Lens Exposure during Brain Scans Using Multidetector Row CT Scanners: Methods for Estimation of Lens Dose

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Lens Exposure during Brain Scans Using Multidetector Row CT Scanners: Methods for Estimation of Lens Dose

BACKGROUND AND PURPOSE: Some recent studies on radiation lens injuries have indicated much lower dose thresholds than specified by the current radiation protection guidelines. The purpose of this research was to measure the lens dose during brain CT scans with multidetector row CT and to assess methods for estimating the lens dose.

MATERIALS AND METHODS: With 8 types of multidetector row CT scanners, both axial and helical scans were obtained for the head part of a human-shaped phantom by using normal clinical settings with the orbitomeatal line as the baseline. We measured the doses on both eyelids by using an RPLGD during whole-brain scans including the orbit with the starting point at the level of the inferior orbital rim. To assess the effect of the starting points on the lens doses, we measured the lens doses by using 2 other starting points for scanning (the orbitomeatal line and the superior orbital rim).

RESULTS: The CTDIVol and the lens doses during whole-brain CT including the orbit were 50.9–113.3 mGy and 42.6–103.5 mGy, respectively. The ratios of lens dose to CTDIVol were 80.6%–103.4%. The lens doses decreased as the starting points were set more superiorly. The lens doses during scans from the superior orbital rim were 11.8%–20.9% of the doses during the scans from the inferior orbital rim.

CONCLUSIONS: CTDIVol can be used to estimate the lens dose during whole-brain CT when the orbit is included in the scanning range.

ABBREVIATIONS: CTDI = CT dose index; CTDIVol = volume CT dose indices; DORM = lens dose during whole-brain scanning from the inferior orbital rim; DORM = lens dose during scanning from the orbitomeatal line; DSOR = lens dose during scanning from the superior orbital rim; ICRP = International Commission on Radiological Protection; mAs = mAs divided by helical pitch; RPLGD = radiophotoluminescent glass dosimeter
relationship between the patient’s lens dose and CTDI during brain CT scans with multidetector row CT.

The purpose of this research was to measure the lens dose during brain CT with multidetector row CT and to assess methods for estimating the lens dose with CTDIvols.

**Materials and Methods**

**CT Scanning**

Using 8 types of multidetector row CT scanners, we obtained whole-brain CT scans for the head part of a Rando phantom (Phantom Laboratories, Salem, New York), which represented a 163-cm-tall and 54-kg female figure. We used both axial and helical scans for each CT scanner. Table 2 shows the scanning parameters. For each scanner, tube voltage was set at 120 kV, and the scanning parameters in Table 2 represent the normal clinical settings. We used the orbitomeatal line as the baseline. In each scanner, the CTDIvol was displayed on the console. The starting point of the whole-brain CT scan was 15 mm below the orbitomeatal line, and the end point was the top of the head. The former corresponded to the level of the inferior orbital rim.

**Lens-Dose Measurement on Human-Shaped Phantoms**

We measured the doses on the centers of both eyelids by using a RPLGD. We regarded the average dose of both sides as the lens dose. To estimate the uncertainty in these dose assessments, we repeated the measurements 3 times. The RPLGD chip (GD-352M, Asahi Techno Glass, Shizuoka, Japan) consists of a glass element with a 1.5-mm diameter and 12-mm length and a holder with an energy-compensation filter of 0.75-mm tin. We annealed the glass elements of the RPLGD for 1 hour at 400°C and cooled them down slowly to room temperature before the exposure. A preheating process was performed for 30 minutes at 70°C after the exposure, and a fully automatic system (FGD-1000, Asahi Techno Glass) was used for the readout. For calibration, we used a standard glass irradiated with 137 Cs of gamma ray energy (0.662 MeV) of 6 mGy. According to the data provided by the manufacturer, the coefficient of variation is ±2% at ±1 mGy.

**Effect of the Starting Point of the Scanning on Lens Dose**

To assess the effect of the starting points on the lens doses, we measured the lens doses during brain CT scanning for axial scans by using 2 other starting points of scanning (the orbitomeatal line and the superior orbital rim). The latter corresponded to the level 15 mm above the orbitomeatal line. The end points were the top of the head in all scans.

**Results**

Table 3 shows CTDIvols and the lens doses during whole-brain CT including the orbit for both axial and helical scans with each CT scanner. The CTDIvols and the lens doses were 50.9–113.3 mGy and 42.6–103.5 mGy, respectively. The former tended to be larger than the latter, and the ratios of lens dose to CTDIvol were 80.6%–103.4%.

Table 4 shows the effects of the starting point of the scanning on the lens dose. The lens doses decreased as the starting points were set more superiority. The lens doses during scanning from the superior orbital rim were 11.8%–20.9% of the doses during scanning from the inferior orbital rim. The ratios

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**Table 1: Formulas for CTDI and its variations**

| Dose Index | Formula | Notes |
|------------|---------|-------|
| CTDI | \[CTDI = \frac{1}{T} \int_{-\infty}^{\infty} D(z) dz\] | T is the nominal width of a section and \(D(z)\) is the dose at point \(z\) parallel to the \(z\)-axis |
| CTDI measured > 100 mm | \[CTDI_{100} = \frac{1}{N} \int_{50 \text{ mm}}^{50 \text{ mm}} D(z) dz\] | \(N\) is the number of acquired sections per scan, \(T\) is the nominal width of each acquired section, and \(D(z)\) is the dose at point \(z\) parallel to the \(z\)-axis |
| Weighted CTDI | \[CTDI_w = \frac{1}{3} \cdot CTDI_{100,\text{center}} + \frac{2}{3} \cdot CTDI_{100,\text{periphery}}\] | \(CTDI_{100,\text{center}}\) is the \(CTDI_{100}\) measured at the center of the standard CTDI phantom and \(CTDI_{100,\text{periphery}}\) is the \(CTDI_{100}\) measured at the periphery of the phantom |
| CTDIvol | \[CTDIvol = \frac{CTDI_w}{\text{pitch}}\] | Pitch is table travel distance per rotation divided by nominal beam width |

**Table 2: Scanning parameters for both axial and helical scans with each CT scanner**

| CT Scanner (number of detector rows) | Collimation (mm) | Rotation Time (sec) | mAs | Axial Scan | Collimation (mm) | Rotation Time (sec) | mAs,eff | Helical Scan | Pitch |
|-------------------------------------|------------------|---------------------|-----|------------|------------------|-------------------|--------|--------------|-------|
| Aquilion 64 (64), Toshiba Medical Systems, Tokyo, Japan | 8 × 0.5 | 1 | 350 | 64 × 0.5 | 1 | 300 | 0.641 |
| LightSpeed VCT (64), GE Healthcare, Milwaukee, Wisconsin | 16 × 0.625 | 2 | 420 | 32 × 0.625 | 1 | 433 | 0.531 |
| LightSpeed Ultra 16 (16), GE Healthcare | 8 × 1.25 | 2 | 400 | 16 × 0.625 | 0.7 | 261 | 0.938 |
| LightSpeed Ultra 8 (8), GE Healthcare | 4 × 3.75 | 2 | 360 | 8 × 1.25 | 0.8 | 256 | 0.625 |
| LightSpeed QX/i (4), GE Healthcare | 4 × 2.5 | 2 | 400 | 4 × 2.5 | 0.7 | 326 | 0.75 |
| Brilliance CT 64 (64), Philips Medical Systems, Best, the Netherlands | 16 × 0.625 | 1.5 | 450 | 64 × 0.625 | 0.5 | 450 | 0.423 |
| MX 8000 IDT (16), Philips Medical Systems | 16 × 1.5 | 1.5 | 400 | 16 × 0.75 | 0.75 | 400 | 0.5 |
| Somatom Sensation Cardiac 64 (64), Siemens, Malvern, Pennsylvania | 12 × 1.2 | 2 | 380 | 20 × 0.8 | 1 | 422 | 0.9 |
of lens dose to CTDIvol during scanning from the orbito-meatal line and from the superior orbital rim were 60.3%–86.1%, and 10.4%–17.8%, respectively.

Discussion
As pointed out in ICRP publication 103,7 some recent studies on radiation lens injuries have indicated much lower dose thresholds than specified by the current radiation-protection guidelines. In a study conducted on atomic bomb survivors by Nakashima et al,5 the threshold doses for cortical cataract and posterior subcapsular cataract were 0.6 Sv and 0.7 Sv, respectively.2 In another study of atomic bomb survivors, Neriishi et al3 reported that the dose threshold was 0.1 Gy for postoperative cataracts. As for protracted radiation exposures, Worugl et al8 investigated cataracts in Chernobyl clean-up workers. Their data indicated that the cumulative dose threshold for cataracts was <700 mGy. Other recent studies of radiation cataracts in airline pilots and astronauts also supported much lower dose thresholds for cataracts than do the guidelines.12,13

Furthermore, the lens of a child is more sensitive to radiation exposure than that of an adult.2,14,15 Wilde and Sjöstrand16 reported a clinical study of radiation-induced lens injuries among patients receiving radium irradiation to treat hemangioma in the eyelid in early childhood (age range, 1.5–13 months). In 13 of 16 untreated eyes with irradiation of 0.04–0.12 Gy, posterior subcapsular opacities (n = 12) or posterior subcapsular cataract (n = 1) was found.

In the current study with multidetector row CT, the lens doses during 1 series of whole-brain CT scans were 50–100 mGy. Considering the data of the above-mentioned recent studies, the cumulative lens doses of several series of CT scans should not be neglected from the viewpoint of radiologic protection. In fact, a population-based study of common age-related eye disease by Klein et al in 199314 showed that nuclear sclerosis and posterior subcapsular opacity were significantly associated with CT scans of the head. Another study of radiation cataracts indicated a significant association between a history of ≥3 diagnostic x-rays to the face or neck and increased risk of cataract.17

The lens dose during brain CT is affected by the type of CT scanner and the scanning settings. Therefore, it is important to estimate the lens dose during brain CT in individual cases in each institution. Bauhs et al10 reported that the CTDI can be used theoretically to estimate the average dose from multiple scans with table increments. However, the dose is not constant along the z-axis in the scanning range of whole-brain CT. During whole-brain CT by using axial scanning, multiple axial scans are needed to cover the scanning range. The dose profile along the z-axis has multiple peaks, according to the number of axial scans.19 Even with helical scanning, the doses near the starting and end points are lower than the dose of the central portion of the scan range along the z-axis. Scatter radiation exists outside the beam width both cranially and caudally. The central portion is exposed by both cranial and caudal scatter radiation. On the other hand, the starting or end point of the scanning receives either cranial or caudal scatter radiation. Furthermore, bow-tie filters affect the dose distribution in the x-y plane.

According to the data of Avilés Lucas et al,11 surface dose decreases as the measurement point moves vertically away from the scanning center. In their study, the surface doses were 83% and 62% at 8 and 12 cm from the scanning center, respectively, compared with the dose at 2.9 cm. Moreover, the homogeneous polymethylmethacrylate phantom for CTDI measurement does not simulate the different tissue types and heterogeneities of a real patient.18 Therefore, CTDI does not generally serve as an accurate estimate of the radiation dose to
a point in a real patient, though it is an index of radiation dose due to CT scans.

In the current study, the ratios of lens dose to CTDIvol were 80.6%–103.4%, and the lens doses tended to be smaller than the CTDIvols during whole-brain CT including the orbit. As mentioned above, scatter radiation decreases at the starting point of the scanning, and the peripheral dose is decreased by the bow-tie filter in the x-y plane. Therefore, the lens doses during the whole-brain CT were probably smaller than the CTDIvols. When the orbits were included in the scanning range, the differences between the lens dose and CTDIvol were within 20% for both helical and axial scans with each CT scanner, with this degree of difference being acceptable for clinical use. Therefore, the lens dose can be estimated approximately by the CTDIvol, when the orbit is included in the scanning range. This method is useful to easily estimate the patient’s lens dose during brain CT on the basis of CTDIvol because the values of CTDIvol are displayed on the monitors immediately after the scanning.

The lens doses decreased as the starting points were set more superiority. The ratios of lens dose to CTDIvol were 10%–20% when the scanning started from the superior orbital rim. These results are in agreement with the work of Smith et al in 1998,19 who measured weighted CTDI values and lens doses during brain CT on phantoms by using single-detector row CT scanners. On the basis of their data, we calculated the ratio of lens doses to weighted CTDIs. The ratio was calculated as 88.4 ± 12.7% during scanning including the whole orbit (baseline: orbitomeatal line or infraorbitomeatal line), while it was 13.9 ± 4.8% during scanning excluding the orbit (baseline: supraorbitomeatal line).

Considering the lens dose during brain CT scans and the above-mentioned uncertainty about the risk of radiation lens injuries, we believe that the exposure to the lens during brain CT scans should be optimized. For dose reduction, it is fundamental to decrease CTDIvol by optimal selection of scanning parameters. However, this method has a limit, given the above-mentioned uncertainty about the risk of radiation lens injuries for diagnostic x-rays is desirable.

In conclusion, CTDIvol can be used to estimate the lens dose during brain CT scanning, when the orbit is included in the scanning range. It is important to estimate the dose to the lens during brain CT scans and try to reduce it.

References

1. 1990 Recommendations of the International Commission on Radiological Protection. Ann ICRP 1991;21:1–211
2. Nakashima E, Neriishi K, Minamoto A. A reanalysis of atomic-bomb cataract data, 2000–2002: a threshold analysis. Health Phys 2006;90:154–60
3. Neriishi K, Nakashima E, Minamoto A, et al. Postoperative cataract cases among atomic bomb survivors: radiation dose response and threshold. Radiat Res 2007;168:404–9
4. Minamoto A, Taniguchi H, Yoshitani N, et al. Cataract in atomic bomb survivors. Int J Radiat Biol 2004;80:339–45
5. Orate M, Neriishi K, Schull WJ. Cataract in atomic bomb survivors based on a threshold model and the occurrence of severe epilation. Radiat Res 1996;146:339–48
6. Worgul BV, Kundiyev YI, Serjienko NM, et al. Cataracts among Chernobyl clean-up workers: implications regarding permissible eye exposures. Radiat Res 2007;167:233–43
7. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103, Ann ICRP 2007;39(1–4)
8. Jones TR, Kaplan RT, Lane B, et al. Single versus multi-detector row CT of the brain: quality assessment. Radiology 2001;219:750–55
9. Yeoman LJ, Howarth L, Bannister A, et al. Gontry angulation in brain CT: dosage implications, effect on posterior fossa artifacts, and current international practice. Radiology 1992;184:13–16
10. Baush JA, Vrieze TJ, Primak AN, et al. CT dosimetry: comparison of measurement techniques and devices. Radiographics 2008;28:245–53
11. Avilés Lucas P, Castellano IA, Dance DR, et al. Analysis of surface dose variation in CT procedures. Br J Radiol 2001;74:1120–38
12. Raffuson V, Oladsottir E, Hafsteinsdottir J, et al. Cosmic radiation increases the risk of nuclear cataract in airline pilots: a population-based case-control study. Arch Ophthalmol 2005;123:1102–05
13. Cucinotta FA, Manuel FK, Jones J, et al. Space radiation and cataracts in astronauts. Radiat Res 2001;156:460–66
14. Wäde G, Sjöstrand I. A clinical study of radiation cataract formation in adult life following gamma irradiation of the lens in early childhood. I Ophthalmol 1997;81:261–66
15. Chen WL, Hwang JS, Hu TH, et al. Lenticular opacities in populations exposed to chronic low-dose-rate gamma radiation from radiocompeted buildings in Taiwan. Radiat Res 2001;156:71–77
16. Klein BE, Klein R, Linton KL, et al. Diagnostic x-ray exposure and lens opacities: the Beaver Dam Eye Study. Am J Public Health 1993;83:588–90
17. Chodick G, Bekiroglu N, Hauptmann M, et al. Risk of cataract after exposure to low doses of ionizing radiation: a 20-year prospective cohort study among US radiologic technologists. *Am J Epidemiol* 2008;168:620–31
18. McNitt-Gray MF. AAPM/RSNA physics tutorial for residents: topics in CT—radiation dose in CT. *Radiographics* 2002;22:1541–53
19. Smith A, Shah GA, Kron T. Variation of patient dose in head CT. *Br J Radiol* 1998;71:1296–501
20. Task Group on Control of Radiation Dose in Computed Tomography. Managing patient dose in computed tomography: a report of the International Commission on Radiological Protection. *Ann ICRP* 2000;30:7–45
21. Lai KF, Cheung YK, Tan CB, et al. Lens exclusion in computed tomography scans of the brain: the local practice. *J HK Coll Radiol* 2001;4:181–84
22. Perisinakis K, Raissaki M, Theocharopoulos N, et al. Reduction of eye lens radiation dose by orbital bismuth shielding in pediatric patients undergoing CT of the head: a Monte Carlo study. *Med Phys* 2005;32:1024–30
23. Hopper KD, Neuman JD, King SH, et al. Radioprotection to the eye during CT scanning. *AJNR Am J Neuroradiol.* 2001;22:1194–98
24. Demura S, Yamaji S, Nakada M, et al. Prediction equation for head volume of Japanese young adults. *J Sports Sci* 2005;23:541–48
25. Shrimpton PC, Jones DG, Hillier MC, et al. Survey of CT practice in the UK. Part 2. Dosimetric aspects. In: National Radiological Protection Board, Report NRPB-R 249. London, UK: HMSO; 1991
26. Moss M, McLean D. Paediatric and adult computed tomography practice and patient dose in Australia. *Australas Radiol* 2006;50:33–40