The impact of head miscentering on the eye lens dose in CT scanning: Phantoms study

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Abstract. The aim of this study was to evaluate the eye lens dose due to miscentering, either above or under the isocenter, and to assess the possibility of eye lens dose reduction by using miscentering phenomenon. We used two types of phantoms (head CTDI and adult anthropomorphic phantoms) and two types of detectors (pencil ionization chamber and radiophotoluminescence detectors). Measurements using the head CTDI phantom and pencil ionization chamber were performed at the upper peripheral hole of the CTDI phantom, whereas measurements using RPL detectors were performed on the surface of the eyes of the anthropomorphic phantom. Each measurement was performed with position phantoms at the isocenter and also at the positions ±2, ±4, and ±6 cm under and above the isocenter. The impact of miscentering on noise was also observed. Our results show that the dose to the eye decreases with increasing position of the phantoms from the isocenter, and increases with decreasing position of the phantoms from the isocenter. Miscentering above the isocenter can potentially reduce the dose to the eye lens, which is a sensitive organ to ionizing radiation.

1. Introduction

The eye is a very sensitive organs in the head to ionizing radiation. The International Commission on Radiological Protection (ICRP) estimated that the threshold for opacities in the lens of a single short exposure is in the range of 500–2000 mGy and the threshold for the visual impairment or cataract is about 5000 mGy [1]. The dose for the eye on a head CT scanning with the eye in the primary beam has been reported to be around 50 mGy [2, 3]. In some cases, head CT examinations are carried out twice, with and without media contrast, so that the dose received by the eye would be about 100 mGy [4]. This level of dose is significantly lower than the dose threshold for lens opacities. However, Klein et al. [5] reported that X-ray exposure from CT scanning could produce a high probability of posterior subscapular cataracts. Yuan et al. [6] also reported a correlation between increased of cataract incident and CT scanning of the head and neck region. Hence, the eye lens dose optimization is important and the radiation dose should be kept as low as possible while maintaining image quality for diagnosis.
Among the techniques to optimize the dose to the eye is to utilize the proper gantry angulation [7, 8]. Nikuupave et al. [7] reported that gantry tilt was an effective technique for reducing exposure of the eye lens in CT of the brain up to 75% without compromising the quality of image. Heaney and Norvill [8] also reported that use of the proper gantry angle could reduce the dose to the eye by approximately 88%. Another technique that potentially reduces the eye dose is by using local exterior shielding (bismuth or lead shields) [9-12]. Hopper et al. [11] reported that the use of bismuth-coated shielding over the eyes reduced radiation dose up to 65% and that it strongly depend on thickness of the bismuth shielding. Ngaile et al. [12] also reported that use of modified lead shields with thickness up to 0.25 mm could be used to reduce the lens dose by approximately 44% without significant effect on the quality of the image. Another technique that can be used to reduce the dose to the eye is the use of organ-based tube current modulation (OB-TCM) [13, 14]. Duan et al. [13] reported that with OB-TCM, the dose to the midline of the anterior surface of anthropomorphic phantoms was reduced by 27–50%, depending on the anatomic region (head or thorax) and size of the patient, without significantly affecting the image noise.

The use of proper miscentering may potentially be used to reduce the dose to the eye [15-18]. The CT dose distribution in a patient or phantom is strongly influenced by the bowtie filter and its relative position to the isocenter [19]. The bowtie filter has a specific shape, with minimum thickness in the middle and maximum thickness at the edges, producing maximum intensity in the middle part of the filter and minimum intensity in the edge regions [18]. The X-ray incident to the patient or phantom originates from various angles of rotation, so that the proper bowtie filter will produce a relatively homogeneous dose within a patient or phantom, if they are located properly at the isocenter. The miscentering of the phantom or the patient will affect the dose distribution, especially at the edges. We hypothesize that if the patient position is lower than the isocenter, the dose at the upper surface (or at the anterior region) will tend to be larger, but if the patient is higher than the isocenter the dose at that region will tend to be smaller. This study aimed to evaluate the dose of the eye due to miscentering, either above or below the isocenter, and assess the possibility of eye lens dose reduction by elevating the head or phantom position above the isocenter.

2. Method

2.1. Dose measurements
To evaluate the impact of miscentering to the dose of the eye, we used two types of phantoms and two types of detectors. The first was the head CTDI phantom with a diameter of 16 cm and a pencil ion chamber with a length of 10 cm. Measurements were performed at the center hole and the upper peripheral hole of the phantom. Figure 1(a) shows the CTDI measurement position in the upper peripheral hole of the head CTDI phantom.

Figure 1. Phantom set-up and detector locations. (a) Pencil ionization chamber was inserted in the peripheral hole of head CTDI phantom, (b) PLDs were located at the surface of anthropomorphic eyes.
Additionally, measurements using radio-photoluminescence (RPL) detectors (type GD352M, Chiyoda Technol Corporation, Japan), with a diameter of 1.5 mm and a length of 12 mm, were placed on the surface of the eye of the anthropomorphic phantom, as shown in Figure 1(b). Three RPL detectors were placed at the surface of the left eye and three RPL detectors were placed at the surface of the right eye. Before and after the scanning (irradiation) process, the RPL detectors were read using RPL Dose Ace reader, type FGD-100. Each detector was read three times.

2.2. Noise calculation
Noise was calculated as the standard deviation of the pixel values in the regions of interest (ROIs) [20] on the images of the head CTDI and head anthropomorphic phantoms. The respective ROIs are shown in Figure 2. In the head CTDI phantom image, there were two ROIs, one on the left and one on the right, with each ROI having an area roughly equal to the hole of the phantom. In the head anthropomorphic phantom image, there were also two ROIs located inside the left eye and the right eye.

2.3. CT scanner and setting parameters
The evaluation of the effect of the miscentering on eye radiation dose was performed using a MDCT Toshiba AlexionTM 4. Each measurement was performed with position phantoms at the center of rotation of the x-ray tube, marked with a laser beam (isocenter). The position of the phantoms were then varied in the vertical direction, namely at 2, 4, and 6 cm above and below the isocenter. The input setting parameters in the current study are shown in Table 1. The head CTDI phantom was scanned only along the central z-axis, while the anthropomorphic phantom was scanned in the head area with a sequential mode. All the measurements used a field of view (FOV) of 24 cm and a gantry tilt of 0°.

Table 1. Input setting parameters of CT scanner

| Setting parameter     | Head CTDI phantom | Anthropomorphic phantom |
|-----------------------|-------------------|-------------------------|
| Tube voltage (kVp)    | 120               | 120                     |
| Tube current (mA)     | 100               | 100                     |
| Time rotation (s)     | 1                 | 1                       |
| Field of view (cm)    | 24                | 24                      |
| Filter type           | Large             | Large                   |
| Type of scanning      | Axial scanning    | Axial scanning          |
| Slice thickness (mm)  | 8                 | 4                       |
| Gantry tilt (degree)  | 0                 | 0                       |
3. Results

3.1. Miscentered images
The axial images of head CTDI phantom and the head of the anthropomorphic phantom at the isocenter position are shown in Figure 2. The off-center positions for the head CTDI phantom and head anthropomorphic phantom are shown in Figures 3 and 4. The head CTDI phantom was not truncated for miscentering up to ±4 cm above and below the isocenter. This is reasonable, because the diameter of head CTDI phantom was 16 cm and the FOV was 24 cm. The axial images of the head of the anthropomorphic phantom were not truncated up to a miscentering of ±2 cm, either above or below the isocenter. The diameter of the head of the anthropomorphic phantom in the AP direction was about 20 cm. The axial image truncation is strongly influenced by the field of view (FOV) and size of the object (phantom or patient) being imaged.

![Image](image1)

**Figure 3.** The axial images of the head CTDI phantom with off-center positions ±2, ±4, and ±6 cm above and below the isocenter.

![Image](image2)

**Figure 4.** The axial images of the head anthropomorphic phantom with off-center positions ±2, ±4, and ±6 cm above and below the isocenter.

3.2. Impact of miscentering on eye dose
Measurements in the center hole of the head CTDI phantom showed the highest CTDI value when the phantom was positioned at the isocenter. If the position of the head CTDI phantom moves from the isocenter, the CTDI value will decrease, as it was shown by Figure 5(a). The CTDI values decrease by up to about 15% for a miscentering of ±6 cm.

The CTDI value in the upper peripheral hole of the CTDI phantom was interesting as shown in Figure 5(b). The CTDI value increased if the position of the head CTDI phantom was lower than the isocenter, and decreased if the position of the head CTDI phantom was higher than isocenter. At a miscentering of
+2 cm, the CTDI value decreased by 3%. For miscentering of -2 cm or less, the CTDI value increased by 20% or more.

The same pattern also occurred at doses in the eye surfaces of the anthropomorphic phantom, measured by a RPL detector, as shown in Figure 6. In the anthropomorphic a position of +2 cm above the isocenter reduced the dose by about 10%, at a position of +4 cm above isocenter the dose was reduced by about 20%, and at a position +6 cm above center the dose was reduced by more than 30%. And if the position of the anthropomorphic phantom was -2 cm below the isocenter, the dose increased by about 20%, at a position of -4 cm under the isocenter the dose increased by about 30%, and at a position of -6 cm under the isocenter the dose increased by more than 40%.

Figure 5. Normalized CTDI values vs off-center positions ±2, ±4, and ±6 cm above and under isocenter for (a) center hole and (b) upper edge hole.

Figure 6. Normalized eye doses vs off-center positions ±2, ±4, and ±6 cm above and under isocenter measured at surface of (a) right eye and (b) left eye of anthropomorphic phantom.

3.3. Impact of miscentering on noise
Figure 7(a) shows the noise in the area of the region of interest (ROI) in a CTDI phantom and Figure 7(b) shows the noise in an anthropomorphic phantom. Calculation of noise at a position of miscentering +6 cm above the isocenter was not possible because the image in the ROI area had been truncated. Noise tends to be lower at the isocenter position and higher at off-center positions.

Figure 7. Normalized noise vs off-center positions ±2, ±4, and ±6 cm above and under isocenter for (a) noise at head CTDI phantom and (b) noise at anthropomorphic phantom's eye.
Figure 7. Noise vs off-center positions above and under isocenter measured at the area of the region of interest (ROI) in (a) a CTDI phantom and (b) an anthropomorphic phantom.

4. Discussion

The impact of a miscentering to the eye dose during CT exams is due to the use of the bowtie filter, which is thinner in the middle and thicker at the edges. The design of bowtie filters is generally tailored to the body part to be scanned, so there are a number of distinct types. If the patient or phantom is positioned properly at the isocenter, the dose distribution in the phantom or the patient will tend to be uniform [21]. However, if patient or phantom is not properly positioned (miscentering), the dose distribution will change. Many investigators reported that in the case of miscentering, the dose on the upper surface (or anterior regions) will tend to rise [16-18]. Our current study shows that the dose to the eye (or to the anterior area of the head) increases with decreasing position of the phantoms from isocenter, and decreases with increasing position of the phantoms from isocenter.

Therefore, miscentering higher than the isocenter has a potential benefit for reducing the dose to the eye, which is a sensitive organ to ionizing radiation. Similar results were reported by Kassalainen et al. [19] in adult chest phantoms using a 64-MDCT unit (XTE LightSpeed VCT, GE Healthcare). They reported that the doses decreased around 23% for the highest table position (6 cm upper the isocenter). Similar result were observed for 5-year-old and newborn phantoms; the doses decreased by approximately by 12% and 8% in the highest table position, respectively. Kataria et al. [22] also studied organ and surface doses measured on the head, neck/thorax and abdomen of adult anthropomorphic phantom using the SOMATOM Definition AS CT scanner (Siemens, Erlangen, Germany) and thermoluminescent dosimeters (TLDs). They reported that if the phantom was positioned 3 cm upper the isocenter, the doses of the ventral (anterior) region were smaller (5.6%-39.0%) than those measured in the isocenter.

However, it should be noted that raising the phantom position above the isocenter also increased the noise at the eye (or at the anterior area of head). The current study shows the pattern of increasing noise due to miscentering. If the phantoms were positioned 2 cm higher than the isocenter, noise increased up to about 10% in the CTDI phantom and about 2% in the head anthropomorphic phantom. And if the phantoms were positioned 4 cm higher than than isocenter, the noise increased up to about 20% in CTDI phantom and about 40% in head anthropomorphic phantom. Similar results were reported by Kassalainen et al. [19] on chest phantoms. In general, for miscentering of 2 cm higher than the isocenter noise increased up to about 10%, and for miscentering of 4 cm higher than the isocenter noise increased by up to about 20%.

Placing the patient at the isocenter position is the best practice in terms of dose and image quality. However, positioning the patient correctly at the isocenter may not easy, especially in busy CT centers. The studies have shown that patient positioning in the clinical environment tends to result in miscentering below the isocenter [18, 19]. Kassalainen et al. [19] reported that, in a clinical set-up, the median offset varied from 2.5 to 3.5 cm below the isocenter. Habibzadeh et al. [18] reported that an analysis of patients positioning using CT localizer radiographs showed miscentering of 2.2 cm on average below the isocenter with a resulting dose increase of approximately 23%. Consequently, for head examinations it is recommended to perform a proper centering using an automated method [17]. If it is difficult to set the patient at the proper position, it is recommended to incline slightly higher than isocenter, because miscentering above the isocenter will tend to decrease the dose to the eye of the patient.

Another consideration when considering miscentering is truncation of the images. In clinical applications this is mainly due to the FOV selection and size of the phantom or patient [23]. For example, if head size is 16 cm, the use a FOV of 24 cm will produce truncation at a miscentering ±4 cm. And if the size of the head is 20 cm, truncation of the image will occur at a miscentering of ±2 cm. The truncated image and limit of miscentering (LM) can be estimated by the: 

\[ LM = \frac{(FOV-d)}{2}, \]

where d is the maximum diameter of patient. In fact, the diameter of patient does not only determine the image
truncation, but also determines the patient dose. If the size of patient increases, the dose will decrease [24, 25].

One of the limitations of the current study was that the measurements of eye dose were performed only using head CTDI phantoms and anthropomorphic phantom. In the anthropomorphic phantom, measurements were taken at the surface of the eyes rather than inside the eyes. This study was only conducted with gantry tilt of 0°. A further study needs to be done using different sizes of anthropomorphic phantom and with various gantry tilt.

5. Conclusions
Miscentering affects the eye lens dose in head CT examinations. The eye dose decreased with increasing positions of the head above the isocenter, and increased with decreasing positions of the head below the isocenter. Consequently, miscentering above the isocenter has the potential for reducing the dose to the eye lens. However, the noise in the eye will be higher and the image of the head is likely to be truncated if the size of the FOV is not correctly adjusted.

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