiation exposure in supposed position of the crystalline lens was reduced to about one third and radiation exposure in supposed position of the gonadal glands was reduced to about one seventh, compared to radia-

tion exposure without employing the barrier.

The radiation exposure was monitored at the left breast of three radiologists, in 215 cases of cerebral angiography. Employing the barrier in cerebral angiography, average equivalent dose at the left breast measured 1.49 μ Sv during 10 min of fluoroscopy. In three kinds of neuroendovascular therapy in 40 cases, radiation exposure in an operator was monitored in the same fashion and the dose was recorded less than the result reported in previous papers in which any protective barrier have not been employed in the procedure^{1,2}.

As a result, the two above mentioned protective tools are considered practical in clinical usage and very effective to reduce radiation exposure in an operator of interventional neuroradiology which may sometimes require many hours to complete the therapy under extended fluoroscopic time.

- 1) The first topic of this report is double focus spectacles for the aged with a highly refracted glass lens (special spectacles for the aged)

Introduction

The purpose of this study was to clarify the usefulness of special spectacles for the aged as a protective tool against X-ray exposure.

It was discovered under fluoroscopy that the

Figure 1 Various protective spectacles for X-ray are shown. A) Goggle type shield, corresponding to a 0.07 mm-lead equivalent shield (weight = 42 g). B) Our specially ordered spectacles, double focus spectacles for the aged with a highly refracted glass lens, consisting of large and small lens parts (w = 50 g). C) Shield with head gear, corresponding to a 0.1mm-lead equivalent shield (w = 270 g). D) Spectacles for radiation protection made with a 0.5 mm-lead equivalent glass lens (w = 75 g).

small lens part of a highly refracted glass lens in ordinary double focus spectacles for the aged was relatively radio-opaque part in the projection of the large lens part.

By the film densitometry method, the highly refracted glass lens demonstrated heavy radiation protectability and therefore reduced radiation exposure through the lens.

As a result, special spectacles for the aged are considered very effective to reduce radiation exposure to the crystalline lens. Especially for physicians who are working as interventional neuroradiologists over many years, reducing radiation exposure to the crystalline lens of the eye is as important as reducing radiation exposure of the thyroid gland and gonadal glands³.

Any radiation-induced cataract would result in minimal loss of vision but would probably be identifiable as being radiation induced⁴.

Methods

Many kinds of spectacles, goggle type shields or shields with head gear for radiation protection to the crystalline lens are sold on the market (figure1).

It has been well known that a glass lens including heavy metal i.e. lead are provided strong protectability against X-ray and we discovered that the small lens part of ordinary double focus spectacles for the aged has higher radioopacity than the large lens part of them under fluoroscopy.

Generally refractory ratio of a glass in the small lens of double focus spectacles for the aged is higher than refractory ratio of a glass in the large lens of them and in this paper the highly refracted lens was defined as the lens whose refractory ratio (r.r.) was larger than 1.7.

Figure 2 The relative radio-opacity of various spectacles and glass lenses in various refractory ratios exposed to the same dose of X-ray on the film is shown. A-a) Spectacles with a plastic lens; A-b) Ordinary double-focus spectacles for the aged; A-c) Our special spectacles for the aged (r.r. of the large lens = 1.7); A-d) Goggle type shield (0.07 mm-lead equivalent). B-a) r. r. of the large lens = 1.7, r.r. of the large lens = 1.8; B-b) r.r. of the large lens = 1.5; B-c) r.r. of the large lens = 1.6. C-a) r.r = 1.9 (including lead); C-b) r.r = 1.8; C-c) r.r = 1.6.

At first we ordered special spectacles for the aged with a highly refracted glass lens (figure 2B). The small lens part was made of a glass with a r.r. of 1.8 and the large lens part was made of a glass with a r.r. of 1.7. In the next phase we compared spectacles made with a plastic lens, ordinary double focus spectacles for the aged, special spectacles for the aged and a goggle type shield on the market for radiation protection (figure 2A), based on the measurement of X-ray film density with the densitometry method to evaluate higher radiation protectability through the lens of them.

The higher density part of the exposed film was considered to be obtained by using a lens which included higher lead-equivalent content, while lighter spectacles with a lens of less lead content are more practical to wear for clinical use.

Results

The results regarding film densitometry in many kinds of spectacles and lenses are presented in figure 2A. The film density of the plastic lens was nearly equal to the density of the film base and the radiation protection effect of the plastic lens was seldom mentioned.

Radiolucency decreased slightly in large lens part (r.r. = 1.5) of the ordinary glass lens spectacles but decreased prominently in the small lens part of the spectacles with the highly refracted glass lens (r. r. = 1.7).

In special spectacles for the aged, in which the highly refracted lens (r.r. = 1.7) was used in the large lens part, radio-opacity in the large lens part was almost equal to the radio-opacity in the goggle type shield for radiation protection. The radio-opacity of each lens in many

Figure 3 The relative radio-opacity of various spectacles in figure 2 is shown in variable exposure conditions. A) The films are taken with variable voltages of X-ray at the same current and exposure time. B) The films are taken in variable voltages with a photo-timer obtaining similar film density (plastic spectacles excluded).

Figure 4 The results of densitometry in the film of large and small lens part of our special spectacles, goggle type shield, film D-min (minimum density of the film), and film D-max (maximum density of the film) are shown.

kinds of opticles with variable voltage is shown in figure 3. When a higher voltage of X-ray was given to each spectacle at the same current, a higher density on the films through each lens was obtained (figure 3A).

With the phototimer system, we changed the exposure time automatically and tried to obtain the same density of lenses of spectacles on the film, both the small and large lens parts of the special spectacles were shown as the radio-opaque part of the density on the film (figure 3B). Many kinds of glass lenses were shown on the X-ray film with the same dose of X-ray (figures 2B, 2C). The lens including the lead (r.r. = 1.9) demonstrated the heaviest radio-opacity (figure 2Ca) and the ordinary lens in large lens part (r.r.=1.5-1.6) demonstrated less radio-opacity (figure 2Bb, c) (figure 2Cc). The highly refracted lens not including lead (r.r. = 1.7-1.8) showed intermediate radio-opacity (figure 2Ba, figure 2Cb). In figure 4, the results of densitometry in the film of special spectacles for the aged and the goggle type shield are shown.

The density of film was shown on the vertical line and the selected voltage level was shown on horizontal line.

The goggle type shield of and large lens part of special spectacles for the aged are showed almost the same density on the films.

Discussion

We asked a lens maker to give us information about the contents of the highly refracted glass lens. According to the data sent by the lens maker, the contents of the highly refracted lens without lead (r.r. = 1.8) are the following: niobium, zirconium and tantalum.

These material of large atomic number are considered to attribute to the radio-opacity of the lens. While we have already presented data of various lenses regarding radiation protective capability with film densitometry, the measurement of radiation exposure should be performed using thermoluminescent dosimetry for accurate evaluation. If operators or radiological technicians have an opportunity to wear spectacles during procedures of angiography in angiographic rooms, it is better for them to select and use spectacles with a highly refracted glass lens.

Ideally, using these special spectacles combined with the goggle type shield, they can ob-

tain thick shield against X-ray to the crystalline lens corresponding to more than 0.1 mm-lead equivalent.

2) *The second topic of this report is the evaluation of our remodeled barrier for radiation protection*

Introduction

The purpose of this study was to investigate the effectiveness of the barrier we remodeled as a protective tool for radiation exposure in cerebral angiography or neuroendovascular therapy. In the experimental study with the protective barrier and the head phantom, radiation exposure of the crystalline lens of the eye was reduced to about one third and radiation exposure of the gonadal glands was reduced to one seventh, compared with radiation exposure to them in 20 seconds of DSA without employing the barrier.

In cerebral angiography, radiation exposure outside the lead apron at the left breast of operators was measured at 1.49μ Sv during 10 min of fluoroscopy and the barrier was very helpful to reduce radiation exposure of operators in various kinds of neuroendovascular therapy. After effectiveness of our barrier was verified, we do not want to perform neuroendovascular therapy without employing it.

Methods

In our hospital we employed Angiostar and Polytron S (Siemens, Erlangen, Germany) as angiographical equipments. The protective tool consisted of a main board made of acrylic plate including 1 mm-equivalent lead, a movable lead acrylic plate, extended lead curtain from the main board, and the main board was stabilized on four legs with a carrier. We made three modifications on the barrier for radiation protection on the market and made our remodeled barrier. The remodeled barrier in our hospital is shown in figure 5. Firstly a curved cut was added to the movable part of the lead acrylic plate for the purpose of narrowing the vacant space between the movable plate and the thoracic cage of the patient.

Secondly one of four legs of the barrier, the nearest one to the operator was shortened and removed for the purpose of saving space

Figure 5 Our remodeled protective barrier system for radiation exposure is shown. The main board is made of an acrylic plate including 1mm equivalent lead. A) the additional curve cut on the movable part of the lead acrylic plate. B) the lead curtain suspended from the arm of the barrier. C) the shortened and removed leg with carrier. D) the lead skirt suspended beside the tissue table as the barrier system which is always employed.

around operator's foot and protecting against collision between the leg of the barrier and the foot of the operator. Lastly a lead curtain suspended from the arm of the barrier was set and intended to be positioned in front of the X-ray tube.

An experimental study was planned to measure the radiation exposure in operators and to evaluate our remodeled barrier for radiation protection in the angiographic room. A head phantom was employed on the supposition that cerebral angiography was performed. Electronic pocket dosimeters were used to measure the equivalent dose to the operator and were placed in the supposed position of the crystalline lens, the left breast and the gonadal glands of the operator. Measurement of radiation exposure in the operator was performed under various conditions, with or without the remodeled barrier, and in 20 seconds of DSA

or under 2 min of fluoroscopy, and with 17 cm of image intensifier or with 23 cm of image intensifier⁵.

The average equivalent dose to each supposed site was calculated from 5 times of X-ray exposure to the site. A general view of the experimental study with the head phantom and the body phantom is demonstrated in figure 6. The dosimeter employed was the electronic pocket dosimeter made by Aloka Japan. We could obtain measurement personally and quickly with it, but the value of the measurement was influenced by the direction of the scattered X-ray.

In clinical usage, dosimetry was performed in the operator in 215 cases of cerebral angiography for 3 radiologists including the author. The dosimeter was placed on the left breast over the apron of the operator. Operator A was a beginner of cerebral angiography and per-

formed it in 47 cases without the barrier. Operator B was a radiologist who experienced cerebral angiography for a few years, and performed it in 50 cases. Operator C was the author, who experienced over 1200 cases of cerebral angiography for 25 years, and performed it in 118 cases. In all cases, a lead skirt is hung beside the tissue table, in front of the operator. Operator A did not want to use the barrier in spite of extended fluoroscopic time. Operator B did not use the barrier but fluoroscopic time was not so extended in the procedures. Operator C used the barrier for all cases including aged patients which was difficult but the average fluoroscopic time was nearly equal to the time of Operator B. Next, operator dosimetry was performed in 40 cases of interventional neuroradiology with only the the author as the operator.

The neurointervetional procedures consisted of preoperative transarterial embolization (TAE) for brain tumors, TAE for cerebral AVMs and coiling for cerebral aneurysms with GDC.

Results

The results of the experimental dosimetry which was performed separatory at different supposed sites of the body in operators and was performed in different combinations of the test condition, are shown in table 1. Our barrier system consisted of the remodeled barrier and the lead skirt hung from the tissue table. The lead skirt was effective for protecting the gonadal glands and the remodeled barrier itself was very effective for protecting the crystalline lens

Figure 6 The schema of an overviewing of our experimental study with the head phantom is shown. A) supposed position of the crystalline lens of the eye (160 cm in height), B) left breast (130 cm), C) gonadal glands (90 cm).

and the left breast in supposed sites. By employing the barrier system during 20 seconds of DSA using 17 cm of image intensifier, the radiation exposure of the crystalline lens was reduced about one third, and at the gonadal glands reduced about one eighth, compared with radiation exposure without the barrier system.

Results of operator dosimetry in cerebral angiography is shown in table 2. The average equivalent dose of operator A was $10.7 \mu\text{Sv}$ which is the biggest in the three operators due

Table 1 The results of equivalent doses at the three supposed sites in various conditions in the experimental study are shown

Supposed position		160 cm Crystalline lens			130 cm Left breast			80 cm Gonadal glands		
		(+)	(-)	Ratio	(+)	(-)	Ratio	(+)	(-)	Ratio
20 sec of DSA	17 cm of I.I.	2.0 μSv	6.5 μSv	0.30	3.3 μSv	6.0 μSv	0.55	4.6 μSv	36.5 μSv	0.12
	23 cm of I.I.	2.5 μSv	7.5 μSv	0.33	4.0 μSv	6.5 μSv	0.61	5.0 μSv	34.5 μSv	0.15
2 min Fluoro scopy	17 cm of I.I.	0 μSv	0.6 μSv	≥ 0	0 μSv	0.6 μSv	≥ 0	0 μSv	5.6 μSv	≥ 0
	23 cm of I.I.	0 μSv	1.5 μSv	≥ 0	0.5 μSv	1.0 μSv	0.5	1.0 μSv	8.0 μSv	0.16

Figure 7 Relationship between the fluoroscopic time (less than 20 min) and the equivalent dose of radiation exposure in three operators at the left breast over the lead apron in cerebral angiography is shown. Operator A: the beginner operator, Operator B: the operator with a few years experiences in cerebral angiography, Operator C: the author, experienced over 25 years.

to extended fluoroscopic time, and performed procedures without employing the barrier. The average equivalent dose of Operator C (the author) was $3.7\mu\text{Sv}$ and minimum in the three operator. On the extracted and dilated graph. (figure 7), the horizontal line indicated fluoroscopic time less than 20 minutes, and the vertical line indicated equivalent doses of X-ray on the left breast of the operator over the lead aprons. The equivalent doses less than $3\mu\text{Sv}$

was measured in 51% cases of operator B, while less than $3\mu\text{Sv}$ of equivalent doses was recorded in 70% cases of operator C. Average equivalent doses of operator B were more than $6\mu\text{Sv}$ during 10 to 20 minutes of fluoroscopy, while $1.49\mu\text{Sv}$ of the average equivalent dose was confirmed in operator C under 10 min of fluoroscopy).

The different exposure doses among operators probalby depended on both the effective-

Table 2 Equivalent doses of radiation exposure at the left breast of three radiologists in 215 cases of cerebral angiography are indicated. Operator A: the beginner operator, Operator B: the operator with a few years experiences in cerebral angiography, Operator C: the author, experienced over 25 years

	Number of cases	Average fluoroscopic time (min)	Average equivalent dose (μSv)
Operator A	47	16.2	10.7
Operator B	50	11.2	4.2
Operator C	118	11.5	3.7

ness of the barrier system and the skill of angiographical technique.

Results of operator dosimetry in interventional neuroradiology are shown in table 3. In cases of preoperative embolization for a brain tumors, the average fluoroscopic time was 40.6 min and not as extended as in cases of TAE for cerebral aneurysms and AVMs, and the average equivalent dose in cases of TAE for brain tumors were 6.1 μ Sv respectively and little. Comparing with average equivalent doses in TAE for cerebral AVMs and coiling for cerebral aneurysms, the former equivalent dose measured at 20.3 μ Sv, was more elevated than the latter equivalent dose in cases of TAE for cerebral aneurysms while TAE for AVMs were performed during the shorter fluoroscopic time.

Discussion

Regarding the results of the experimental study, the remodeled barrier is very effective in reducing radiation exposure to the crystalline lens of the eye and the left breast, because the protecting scattered X-ray mainly passes through the vacant space between the barrier and thoracic cage of the patient.

In addition the lead skirt beside the tissue table is also effective in reducing radiation exposure to the gonadal glands because the exposure is positioned close to the glands of the operators. In 215 clinical cases performed so far by three radiologists, the reduction of radiation exposure to various sites of the operator has been obtained by shortening the fluoroscopic time of each session, employing effective protective barrier and using other reduction techniques i.e. employing collimation to see fluoroscopic images or changing the direction of the

X-ray tube during the procedures. More exposure occurs in embolization therapies of cerebral AVMs than in therapies of cerebral aneurysms is probably due to the more frequent manual injection of the contrast medium performed by the operator under fluoroscopy, while the number of manual injections is not recorded in this document^{6,7}. We must have some knowledge or general consideration about dose distribution in angiographic rooms and the method of dosimetry before discussing how to reduce radiation exposure to personnel in interventional neuroradiology⁸.

In the paper written by K. Nishizawa, the dose distribution of scattering X-ray in an angiographic room is described and the exposure radiation dose is reduced exponentially according to the distance from the X-ray tube to the site of the personnel. The reduction rate of scattering X-ray exposure in a scrub nurse just behind the lead barrier is one fortieth of the non-protective condition of exposure in the nurse⁹.

The other protective system was introduced in the previous paper written by S. Iwasaki and the system consisted of a lead glass beside the patient, and a lead shade around the image intensifier, and a lead skirt beneath the tissue table, which were effective in protecting scattering radiation to the operator considering the three dimensional measurement of scattering X-ray¹⁰.

The average radiation dose without the protective system over the apron protector was 5.8 μ Sv in the diagnostic angiography and decreased to 0.38 μ Sv with the system. According to the recommendation of ICRP60, we must reduce the effective dose in occupational exposure to an average of 20 mSv per year and

Table 3 Equivalent doses of radiation exposure at the left breast of only one operator in 40 cases of interventional neuroradiology are indicated. Cases of interventional neuroradiology consisting of 22 cases of embolization therapy for cerebral AVM and 11 cases of coiling of cerebral aneurysms with GDC, and 7 cases of preoperative TAE for a brain tumor

	Number of cases	Average fluoroscopic time (min)	Average equivalent dose (μ Sv)
TAE for AVMs	22	67.3	20.3
Coiling for aneurysms	11	71.5	11.7
TAE for tumors	7	40.6	6.1

which works out to an average of less than 80 μ Sv per day¹¹.

We can certainly attain this objective while performing a few cases of interventional neuroradiology daily by employing our remodeled barrier combined with table side lead skirt.

Conclusions

1) It is wise to select spectacles with a highly refracted glass lens for operators when wearing spectacles in interventional procedures of neuroradiology, for reducing radiation exposure to the crystalline lens of the eye. If the spectacles are worn in combination with a goggle type shield for radiation protection, it becomes a

very effective tool for protecting against scattered X-ray exposure to the crystalline lens and preventing radiation-induced cataracts.

2) Employing our remodeled barrier for radiation protection with the lead skirt hung from the tissue table can reduce radiation exposure to the crystalline lens about one third of the scattering radiation, and can reduce radiation exposure to the gonadal glands about one seventh of scattering radiation.

3) If we abide by the recommendation of ICRP60, maintaining an average equivalent dose of 20 mSv per year, we can perform a few cases of interventional neuroradiology daily by employing our barrier system consisted of the remodeled barrier and the table side lead skirt.

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Shigeo Kurokawa, M.D.
Department of Radiology
Koshigaya Municipal Hospital,
10-47-1, Higashi-Koshigaya
Koshigaya City, Saitama 343-8577
Japan
E-mail: sigekuro@air.linkclub.or.jp