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ORIGINAL RESEARCH

Comparison of Eye Lens Dose on Neuroimaging Protocols between 16- and 64-Section Multidetector CT: Achieving the Lowest Possible Dose

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BACKGROUND AND PURPOSE: To our knowledge, there has been no study that compares the radiation dose delivered to the eye lens by 16- and 64-section multidetector CT (MDCT) for standard clinical neuroimaging protocols. Our aim was to assess radiation-dose differences between 16- and 64-section MDCT from the same manufacturer, by using near-identical neuroimaging protocols.

MATERIALS AND METHODS: Three cadaveric heads were scanned on 16- and 64-section MDCT by using standard neuroimaging CT protocols. Eye lens dose was measured by using thermoluminescent dosimeters (TLD), and each scanning was repeated to reduce random error. The dose-length product, volume CT dose index ($CTDI_{vol}$), and TLD readings for each imaging protocol were averaged and compared between scanners and protocols, by using the paired Student *t* test. Statistical significance was defined at $P < .05$.

RESULTS: The radiation dose delivered and eye lens doses were lower by 28.1%–45.7% ($P < .000$) on the 64-section MDCT for near-identical imaging protocols. On the 16-section MDCT, lens dose reduction was greatest (81.1%) on a tilted axial mode, compared with a nontilted helical mode for CT brain scans. Among the protocols studied, CT of the temporal bone delivered the greatest radiation dose to the eye lens.

CONCLUSIONS: Eye lens radiation doses delivered by the 64-section MDCT are significantly lower, partly due to improvements in automatic tube current modulation technology. However, where applicable, protection of the eyes from the radiation beam by either repositioning the head or tilting the gantry remains the best way to reduce eye lens dose.

BRAIN ORIGINAL RESEARCH

CT examination is a high-radiation-dose imaging technique using x-rays. Radiation has well-known stochastic and deterministic effects on body organs. Studies have shown that exposure to low levels of ionizing radiation even in diagnostic radiologic procedures can cause leukemia and cancers of the thyroid, breast, and lung.[1-4] With rapid increase in CT usage, the risk estimate of cancer has increased from a previous estimate of 0.4% to 1.5%–2%.[5] As radiation gate keepers, radiologists need to practice the "as low as reasonably achievable" principle to minimize health risks associated with ionizing radiation.[6]

Many different types of multidetector CT (MDCT) scanners can be found in the market and even within the same imaging center today. Ideally, all scanning should be performed on the most efficient scanner that offers the best image quality at the lowest radiation dose. However, logistic and workflow segregation problems related to infection control may not allow this. To our knowledge, there has been no study to date that compares the radiation dose delivered to the eye lens by 16- and 64-section MDCT for standard clinical neuroimaging protocols. In addition, automatic tube current modulation (ATCM) technology, which strives to maintain constant image quality at the lowest radiation dose, has also improved modern MDCT scanners.[7-10] However, its impact on eye lens dosimetry in neuroimaging scanning is unknown. The purposes of our study were: 1) to compare radiation doses delivered by 16- and 64-section MDCT on standard clinical neuroimaging protocols and 2) to assess the potential implications for patient care.

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Materials and Methods

This study was approved by the institutional review board.

Neuroimaging Protocols

We assessed the following standard neuroimaging protocols used in our department:

1) Brain CT in tilted axial and helical modes, with and without ATCM.

2) Navigational paranasal sinus CT for sinus surgery.

3) Temporal bone and orbital CT.

The CT parameters are listed in Table 1. CARE dose refers to the ATCM technology on Siemens CT scanners (Siemens Medical Solutions, Forchheim, Germany).[7,8] ATCM on CT scanners enables automatic adjustment of tube current in the x-y plane (angular modulation) or along the z-axis (z-axis modulation) based on size and attenuation characteristics of the body part being scanned. The ATCM software on our 16-section MDCT uses only angular modulation, whereas that on the 64-section MDCT uses both angular and z-axis current control. ATCM software is available in MDCTs offered by various vendors using different techniques and nomenclature, for

Table 1: Standard clinical head and neck CT protocols used with the CT parameters

CT Protocol*	MDCT†	CARE Dose‡	Set mAs	Effective mAs	Tube Voltage (kV)	Section Collimation (mm)	Beam Width (mm)	Rotation Time (s)	Kernel	Pitch	No.
Brain (tilted axial mode)	16	+	400	360	120	5	12	1.0	B31f/cerebrum	NA	1
		−	400	NA	120	5	12	1.0	B31f/cerebrum	NA	2
Brain (helical mode)	16	+	400	394	120	0.75	12	0.75	B31f/cerebrum	0.6	3
		−	400	NA	120	0.75	12	0.75	B31f/cerebrum	0.6	4
	64	+	400	266	120	0.6	19.2	1.0	B31f/cerebrum	0.8	5
		−	400	NA	120	0.6	19.2	1.0	B31f/cerebrum	0.8	6
Paranasal sinus navigation	16	+	200	189	120	0.75	12	0.75	B70fSharp/bone	0.6	7
	64	+	200	132	120	0.6	19.2	1.0	B70fSharp/bone	0.9	8
Temporal bone/orbits	16	+	400	385	120	0.6	9.6	0.75	B70fSharp/bone	0.6	9
	64	+	400	355	120	0.6	19.2	15	B70fSharp/bone	0.8	10

Note:—MDCT indicates multidetector CI; NA, not applicable.
* Coverage for CT orbits is similar to that of a CT temporal bone, but a different CT kernel is used.
† 16 MDCT refers to 16-section MDCT scanner and 64 MDCT refers to 64-section MDCT scanner.
‡ CARE dose + indicates that the ATCM program is on; CARE dose − indicates that the program is off.

Table 2: Average eye lens dose for each imaging protocol with $CTDI_{vol}$ and DLP measurements*

CT Protocol	MDCT	CARE Dose	$CTDI_{vol}$ (mGy) (mean ± SD)	DLP (mGy.cm) (mean ± SD)	Eye Lens Dose (mGy) (mean ± SD)	*P* Value	No.
Brain (tilted axial mode)	16	+	63.36 ± 2.18 (60.48, 65.86)	930.50 ± 61.08 (847.00, 988.00)	15.56 ± 4.18 (10.20, 22.50)	NS (.183)	1
		−	67.20 ± 0 (67.20, 67.20)	985.67 ± 32.26 (941.00, 1008.00)	18.14 ± 7.59 (10.60, 36.00)		2
Brain (helical mode)	16	+	83.44 ± 0.42 (83.15, 84.02)	1421.33 ± 94.54 (1301.00, 1512.00)	82.16 ± 13.43 (56.50, 97.90)	NS (.096)	3
		−	84.30 ± 0 (84.30, 84.30)	1449.67 ± 94.43 (1319, 1517)	88.83 ± 13.47 (65.30, 102.60)		4
	64	+	36.77 ± 1.76 (35.31, 39.34)	601.33 ± 47.48 (559, 669)	47.18 ± 5.99 (36.2, 60.0)	<.000	5
		−	53.33 ± 0.06 (53.30, 53.46)	870.83 ± 32.00 (831, 909)	63.90 ± 7.74 (49.10, 75.90)		6
Paranasal sinus navigation	16	+	40.57 ± 0.66 (39.42, 41.14)	563.67 ± 28.24 (524, 595)	45.90 ± 2.65 (40.3, 50.00)	<.000	7
	64	+	20.69 ± 0.77 (19.96, 21.82)	301.83 ± 7.11 (289, 310)	28.96 ± 3.35 (22.80, 35.30)		8
Temporal bone/orbits	16	+	102.86 ± 7.08 (92.71, 109.31)	483.33 ± 48.84 (424, 541)	98.58 ± 9.03 (83.00, 111.7)	<.000	9
	64	+	46.71 ± 2.07 (43.88, 48.59)	298.50 ± 20.97 (270, 318)	53.57 ± 10.07 (39.10, 70.50)		10

Note:—NS indicates not significant; $CTDI_{vol}$, volume CT dose index; DLP, dose-length product.
* The $CTDI_{vol}$, DLP, and eye lens doses are tabulated as mean ± SD with the minimum and maximum values in parentheses. Comparison was made between protocols using the paired Student *t* test, and statistical significance was defined at $P < .05$.

example, AutomA (z-axis modulation; GE Healthcare, Milwaukee, Wis), Real E.C. (z-axis modulation; Toshiba Medical Systems, Tokyo, Japan), and DoseRight dose modulation (angular modulation; Philips Medical Systems, Best, the Netherlands). Each imaging protocol was performed twice on each cadaver to reduce random error.

Cadaveric CT Imaging

Three frozen cadaveric heads were scanned on a 16-section MDCT (Somatom Sensation 16; Siemens Medical Solutions), and the scanning was repeated by using near-identical parameters on a 64-section dual source MDCT (Somatom Definition; Siemens Medical Solutions). For the purpose of this study, the dual-source MDCT was used in a single-source mode; hence, its performance was essentially the same as that of a 64-section MDCT.[11,12] The volume CT dose index ($CTDI_{vol}$) and dose-length product (DLP) displayed on the console of each CT scanner were recorded during each scanning.

Two lithium fluoride thermoluminescent dosimeters (TLD-100) were taped over the center of each cadaveric eye. Each scanning had a total of 4 TLDs. Each of the 10 scanner-specific imaging protocols (Table 1) had an average of 4 TLDs × 6 cadaveric scans. The brains of the cadaveric heads were previously removed, and the cranial cavities were stuffed with gauze. For some of the neuroimaging protocols, the $CTDI_{vol}$ and DLP values from 6 clinical cases performed by using near-identical parameters were also collected for comparison.

TLD Dosimetry

Calibration and reading of the TLD-100 chips were performed with a Harshaw 3500 (Thermo Fisher Scientific, Waltham, Mass) system. Using a fixed calibrated dose of 1 Gy from a 6MV photon beam output of a linear accelerator (21EX, Varian Medical Systems, Palo Alto, Calif), we irradiated each TLD chip and calibrated it individually for its glow curve response to 1 Gy. The energy sensitivity of the TLD chips for use in the diagnostic range of 120 kV is small (~8%). This was not thought to be significant because the main focus of the study was the relative comparison of doses by using near-identical imaging protocols.

To prepare each TLD for irradiation, we performed annealing at 400°C. After irradiation, annealing was done at 100°C to remove short-lifetime peaks. This allowed for a more stable and predictable dose-output reading. The TLD-100 chips are characterized by a linear dose response between 0.01 mGy and 1 Gy.

Results

The DLP, $CTDI_{vol}$, and lens doses for each imaging protocol are detailed in Table 2 and graphically summarized in Fig 1. The DLP, $CTDI_{vol}$, and eye lens dose delivered by the 64-section MDCT were consistently lower than those delivered by the 16-section MDCT ($P < .000$, using a paired Student *t* test) on near-identical CT neuroimaging protocols by using the helical mode (Table 2). The differences in radiation dose varied from 28.1% to 45.7% for the various CT protocols.

For CT brain scanning, the tilted axial mode on the 16-section MDCT yielded the highest dose reduction, despite dose savings with ATCM on the 64-section MDCT (Table 3). On the 16-section MDCT, there were no significant dose dif-

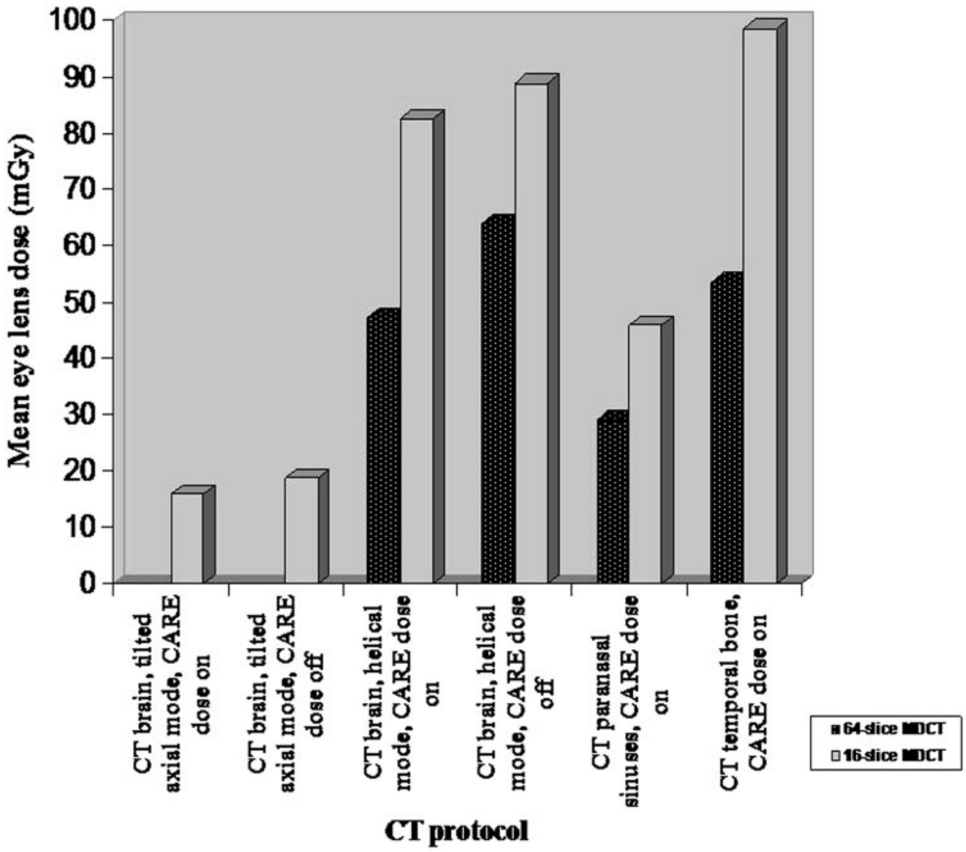

Fig 1. Graphic comparison of mean eye lens dose between 16-section and 64-section MDCT for the neuroimaging CT protocols studied.

Table 3: Comparison of eye lens dose savings on CT brain protocols using ATCM between titled axial-versus-helical modes and 16-section-versus-64-section MDCT

CT Brain Protocol*	MDCT	CARE Dose	Mean Eye Lens Dose (mGy)	Dose Savings (%) (*P* value)	Protocol No.
Tilted axial	16	+	15.56	81.1 (.000)	1
Helical			82.16		3
Tilted axial	16	+	15.56	67.0 (.000)	1
Helical	64		47.18		5
Helical	16	+	82.16	42.6 (.000)	3
	64		47.18		5

Note:—ATCM indicates automatic tube current modulation.
* Comparison was made between protocols using the paired Student *t* test, and statistical significance was defined at $P < .05$.

ferences with or without ATCM, on either the tilted axial or helical mode (Table 2).

Among the protocols studied, the temporal bone and orbit CT scans delivered the greatest radiation to the eye lens.

Comparison of the $CTDI_{vol}$ and DLP values between our cadaveric study and clinical cases is tabulated in Table 4. As can be seen from the table, the relative dose difference between the protocols on the 16- and 64-section MDCT was fairly comparable.

Discussion

Rapid advancement in MDCT technology outstripping scanner life spans has led to a wide range of MDCTs available. Increasing the number of detector rows brings with it the benefits of shorter scanning acquisition time and better image and temporal resolution. The effect on radiation dose is, however, less well established. In a phantom study comparing radiation dose on 4-, 8-, and 16-MDCT for chest CT, it was observed that there was a trend toward a decreasing radiation dose with an increasing number of detector rows. However even though statistical significance was shown between the 4-section MDCT and the 16-section MDCT, there was no statistically significant difference between the 8-section MDCT and the 16-section MDCT.[13] Articles comparing radiation exposure between single-detector CT and MDCT have shown an increase in radiation exposure in the latter.[14,15]

Some of the reasons for the difference in radiation doses in our study may be related to the presence of an additional narrow-shaped filter specifically for head applications in the 64-section MDCT, smaller penumbra of the radiation-dose profile in the 64-section MDCT, and differences in the ATCM technology on the scanners. ATCM aids in radiation-dose optimization by allowing adjustment to the tube current according to the size and attenuation characteristics of the body re-

Table 4: Comparison of $CTDI_{vol}$ and DLP values between cadaveric cases and clinical scans*

			Cadaveric Cases		Clinical Cases	
CT Protocol	MDCT	CARE Dose	$CTDI_{vol}$ (mGy) (mean ± SD)	DLP (mGy.cm) (mean ± SD)	$CTDI_{vol}$ (mGy) (mean ± SD)	DLP (mGy.cm) (mean ± SD)
Brain (tilted axial mode)	16	+	63.36 ± 2.18	930.50 ± 61.08	59.56 ± 2.25	857.00 ± 24.49
Brain (helical mode)	64	+	36.77 ± 1.76	601.33 ± 47.48	39.43 ± 1.30	711.67 ± 35.43
Paranasal sinus navigation	16	+	40.57 ± 0.66	563.67 ± 28.24	40.19 ± 1.01	587.17 ± 60.49
	64	+	20.69 ± 0.77	301.83 ± 7.11	23.37 ± 1.19	334.33 ± 28.79
Temporal bone/orbits	16	+	102.86 ± 7.08	483.33 ± 48.84	104.45 ± 6.78	648.17 ± 132.09
	64	+	46.71 ± 2.07	298.50 ± 20.97	58.34 ± 7.08	487.00 ± 84.38

* Clinical scanning is routinely performed with ATCM. The $CTDI_{vol}$ and DLP values for clinical brain scans acquired in the helical mode on the 16-section MDCT are not available for comparison. This is because the protocol is only used in the rare clinical situation when the tilted axial mode cannot be executed (eg, patients in a cervical collar).

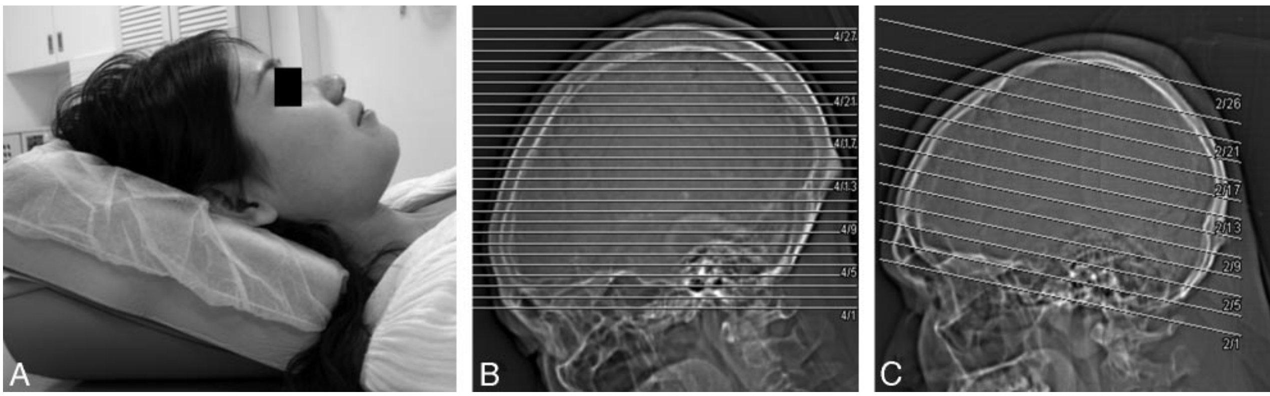

Fig 2. *A*, Photograph of a volunteer; *B*, sagittal scout image with section lines of a patient in the chin tuck position during a CT brain scanning on a 64-section MDCT to remove the eyes from the radiation beam. *C*, Sagittal scout image with section lines for a CT brain scanning in a tilted axial mode on the 16-section MDCT for comparison.

gion being scanned. There are 2 basic techniques involved, namely the angular (x-y axis) modulation and z-axis modulation. The former varies the tube current according to the cross-sectional dimensions of the patient within the imaging section, whereas the latter adjusts the tube current automatically along the length of the patient in the scanning direction.[9,16] The ATCM program on our 16-section MDCT uses only the angular modulation technique and was clearly not effective in dose reduction on brain scanning. The angular and z-axis modulation techniques have complementary roles in minimizing the patient's dose, and their combined use on our 64-section MDCT resulted in significant dose reductions. A study by Mulkens et al[17] showed similar results with the mean effective tube current being significantly lower for the 3D modulation system than for the angular modulation system in the thorax, abdomen-pelvis, and cervical and lumbar spine. To the best of our knowledge, other MDCTs in the industry offer either the z-axis or angular modulation, but not both.

Traditionally, temporal bone and orbital CT scans are well known for delivering the highest radiation dose to the eyes. The lens dose for temporal bone scanning is the highest (98.58 mGy) compared with that in helical brain scanning with (82.16 mGy) or without ATCM (88.83 mGy) on the 16-section MDCT. In fact, the 3D ATCM software on the 64-section MDCT effectively reduced the eye lens dose on a temporal bone CT to such a degree that it was even lower than that from a helical brain scanning on the 16-section MDCT. However, it remains to be seen if diagnostic accuracy is hindered as a result. In essence, this comparison highlights the inherently excessive and unwarranted radiation to the lens on a helical brain scan acquisition.

From a dosimetric standpoint, our results suggest that lens protection should be considered for temporal bone scans on our 16-section MDCT. Use of a bismuth-containing latex shield for lens protection in CT paranasal sinus studies has been shown to reduce the surface radiation dose by 40%,[18] without the loss of diagnostic information, though its impact on temporal bone studies is unknown. Because the orbits are rarely of concern during the interpretation of a temporal bone study and lie a far distance anterior to the middle and inner ear structures, any beam-hardening artifact related to lens protection should theoretically not affect image quality in the region of interest.

On the 16-section CT, there is the option of acquiring CT brain studies in either the tilted axial or helical mode. It is apparent from our results that the tilted axial mode translates to the greatest (81.1%) eye lens dose reduction in CT brain scanning. This is most likely due to total protection of the eyes from the tilted x-ray beam, advances in automatic tube current modulation notwithstanding. This suggests that if logistics allow, all CT brain scanning in an imaging center should ideally be channeled to an MDCT that allows a tilted axial mode of acquisition for the patient's benefit. This is especially so for patients requiring multiple repeat scanning. However, this recommendation has to be weighed against the advantages of multiplanar reconstruction on a helical scanning mode. Tilted axial scanning is not possible on our 64-section MDCT due to the large size of the scanner, which does not permit gantry angulation. Since the conduction of this study, we have solved this clinical issue by positioning the patient's head in a chin tuck/hyperflexed position (Fig 2) for brain scanning performed on our 64-section MDCT. Thereafter, the acquired scan is reconstructed into the more familiar axial plane required for interpretation. We have found this to be effective without compromise to image quality.

There are several limitations in our study. The tissue-attenuation properties of cadaveric heads may differ from those of living human subjects. Because the cranial cavities were emptied of cerebral contents, the eye lens dose for the CT head protocols cannot be used for absolute dose comparisons with those of other publications. However, because the chief purpose of this CT article was dose comparison between different scanners, acquisition modes, and imaging protocols, we thought that absolute eye lens dose was not imperative. In addition, because the lens lies close to the skin surface, we exercised the assumption that entrance surface dose over the center of the eye (as measured with TLDs) was a reasonable estimate of the lens dose. Because dose measurements for CT temporal bone and CT paranasal sinuses without ATCM were not evaluated (due to limited number of TLDs), the exact percentage of dose savings attributed to ATCM versus increasing detector rows is unknown.

Image-quality assessments are beyond the scope of this cadaveric study. However in practice, diagnostic information on scanning performed on our 64-section MDCT has not been compromised despite the radiation-dose savings. To date, there have been no complaints from clinicians, radiologists, or patients regarding image quality since the implementation of the protocols on the 2 scanners in our department. Nevertheless, further studies directly comparing image quality of the scans acquired on the different scanners may be warranted to assess the true benefit of the dose savings.

Conclusions

The increasing availability and widespread use of CT with time has led to more radiation being delivered to the general population and an increased risk of cancer induction. Radiologists need to be aware of the radiation-dose differences on MDCT scanners in their practice and the effectiveness of the ATCM programs on their scanners, to make informed logistic and workflow decisions and to minimize unnecessary radiation exposure to patients. Improvements in ATCM technology combining both angular and z-axis current control results in more effective dose reduction on clinical neuroimaging studies. However, where applicable, protection of the eyes from the radiation beam by either repositioning the head or tilting the gantry remains the best way to reduce eye lens dose.

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