J of Nuclear Medicine Technology, first published online May 4, 2017 as doi:10.2967/jnmt.117.192849

Title

Corneal Dose Reduction Using a Bismuth-coated Latex Shield over the Eyes During Brain SPECT/CT

Short title

Dose reduction using a bismuth shield

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Original scientific articles

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Word count: 3248

ABSTRACT

Objective This study aimed to determine whether a bismuth-coated latex shield (B-shield) could protect the eyes during brain SPECT/CT.

Methods A B-shield containing the heavy metal bismuth (0.15 mm lead equivalent) was placed over a cylindrical phantom and the eyes of a three-dimensional brain phantom filled with Tc-99m solution. Subsequently, phantoms with and without the B-shield were compared using SPECT/CT. The CT parameters were 30-200 mA and 130 kV. The dose reduction achieved by the B shield was measured using a pencil-shaped ionization chamber. The protective effects of the B shield were determined by evaluating relative radioactivity concentration as well as artifacts (changes in CT number), linear attenuation coefficients, and coefficients of variation (CV) on SPECT images.

Results The radiation doses with and without the B-shield were 0.14–0.77 and 0.36–1.93 mGy, respectively, and the B-shield decreased the average radiation dose by about 60%. The B-shield also increased the mean CT number, but only at locations just beneath the surface of the phantom. Streaks of higher density near the underside of the B-shield indicated beam hardening. Linear attenuation coefficients and the CVs did not significantly differ between phantoms with and without the B-shield, and the relative Tc-99m radioactivity concentrations were not affected.

Conclusions The B-shield decreased the radiation dose without affecting estimated attenuation correction or radioactivity concentrations. Although surface artifacts increased with the B-shield, the quality of the SPECT images was acceptable. B-shields could help to protect pediatric patients and patients with eye diseases who undergo SPECT imaging.

Key word

radiation dose, radiation shielding, image quality, SPECT/CT and attenuation correction

INTRODUCTION

SPECT/CT is a medical imaging technology that combines single-photon emission computed tomography (SPECT) and computed tomography (CT). The computed tomography imaging provides accurate non-uniform attenuation correction for SPECT images of the brain when the position of head is fixed in a holder. Consequently, integrated SPECT/CT systems enable the collection of accurate, qualitative and quantitative, dopamine transporter imaging (1,2). However, the CT procedure increases the radiation dose to the patient, especially to the eye lens, which is among the most radiosensitive tissues in humans (3). From this viewpoint, the International Commission on Radiation Protection (ICRP) has recommended a threshold of 500 mGy for the dose absorbed by the eye lens (4,5). Accordingly, various techniques have been used to reduce the radiation dose delivered by CT (6-8). Widely used approaches include tube current control and automated exposure control (9), iterative reconstruction (10) and shielding organs (11). Although automated exposure control and iterative reconstruction have good potential to reduce the radiation dose while maintaining image quality, these are not available in all systems. On the other hand, superficial organs have been protected with bismuth-coated latex shields (B-shields) which have a reasonable cost and suitable attenuation characteristics. Hein et al. (12) reported that such shields can reduce the surface radiation dose by 40% during paranasal CT. In addition, Hopper et al. (13) reported that B-shields can decrease the average radiation dose by 48.5%. These findings indicate that B-shields might also be useful during SPECT/CT imaging. However, the effects of B-shields on brain SPECT/CT images have not been investigated, especially the accuracy of attenuation correction and SPECT image quality.

The purpose of this study was to assess whether B-shields can be used to protect the eyes during brain SPECT/CT imaging. We evaluated the quality of brain SPECT/CT images acquired when a B-shield was used and the ability of the shield to reduce the radiation dose.

MATERIALS AND METHODS

SPECT/CT instrument, phantoms and B-protection shield

We acquired and reconstructed all images using a Symbia T2 dual-head hybrid SPECT/CT camera (Siemens AG, Erlangen, Germany) equipped with a low-energy, high-resolution collimator. The CT component is the same as that for the Sensation scanner. The radiation dose was measured using a CT dose index (CTDI) phantom, and SPECT image quality was assessed using a cylindrical phantom (diameter 16 cm, height 15 cm) and a three-dimensional (3D) brain phantom (14) containing a solution of Tc-99m (activity 32.8 or 45.8 kBq/mL). A flexible B-shield containing bismuth (0.15 mm lead equivalent, in house) was placed over the surface of the phantom and shaped to cover both eyes.

Dose measurements

We measured the radiation dose at the top area of the CTDI phantom with and without the B-shield (Fig. 1) using a pencil-shaped ionization chamber (Toyo Medic Corp., Tokyo, Japan). The eye lens equivalent dose should ideally be assessed at a depth of 3 mm, but the values more commonly used is at a depth of 70 µm or 1 cm and this is within 10% of the actual values. Therefore, the ionization chamber was inserted at 1 cm depth in the CTDI phantom. The phantom was assessed by CT using the parameters 130 kVp, 30-200 mA, 2 × 0.5 mm collimation, 0.8 s rotation time, 5 mm slice thickness and a pitch value of 0.95. The radiation dose reduction caused by the B-shield was calculated as

$$\text{Reduction value} = \frac{DOSE_{cont} - DOSE_{bismuth}}{DOSE_{cont}} \times 100(\%)$$

where $DOSE_{bismuth}$ and $DOSE_{cont}$ represent radiation doses with and without the B-shield, respectively. The measurements were repeated five times for each CT scan.

Evaluation of image quality

Data acquisition and reconstruction

SPECT/CT data were acquired with and without the B-shield using both cylindrical and 3D brain phantoms. Projection data were obtained in continuous mode with rotation through 120 angular views. The pixel size was 3.3 × 3.3 mm (scale for enlargement, 1.45) with a 128 × 128 matrix. The total acquisition time was 20 min (10 repeats of a 2 min/cycle). A photo-peak of Tc-99m was set as a 21% energy window centered at 140 keV. A low sub-window to correct multi-energy window scatter was set at 7% on the bottom of the photo-peak window (116 keV to 124 keV). All CT images were acquired using the same parameters as in the dose measurement.

All phantom images were reconstructed using ordered-subset expectation maximization with resolution recovery, and both scatter and CT-based attenuation correction were derived from the current in the CT tube. The reconstruction parameters were 15 iterations, 6 subsets and 8.6 mm full width at half-maximum 3D Gaussian filtering as post-smoothing.

Data analysis

Five circular regions of interest (ROIs) were placed on the top, middle and bottom of the CT images and the attenuation correction map (Fig. 2). The mean CT number and linear attenuation coefficients were then measured. The same ROI were placed on the SPECT images and the coefficient of variation (CV) was calculated as

$$\mathrm{CV} = \frac{SD}{MEAN} \times 100\%$$

where the MEAN represents the mean count in the SPECT image ROI and SD is the standard deviation of the ROI. We also investigated the effect of the B-shield on the regional radioactivity by automatically placing ROI templates on 3D stereotactic regions of interest (15). The anterior, precentral, central, parietal, angular, temporal, occipital, pericallosal, lenticular, thalamus, hippocampus and cerebellum regions were used in the analysis. The difference in regional radioactivity was calculated as

$$\text{Difference value} = \frac{MEAN_{ref} - MEAN_{bismuth}}{MEAN_{ref}} \times 100(\%)$$

where $MEAN_{bismuth}$ and $MEAN_{ref}$ are the mean SPECT counts with and without B-shield, respectively.

Statistical analysis

All data were compared using a paired *t*-test with $p < 0.05$ indicating a statistically significant difference.

RESULTS

Dose measurement

The radiation doses and reduction values are shown in Table. The radiation dose was significantly lower

(60.3% ± 0.5%) with the B-shield at each tube current.

Image quality

The mean CT number when using the B-shield was significantly increased at the top of the phantom (Fig. 3a) and slightly increased at the middle and bottom of the phantom (Fig. 3b). Figure 4 shows a comparison of linear attenuation coefficients with and without the B-shield. Although linear attenuation coefficients at the top of the phantom were increased when using the B-shield, Changes could not be detected at the middle or bottom. The CV of SPECT images with and without the B-shield are shown in Fig. 5. The CVs were essentially constant and changes could not be detected with and without the B-shield, especially at the middle or bottom of the phantom.

Figure 6 shows images acquired at tube currents of 50, 100 and 200 mA. For the 3D brain phantom, the radiation dose remained essentially the same with and without the B-shield. The difference with and without B-shield in the radioactivity concentrations was the largest in the thalamus and was less than or equal to 5.1% in all other regions. Figure 7 shows that radioactivity concentrations on SPECT images were similar with and without the B-shield.

DISCUSSION

Although particularly radiosensitive organs are conventionally protected with a lead shield during radiography, lead causes metal artifacts and decreases image quality. However, B-shields and conventional lead shields react differently to X-rays. Lead shields completely absorb radiation, whereas B-shields decrease the amount of soft radiation and thus alter only the X-ray energy distribution. Therefore, B-shields should be useful for protecting radiosensitive organs, such as the eye lens, because B-shields generate less metal artifacts than lead shields.

The present study evaluated whether B-shields could reduce the radiation dose and maintain the accuracy of SPECT images. We found that B-shields reduced the radiation dose to the eye lens by about 60% and that radioactivity concentrations with and without the B-shield were equivalent. These results indicate that B-shields could confer radioprotection, especially for pediatric patients and patients with extant eye diseases who undergo brain SPECT/CT imaging.

The radiation dose was reduced by about 60% at the top of the CTDI phantom at each tube current. For comparison, Ciarmatori et al. (16) reported that bismuth shielding can reduce the entrance surface dose by 21% to 29% during head CT examinations and Wang et al. (17) reported that a bismuth shield and tube-current modulation reduced the radiation dose to the eye lens by 26.4%. Our results are essentially consistent with the previous findings, but the dose was significantly more reduced during CT imaging in the present study. The reasons for this are the difference in lead equivalent of B-shield. The lead equivalent in current and previous study were 0.15 and 0.06 mm. Hopper et al. (13) showed that the CT dose decreased when the shield thickness increased. Therefore, we think that optimization of lead equivalent is necessary for more effective dose reduction. Our results indicated that the CT dose per scan is tiny compared to ICRP recommendation dose (less than 2.0 mGy). However, for radiation examinations, every effort should be made to reduce radiation does without compromising image quality according the “as low as reasonably achievable (ALARA)” concept. The use of B-shield is considered to improve the benefit for patient in brain SPECT/CT.

The mean CT number increased with the B-shield due to beam-hardening artifacts, but this was limited to a superficial region. This result agrees with those of previous studies. Hopper et al. (13) reported that the increased CT number caused by a protection shield did not project into the brain. Hein et al. (12) found that use of an eye shield did not impair diagnostic information in a study of 127 patients. In addition, Hohl et al. (18) showed that a spacer between the surface and shield can reduce the deleterious effects on image quality caused by beam-hardening artifacts.

Linear attenuation coefficients did not significantly differ between with and without the B-shield at the middle and bottom of the phantom. The linear attenuation coefficient was estimated based on the CT number. Because the CT number changed only slightly, we considered that the accuracy of the attenuation coefficient was maintained when using the B-shield. We also found that the CV was similar with and without the B-shield. These findings indicate that B-shields can be used during brain SPECT/CT image acquisition.

The relative amounts of radioactivity in the 3D brain phantom with and without the B-shield did not differ significantly. The maximum difference between measurements with and without B-shield was 5.1% and this was found only in the thalamus. For comparison, Akamatsu et al. (19) reported that the regional radioactivity differed by 1.8% to 11.5% among several reconstruction methods. Ishii et al. (20) showed that the relative SPECT counts obtained by Chang's attenuation correction increased by 5.0% and decreased by 4.6% in the frontal and cerebellar regions, respectively, compared with CT attenuation correction. The results support the notion that the use of a B-shield could benefit patients by decreasing radiation exposure risks to their corneas. Although B-shields have several disadvantages, we recommend their application from the perspective of radiation protection during brain SPECT/CT.

This study has some limitations. One is the simple protocol using several geometrical phantoms. In addition, the region of white matter in the 3D brain phantom did not contain the radioactive solution. Further study is required to evaluate clinical brain SPECT/CT with B-shields. Another limitation is that we did not compare the effects of B-shields with other dose reduction techniques, such as organ-based tube current modulation and CT iterative reconstruction (21, 22). These techniques can also potentially reduce the radiation dose. The effects of the B-shield combined with other methods of reducing the radiation dose should be evaluated.

CONCLUSIONS

We evaluated the effects of a bismuth-coated latex shield (B-shield) on brain SPECT/CT images in a phantom study. The shield reduced the dose of radiation delivered to the eye lens by about 60%. Although the bismuth shield increased image artifacts at the surface, the concentration of radioactivity was acceptable. Our results suggest that the B-shield could help to protect patients undergoing assessment by brain SPECT/CT, especially pediatric patients and those with eye disease.

Conflict of interest

The authors have no conflicts of interest to declare.

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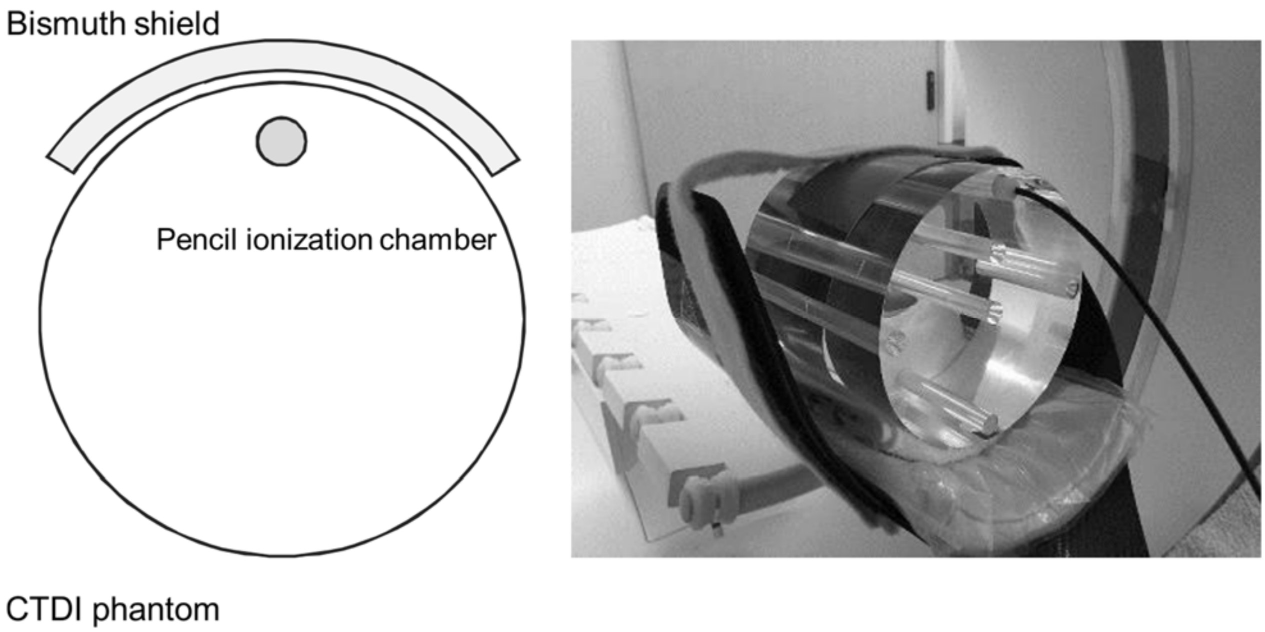

Fig. 1. Phantom with bismuth shielding

(A) CT dose index phantom with bismuth shielding placed over the surface.

(B) Pencil-shaped ionization chamber positioning.

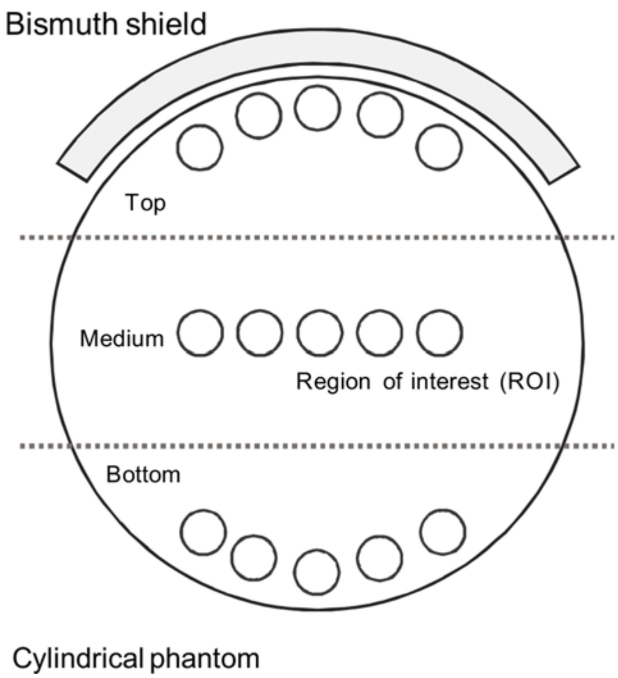

Fig. 2 Images with ROI settings for evaluation

Regions of interest are placed at the top, middle and bottom an image.

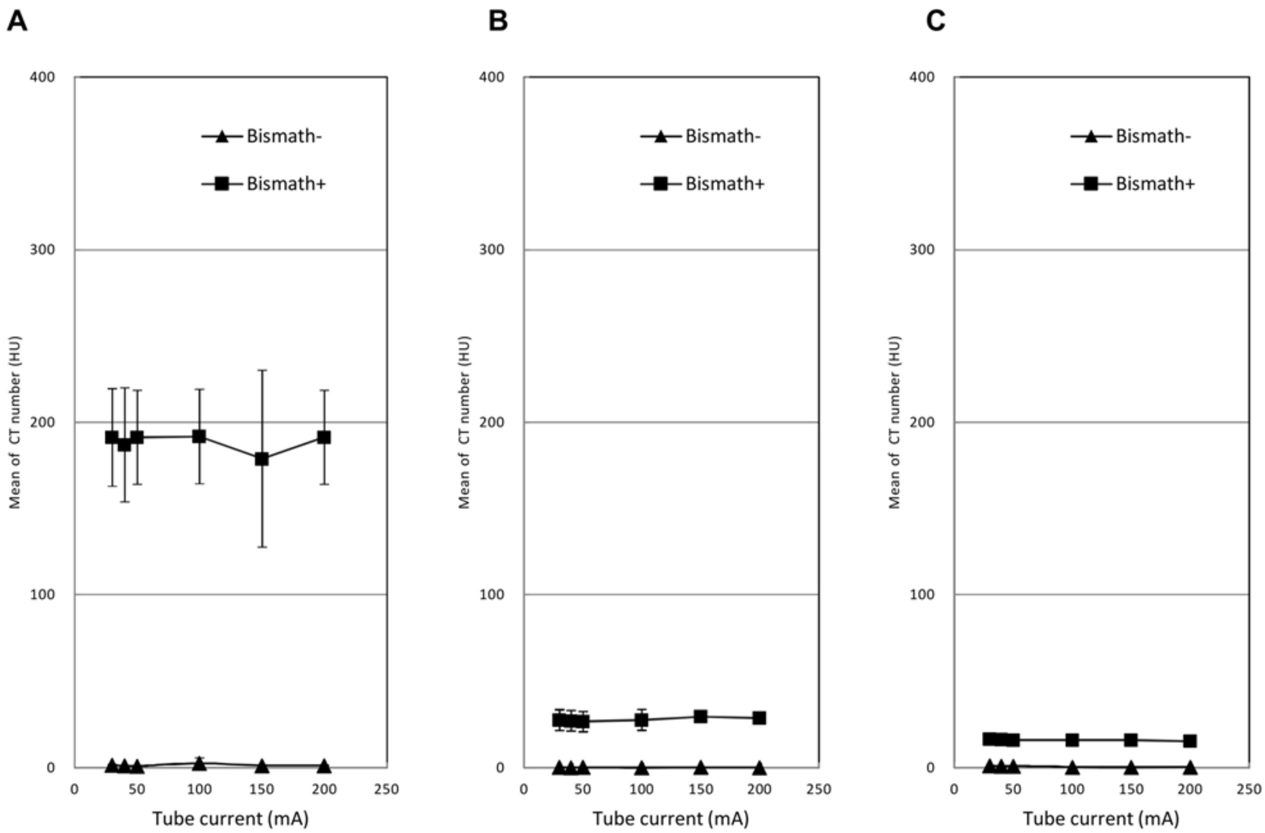

Fig. 3 Mean of CT number determined on CT images as a function of bismuth shielding

(A) Top, (B) middle, and (C) bottom of the image. The mean CT number generated with shielding is slightly higher at the middle and bottom of the image.

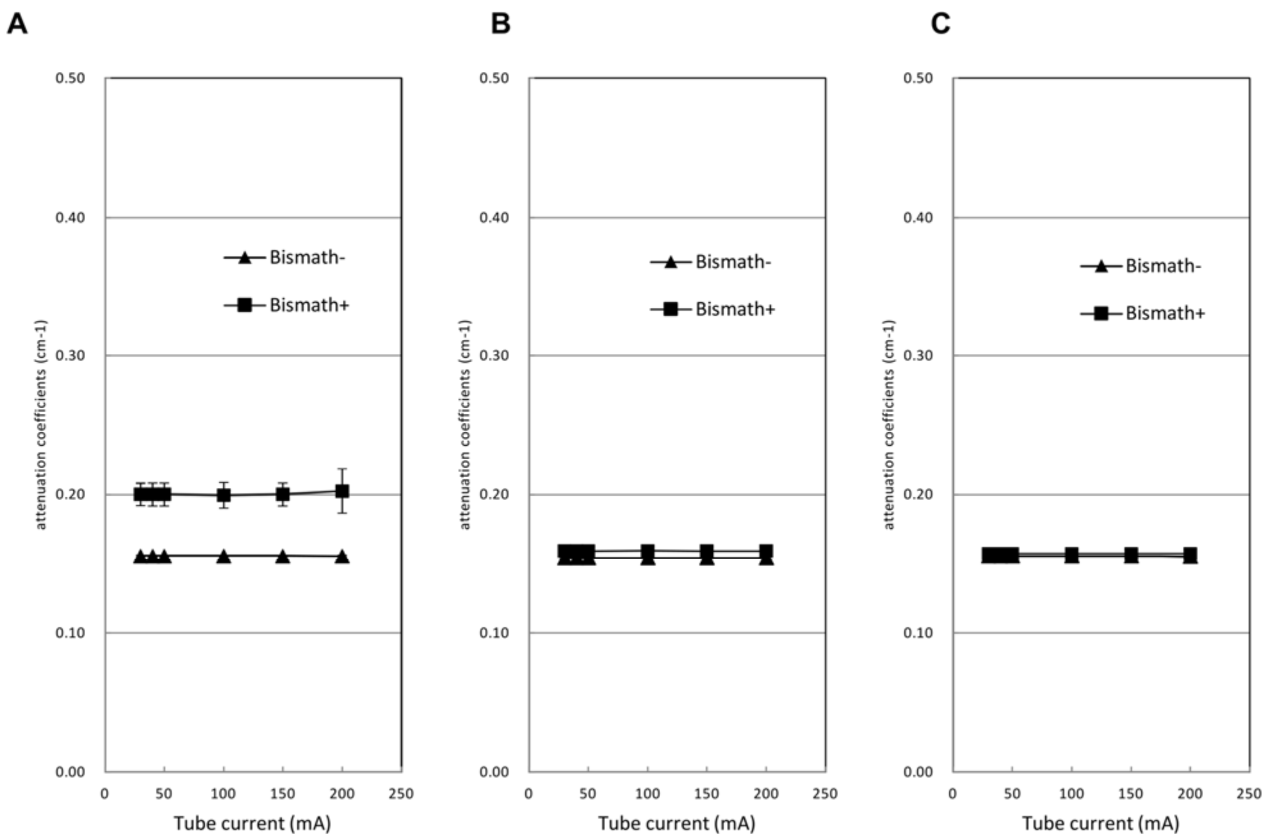

Fig. 4 Comparison of attenuation coefficients with and without bismuth shielding

(A) Top, (B) middle, and (C) bottom of the image. Attenuation coefficients at the middle and bottom of image are not significantly different with and without bismuth shielding.

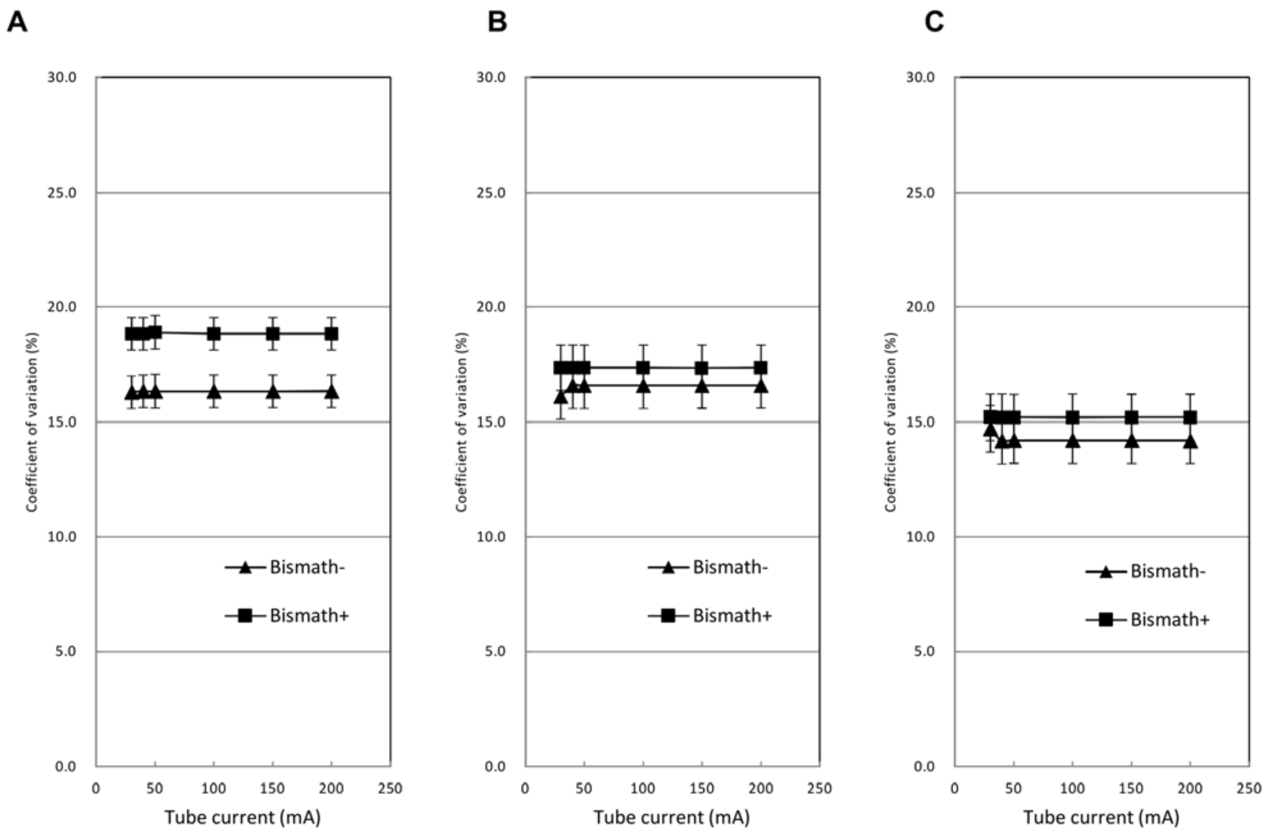

Fig. 5 Coefficient of variation as a function of bismuth shielding (A) Top, (B) middle, and (C) bottom of the image. Coefficient of variation = SD/mean

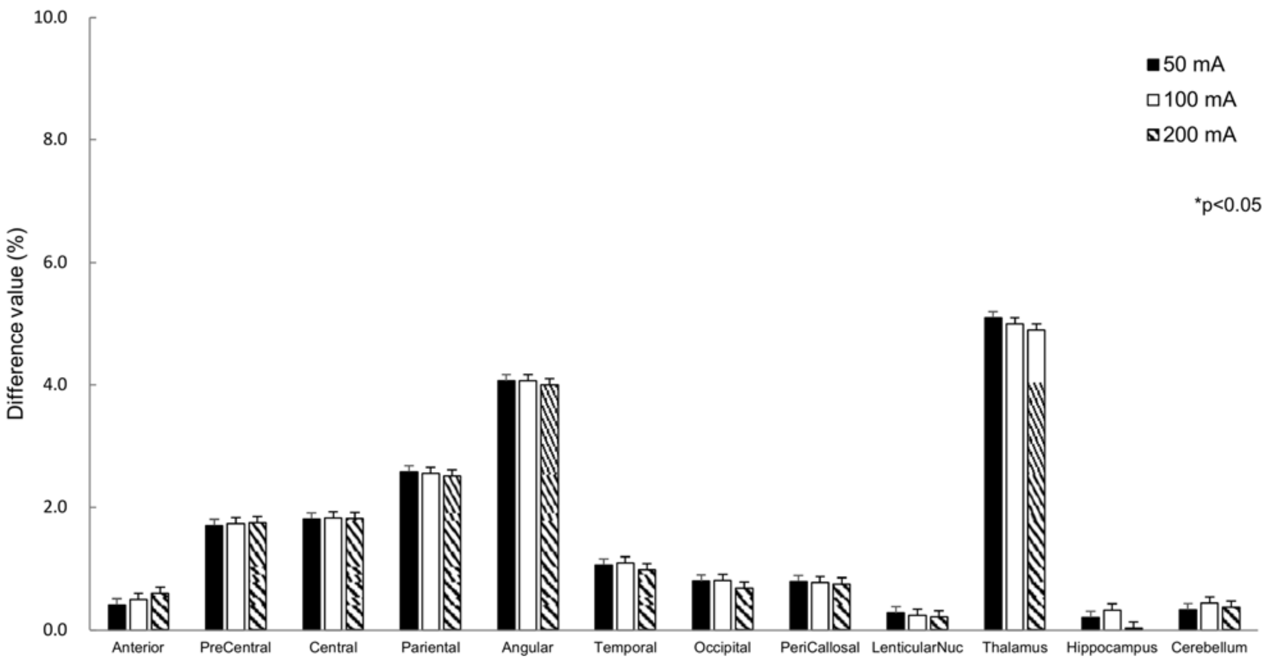

Fig. 6 Comparison regional radioactivity with and without bismuth shielding. Amounts of regional radioactivity do not differ significantly. The difference was highest in the thalamus (5.1%).

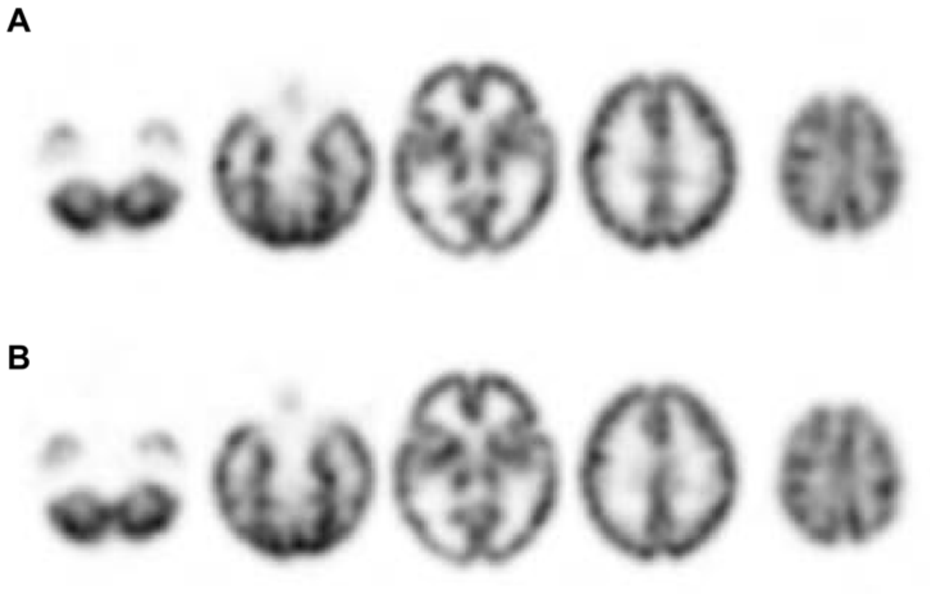

Fig. 7 Examples of SPECT images acquired with bismuth shielding

(A) Reference image from 3D brain phantom. (B) Image acquired with bismuth shielding. The quality of both images is similar.

Table Effect of bismuth shielding on the radiation doses

	Tube current (mA)					
Dose (mGy)	30	40	50	100	150	200
Without shield	0.36	0.42	0.48	0.96	1.45	1.93
With shield	0.14	0.17	0.19	0.38	0.58	0.77
Reduction	61.1%	59.5%	60.4%	60.4%	60.0%	60.1%