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Comparison of entrance surface air kerma to eye lens in head computed tomography protocols between 32-MDCT and 64-MDCT on an anthropomorphic phantom

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ABSTRACT

Background: Brain multi-detector computed tomography (MDCT) is commonly performed for diagnosis of traumatic or non-traumatic brain injury cases. During brain CT scan, the eye lens is highly sensitive to radiation and may cause radiation-induced cataracts irradiated by CT primary beam.

Objectives: This study aimed to determine and compare entrance surface air kerma (ESAK) to the eye lens in clinical routine head protocols between 32-MDCT and 64-MDCT using an anthropomorphic phantom.

Materials and methods: A PBU-60 head phantom was scanned by 32-MDCT and 64-MDCT in helical, axial, and tilted axial modes used in clinical routine head protocols with tube voltage of 120 kVp, tube current of 108-150 mAs for 32-MDCT, and 200-310 mAs for 64-MDCT. The Nanodot™ optically stimulated luminescent dosimeters (OSLDs) was used to measure ESAK to eye lens. Dose length product (DLP), normalized volume CT dose index (${}_{n}CTDI_{vol}$), and normalized mean ESAK were compared between two CT scanners.

Results: The ranges of mean normalized ESAK to the eye lens in each scanning mode was found from 0.41±0.01 to 0.51±0.01 mGy/100 mAs for 32-MDCT and 0.30±0.01 to 0.40±0.01 mGy/100 mAs for 64-MDCT. The normalized ESAKs obtained from 64-MDCT were lower than 32-MDCT by 21.57-37.50%. The lowest normalized ESAK of 0.30±0.01 mGy/100 mAs was obtained in tilted axial scanning mode in 64-MDCT with the difference of 37.50% compared to 32-MDCT of using identical scanning mode.

Conclusion: This study demonstrated that normalized mean ESAK to the eye lens for 64-MDCT in all brain scanning protocols was lower compared to 32-MDCT. In addition, using tilting gantry in axial scanning mode as well as using an automatic tube current modulation system could be beneficial for reducing radiation dose to eye lens during brain CT in clinical routine.

Introduction

Computed tomography (CT) plays an important role as a powerful imaging modality in diagnostic imaging. In the past few decades, the use of CT has increased tremendously, particularly in the emergency department.[1] Multi-detector computed tomography (MDCT) has multiple rows of X-ray detectors, results in faster image acquisition that would be useful for several advance CT applications.[2] However, radiation exposure received from ionizing radiation during CT scans is a point of concern. Since the eye lens is highly sensitive to CT primary beam associated with radiation-induced cataracts[3], the International Commission on Radiological Protection (ICRP) Publication 103 recommended that the threshold dose for preventing radiation-induced cataracts should not be exceeded 0.5 Gy for acute and fractionated

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exposures.[4] Typically, CT scanning parameters and number of detector rows are factors affecting radiation dose to the patients.[5] MDCT scanners from different manufacturers have different included numbers of detector channels. Although the detector configurations can also vary widely, it should be determined based on a type of study performed and a small width of X-ray beam can increase the radiation dose due to increased scanning time.[6]

Most MDCT scanners have similar scanning modes such as helical and axial mode. However, the scanning parameters of these scanners are not definitely identical. Among several techniques for dose reduction in CT, automatic tube current modulation (ATCM) is one of the most effective methods to reduce the radiation dose based on size and attenuation coefficient of the patient's body parts.[7,8] Moreover, utilizing gantry tilt is the another approach that can avoid the primary beam irradiated to the orbit during head CT scans, and could be reduced the radiation dose for the eye lens approximately 75%.[8,9] CT examinations should be performed on a basis of the optimization by balancing radiation dose and adequate image quality for diagnosis in each scanning mode in clinical practice. Therefore, radiological technologists should be concerned in this issue in order to determine optimal scanning protocol for reducing the radiation dose to high sensitivity organs.

To our best knowledge, there were no studies relevant to radiation dose delivered to the eye lens in a routine head CT protocol by comparing between 32-MDCT and 64-MDCT in Thailand. Therefore, in this study, the entrance surface air kerma (ESAK) to the eye lens in clinical routine head protocols was measured using a head anthropomorphic phantom in both 32-MDCT and 64-MDCT.

Materials and methods

Brain phantom

A multipurpose anthropomorphic head phantom-PBU-60 (Kyoto Kagaku, Japan) was employed for this study. The phantom consists of a synthetic skull, cervical spines, and brain with contrast media through arteries in the left side, to simulate a standard human head. This phantom is 30 cm long, measuring from the skull vertex and to the seventh cervical spine. The measurement of the phantom's eye lens dose represents ESAK to the eye lens of a patient who underwent a brain CT scan.

MDCT scanners and scanning parameters

Two MDCT scanners, Canon Aquilion Lightning 32-MDCT at the Department of Radiology, Mettapracharak Hospital and Philips Incisive 64-MDCT at the CT Unit, King Chulalongkorn Memorial Hospital (KCMH) were used for measuring ESAK to the eye lens. Automatic tube current modulation (ATCM) on both MDCT scanners enabled automatic adjustment of tube current in longitudinal (z-axis) and angular modulation (x-y axis) based on size and attenuation coefficient of the patient's body part. ACTM can be estimated through the scan projection radiograph (SPR).

For 32-MDCT, "SureExposure3D" was used for the software of ATCM z-axis modulation. SureExposure3D can be adjusted in order to obtain a preferred image quality for a patient-specific scan. This allows desired standard deviation (SD) for image quality (IQ) reference parameter to maintain the noise level in the image.[10] The SD of 2.61 was set for routine CT head protocol on 32-MDCT. The IQ reference parameter in terms of dose right index (DRI) was utilized for ATCM z-axis tube current modulation in case of 64-MDCT. It was estimated from SPR at the reference standard patient size of 29 cm in diameter with adjustable mA.[10] DRI values can be varied based on patient size and image noise level. The DRI of 34.4 was set for routine CT head protocol on 64-MDCT in this study. The scout protocols of both MDCT scanners were performed with 120 kVp, 20 mA and 300 mm scan length. CT parameters used in clinical routine head examination are listed in Table 1.

Table 1 CT parameters used in clinical routine head examination.

CT protocol	MDCT	ATCM	Setting mAs	Effective mAs	Tube Voltage (kV)	Section collimation (mm)	Beam width (mm)	Rotation time (s)	Reconstructed slice thickness (mm)	Pitch	Gantry tilt (degree)
Brain (*helical mode*)	32	On	108-150*	N/A	120	0.5x1.6	8	0.6	2.0	0.688	0
	64	On	N/A	288	120	64x0.625	40	0.5	3.0	0.600	0
	32	Off	150	--	120	0.5x1.6	8	0.6	2.0	0.688	0
	64	Off	310	--	120	64x0.625	40	0.5	3.0	0.600	0
Brain (*axial mode*)	32	Off	150	--	120	0.5x1.6	8	0.6	2.0	N/A	0
	64	Off	200	--	120	64x0.625	40	1	2.5	N/A	0
Brain (*tilted axial mode*)	32	Off	150	--	120	0.5x1.6	8	0.6	2.0	N/A	10
	64	Off	200	--	120	64x0.625	40	1	2.5	N/A	10

**min-max tube current was set up at 180-250 mA; N/A indicates not applicable.*

Optically Stimulated Luminescence Dosimeter

NanoDot™ (Landauer, Inc., IL, USA), a small-type optically stimulated luminescence dosimeter (OSLD), was used to measure ESAK to the eye lens during head CT scan procedures. As shown in Figure 1, OSLD detector (Al_2O_3:C) consists of a small round crystal with a 0.2 mm layer and 5 mm diameter sealed in 10x10 mm plastic cassettes. NanoDot™ has a wide energy range from 5 keV to 20 MeV with accuracy of ±10%. The calibration and correction factors of NanoDot™ OSLDs for this study were obtained from the reference calibration set of CT dosimeter response.[11] Scarboro et al. found that the signal fading over time had consistency with dose linearity of less than 3%.[12] The angular response of OSL dosimeters with horizontal and vertical rotations are factors affecting the value of ESAK measurement for the eye lens. At the incidence angle of 60 degrees from the normal (relative to 1), variations of dose measurement should be within 10%.[13]

Irradiated OSLDs were read using a microStar Reader (Landauer, Inc., IL, USA). To optically stimulate the dosimeters, an array of light-emitting diodes was utilized. The luminescence emission signal is proportional to the amount of radiation exposure absorbed by OSLDs. To reduce the measurement uncertainty, each dosimeter was read three times consecutively. OSLD signal was corrected for signal depletion for multiple readouts and individual sensitivities. Since the energy response was different between high and low energy, the average of readings was corrected using a correction factor according to the energy dependence after reading out.[11]

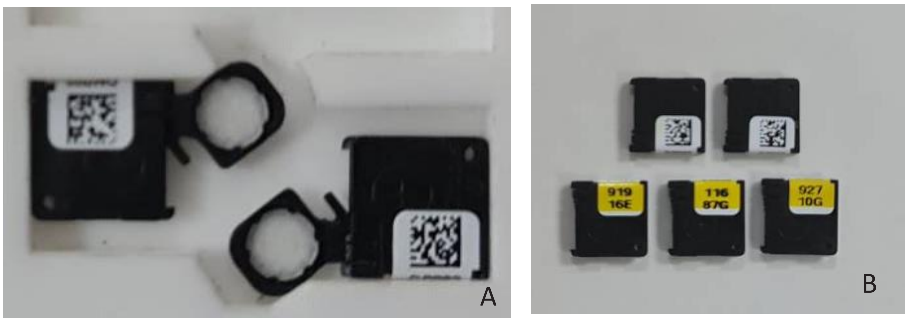

***Figure 1**. NanoDot™ dosimeter. A: an open crystal detector with 2D barcode, B: closed dosimeter showing front and back sides.*

Experimental setup

For accuracy and reproducibility of the measurement, the volume CT dose index ($CTDI_{vol}$) was verified. A 100-mm pencil-ionization chamber model Unfors RaySafe X2 (Billdal, Sweden) was inserted at the center and peripheral holes of polymethylmethacrylate (PMMA) 16 cm diameter head CTDI phantom. The PMMA head phantom was scanned three times with tube voltage of 80-135 kVp. The real-time $CTDI_{vol}$ values displayed on the CT monitor were recorded and compared with the measured values. The percentage differences between measured and displayed values on both CT scanners were then calculated and compared.

To measure ESAK to the eye lens for each scanning protocol, a head phantom was placed in supine position with the midline position located at the center of head support as shown in Figure 2A. To maintain the consistency of measurement for helical and axial scanning modes, the table height was adjusted to be a center of gantry. As a result, the external acoustic meatus (EAM) was at the center of gantry rotation.[14] For tilted axial scanning mode, the gantry was tilted 10 degrees backward parallel to the supraorbital line.[8] Two OSLDs were randomly selected and placed at the center of phantom's eyes surface as shown in Figure 2B. Each imaging protocol was scanned twice to reduce random error (8 protocols x 2 times). The scanning range was set according to a routine head examination and varied from 174 to 180 mm from base of skull to vertex. The field of view (FOV) of 230 mm was fixed for all scanning modes on both MDCT scanners. After scanning, the $CTDI_{vol}$ and the dose length product (DLP) were recorded from the CT monitor. For tube current comparison, mA per slice and effective mAs were collected from the DICOM header. For 64-MDCT, the iterative reconstruction was used for helical with ATCM, while the filtered back projection was used for helical, axial, and tilted axial scanning modes without ATCM. For 32-MDCT, the iterative reconstruction was used for all scanning modes (with and without ATCM). In order to eliminate the bias for comparison of radiation dose between two MDCT scanners, mean ESAK to the eye lens was normalized by 100 mAs.[15] Percent difference of normalized mean ESAK between 32-MDCT and 64-MDCT can be calculated using Equation (1) as follows:

$$\%Difference = \frac{ESAK_{32\text{-}MDCT} - ESAK_{64\text{-}MDCT}}{ESAK_{32\text{-}MDCT}} \times 100,$$

where $ESAK_{32\text{-}MDCT}$ refers to normalized mean ESAK of 32-MDCT, and $ESAK_{64\text{-}MDCT}$ refers to normalized mean ESAK to eye lens of 64-MDCT.

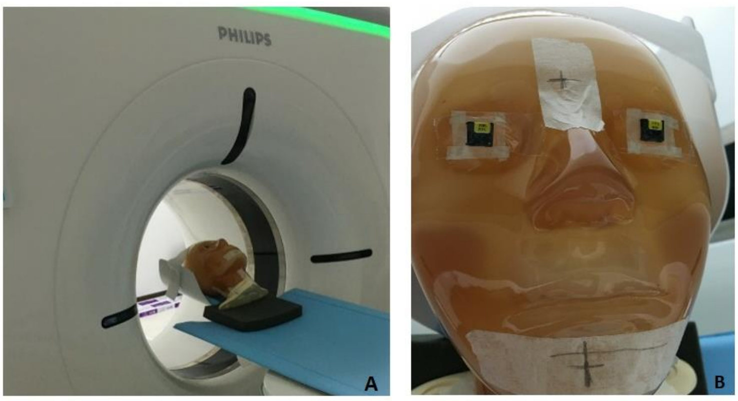

***Figure 2**. A head phantom on the head support (A) and the locations of OSLDs for the measurement of ESAK to eye lens (B).*

Results

For $CTDI_{vol}$ verification, the differences of $CTDI_{vol}$ between measured and displayed values for 32-MDCT and 64-MDCT were within 10% acceptable criteria. Table 2 demonstrates the results of DLP, normalized $CTDI_{vol}$, and normalized mean ESAK to the eye lens measured for each scanning mode on 32-MDCT and 64-MDCT. It was found that the DLP, normalized $CTDI_{vol}$, and normalized mean ESAK obtained from 64-MDCT were lower than those values obtained from 32-MDCT for all scanning modes. However, the DLP values of helical mode with ATCM on 64-MDCT were slightly higher than those from 32-MDCT. Among scanning modes, the minimum and maximum values of normalized mean ESAK to the eye lens varied from 0.41±0.01 to 0.51±0.01 mGy/100 mAs for 32-MDCT and 0.30±0.01 to 0.40±0.01 mGy/100 mAs for 64-MDCT. In Table 2, it can be observed that the tilted axial mode provided the lowest normalized mean ESAK to eye lens of 0.30±0.01 mGy/mAs for 64-MDCT, while helical mode with ATCM offered the lowest normalized mean ESAK to eye lens of 0.41±0.01 mGy/mAs for 32-MDCT. The differences of normalized mean ESAK to eye lens between 32-MDCT and 64-MDCT varied from 21.57% to 37.50% for various scanning modes. Figure 3 depicts the comparison of normalized mean ESAK to eye lens on 32-MDCT and 64-MDCT for each scanning mode. It was seen that tilted axial mode resulted in the highest percentage difference of normalized mean ESAK to the eye lens between two MDCT scanners.

Table 2 Normalized CTDIvol and mean ESAK to the eye lens for each scanning protocol.

CT Protocol	MDCT	ATCM	Normalized $CTDI_{vol}$ (mGy/100 mAs)	DLP (mGy.cm)	Normalized mean ESAK (mGy/100 mAs)	%Difference
Brain (*Helical mode*)	32	On	0.44	859.50	0.41±0.01	N/A
	64	On	0.41	952.95	0.38±0.01	
	32	Off	0.54	1046.80	0.51±0.01	21.57%
	64	Off	0.44	1023.62	0.40±0.01	
Brain (*Axial mode*)	32	Off	0.56	976.80	0.50±0.01	34.00%
	64	Off	0.38	675.85	0.33±0.01	
Brain (*Tilted axial mode*)	32	Off	0.56	976.80	0.48±0.01	37.50%
	64	Off	0.38	675.85	0.30±0.01	

N/A: not applicable.

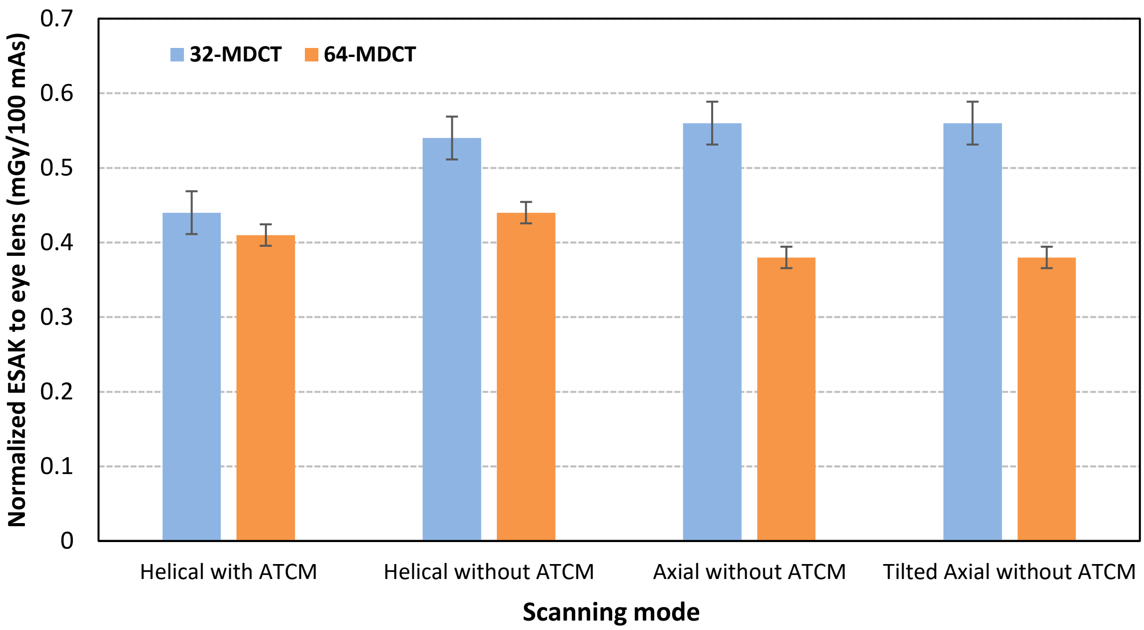

***Figure 3**. Comparison of eye lens dose between 32-MDCT and 64-MDCT for each scanning mode.*

Discussion

According to previous studies, ATCM is one of the most effective methods for radiation dose reduction.[16,17] In this study, the results showed that ATCM could reduce radiation dose to the eye lens by using helical scanning mode. However, the efficiency of using ATCM for radiation dose reduction also depends on tube current used for fixed mAs technique in clinical practice.[14]

The mean normalized ESAK to eye lens of helical mode with ATCM of two MDCT scanners were not comparable due to different IQ reference parameter settings. Each vendor has a different index for IQ reference parameter that directly affects the radiation dose.[10,17] The DLP of helical mode with ATCM of 64-MDCT was slightly higher than the DLP of 32-MDCT due to small difference of scan length related to irradiated range.[18,19] The mean normalized ESAK of 64-MDCT was lower for all scanning modes compared to 32-MDCT as the beam width 40 mm was used, while the beam width of 8 mm was set for 32-MDCT. In addition, 32-MDCT used a gantry rotation time to complete the scan length longer than the 64-MDCT. Beam width and gantry rotation time are factors related to scattered radiation and penumbra of the radiation dose profile distribution.[19,20]

For axial scanning mode, the slice interval was set to zero without overlapping for data acquisition. This setting was slightly affected by eye lens dose when compared to helical mode in order to complete the coverage scan range. Thus, the mean normalized ESAK to eye lens of 64-MDCT was decreased when compared to helical mode. Comparing the axial mode to helical mode without ATCM on 32-MDCT, it could be noticed that the mean normalized ESAK of axial mode was not different from the helical mode without ATCM. Nevertheless, the mean normalized ESAK to eye lens of axial mode was increased when compared to helical mode with ATCM because the tube current setting was different. Moreover, tilted axial scanning mode showed the lowest mean normalized ESAK to eye lens and provided the highest percent dose difference between two scanners accordingly. As a result, the value of mean normalized ESAK was decreased by 5.88% and 25% for 32-MDCT and 64- MDCT respectively, when compared to helical mode without ATCM. In addition, tilting of the gantry at +10 degree along to the supraorbital line is recommended for eye lens dose reduction since the eye lens is completely out of the CT primary beam.[8,14] Although there was variation between the scanners, mean normalized ESAK to eye lens on both scanners was well below the threshold dose of 0.5 Gy recommended by the ICRP Publication 103.[4]

To demonstrate the radiation doses for the eye lens obtained from MDCT in clinical routine, the results obtained from this study were compared only the existing head routine protocols for both CT scanners without any modifications. Although the CT protocols were slightly different from each other, the head brain phantom images acquired from these protocols can provide an adequate image quality as shown in Figure 4. The noise values (SD) at corona radiata and lateral ventricle in each scanning mode ranged from 3.92 to 5.54 HU for 32-MDCT and 2.87 to 4.81 HU for 64-MDCT. Nevertheless, comparison of image quality on different scanners can be used to analyze the impact of eye lens dose reduction and to determine the optimal protocol for further studies.

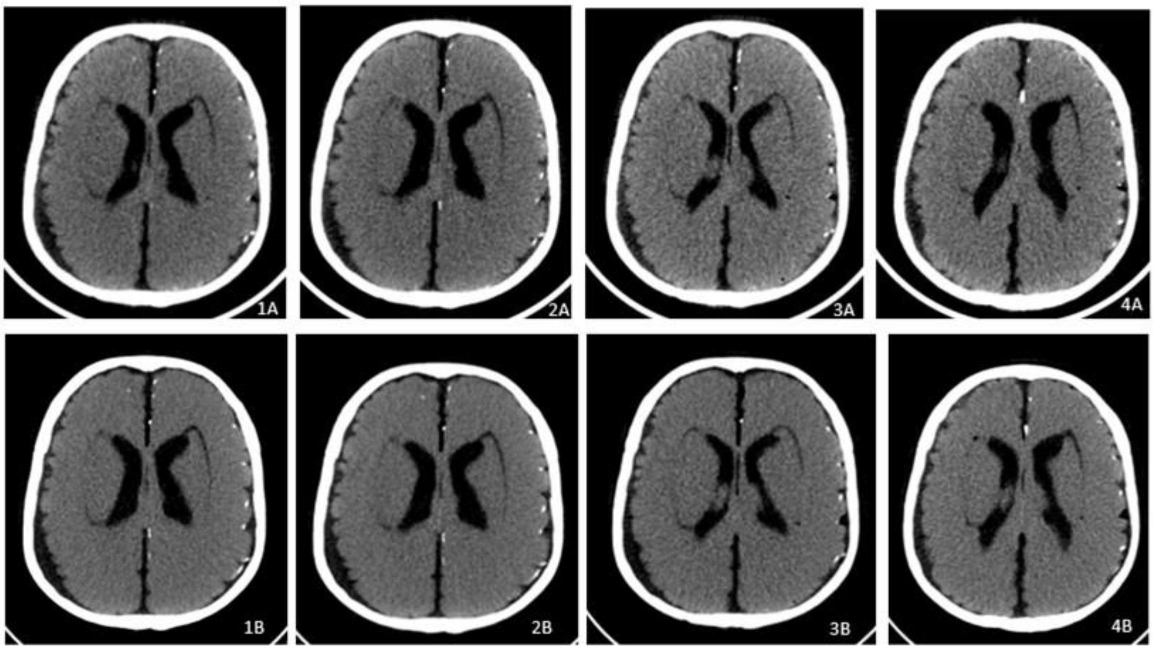

***Figure 4**. CT transaxial brain image of 32-MDCT (A) and 64-MDCT (B) in each scanning mode. 1: helical with ATCM, 2: helical without ATCM, 3: axial without ATCM, 4: tilted axial without ATCM.*

Regarding factors affecting OSLD measurement such as geometry and angular dependence, Perks et al. reported the errors of measurement at a specific incidence angle of gantry rotation.[13] For 60-degree incidence angle, the variation of OSLD measurement could be increased to 10% (relative to 1 at normal incidence). In this study, a 10-degree incidence angle was chosen. As a result, the variation of measurement was relatively low at close to 1% from normal incidence. This study has some limitations. First, the scanning protocols were not exact identical between two scanners resulting in slightly different radiation dose measurement. Second, the eye lens dose obtained from this study was not generalized to the other CT scanners due to different characteristic scanner output. Finally, only a standard size head phantom of 16 cm was used. Therefore, different sizes of head phantom should be examined for further study.

Conclusion

The number of detector rows, scanning mode, and parameter settings are factors affecting eye lens dose in head CT examinations. Comparing the eye lens dose between 32-MDCT and 64-MDCT, normalized mean ESAK of 64-MDCT were lower than 32-MDCT in all scanning modes. The eye lens dose in routine brain CT scan obtained from this study was still below 0.5 Gy. Using tilting gantry in axial scanning mode and ATCM in helical mode could reduce eye lens dose during brain CT. Thus, these scanning techniques should be applied for dose reduction in clinical practice to provide benefit to a patient.

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Conflict of interest

There are no conflicts of interest to disclose.

Ethic approval

The study was approved by the Institutional Review Board (IRB) of the Faculty of Medicine, Chulalongkorn University.

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