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Review article

Radiation dose from CT scanning: can it be reduced?

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CT has been used to save many patients' lives and the demand for CT is still increasing. At the same time, there has been increasing concern of the probability of cancer induction by CT radiation. It is necessary for everyone involved in CT scanning, particularly physicians who have to communicate with patients when planning a CT scan, to have a basic knowledge of the CT radiation dose and its potential adverse effects. We have undertaken a systematic review of the literatures to document the radiation dose from CT, the lifetime cancer risk from CT exposure, CT dose parameters, the internationnal CT diagnostic reference levels, and the use and limitation of the CT effective dose. In addition, we conducted a brief survey of the use of CT scan in some university hospitals in Thailand and estimated current CT doses at these hospitals. Our review and survey suggests that CT scanning provides a great benefit in medicine but it also becomes the major source of X-ray exposure. Radiation doses from a CT scan are much higher than most conventional radiographic procedures. This raises concerns about the carcinogenic potentials. We encourage every CT unit to adhere to the International Guidelines of CT dose parameter references. Our preliminary survey from some university hospitals in Thailand revealed that CT radiation doses are within acceptable standard ranges. However, the justification for utilization of CT scans should also be required and monitored. The importance of adequate communication between attending physician and consulting radiologist is stressed.

Keywords: Computer Scanning, dose calculation, radiation risk, state of the art in Thai university hospitals

Computer assisted radiologic scanning (CT) is a technology that was first developed in 1972, only four decades ago. It is an enormous advance in medical diagnostics but like most medical advances presents both a financial cost and carries some risks of adverse side effects. Concerns regarding radiation have been rising along with the tendency to also use CT in patients where it is inappropriate and other forms of imaging are more cost-risk-benefit effective. After the development of multi-detector CT (MDCT) in 1998, CT examinations worldwide are increasing in adult and pediatric patients. A significant percentage of these have multiple CT scans [1-4]. CT, as well as conventional radiographs, uses X-ray to create an image. X-ray is ionizing radiation, so it can cause biological adverse side effects [5]. The highest concern is an increasing risk of cancer and with relatively smaller probability for hereditary diseases only when gonads are in direct beam. From available data, it is widely believed that there is no threshold dose for this stochastic type of radiation effect. The other type of radiation effect has a threshold dose (deterministic effect) and can cause redness of the skin, epilation, or desquamation when there is exposure above the threshold level. Opacification of the eye lens and cataract can develop when the orbit-absorbed dose is above the threshold, but this has so far not been documented in patients undergoing CT scan.

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Diagnostic radiology does not usually use a dose that can cause deterministic effects, but it could be found in interventional radiology [6] or cardioangiography [7] or accidentally as an over dose in CT imaging [8]. Radiation used in diagnostic radiology is of low-level and overall the benefits exceed the risks for the patients. Repeated routine chest X-rays and mammography are performed worldwide. However, are we all aware of the higher radiation dose in CT chest comparing to a chest X-ray? Is there an increased risk to develop cancer after having multiple CT scans? If the answer is yes, what are the risks?

The probability of cancer development increases when there is an increasing patient's cumulative radiation dose **(Table 1)**. Conventional radiographs entail a very low risk that one needs not worry about so long as the examination is justified. A single PA-view chest radiograph in adult gives a radiation dose of about 0.02 milli-Sieverts (mSv) to the patient **(Table 2)** [9]**.** However, for a chest CT, the dose is about 7 mSv [9], which is about 350 times that of a chest radiograph. The cancer risk may be estimated, based on a nominal probability coefficient for cancer induction of 5.5% per Sv [10], and can be expressed as a risk ratio for easier communication [11]. For example, if a CT scan of the whole thoracic spine results in an effective dose of 10 mSv, using the cancer risk coefficient of 5.5 % per Sv, the estimated cancer risk will be 5.5×10^{-4}, given a risk ratio of 1 in 1800 [11].

Table 1. Effective dose from diagnostic radiology and the lifetime risk of cancer [12].

Procedure	Effective dose (mSv)	Cancer risk
Radiographs of chest, extremities	< 0.1	1 in 1,000,000
Radiographs of lumbar spine, abdomen IVP CT head and neck	1-5	1 in 10,000
Barium enema CT scans of chest or abdomen Nuclear cardiogram Cardiac angiogram	5-20	1 in 2,000
Radiation from natural background	2.4	1 in 5,000

Table 2. Effective dose from different examinations in diagnostic radiology.

Examination	Average effective dose (mSv)	Examination	Average effective dose (mSv)
Chest X-ray (PA)	0.02	CT chest	7
Chest X-ray (PA and lat)	0.1	CT chest for pulmonary	15
Abdomen	0.7	embolism	
Pelvis	0.6	CT abdomen	8
Skull	0.1	CT pelvis	6
Lumbar spine	1.5	CT three-phase of liver	15
Mammography	0.4	CT skull	2
IVP	3	CT neck	3
Upper GI study	6	Coronary CT angiography	16
Barium enema	8	Virtual colonoscopy	10

Selected data from [9]

Data from survivors of atomic bombing in Hiroshima and Nagasaki [13, 14] were used to create a risk model. Radiation doses from CT are usually lower than the dose to those survivors, but this might not be true when multiple CT scans have been performed. Many reviews in the literature have data relating cancer risk to patients receiving diagnostic radiation [15-19]. These relate to breast cancer and fluoroscopy of the chest in tuberculosis patients, to frequent radiographs of the spine in scoliosis patients, to cancer of salivary glands and thyroid gland and imaging of the head and neck region, and to leukemia related to frequent radiation exposure in children. Linear extrapolation and linear quadratic extrapolation are proposed to predict the solid cancer and leukemia incidence for lower radiation doses [20].

CT scans have become the major source of human exposure to diagnostic X-rays as they represent the highest share of collective doses from medical exposures. This is the reason why there is now concern about the increasing use of CT, particularly in pediatric patients whose tissues are more prone to radiation effects **(Fig. 1)** [21]. CT in children should be performed only when the benefit is clearly above the risk. It must be performed only to the area required, with limited phases of scanning, and with the lowest radiation that still gives diagnostic image quality. There is also a higher risk of cancer in females than in males. This can be explained by smaller female size and different position of radiosensitive organs [23].

In USA, where approximately 72 million CT scans were performed in 2007, it was estimated that approximately 29,000 future cancers would develop [1]. The largest contribution would be from CT abdomen and pelvis, followed by chest CT, head CT, and CT angiography [1]. Approximately 60% of the CT scans were performed in females and two-thirds of the projected cancers would occur in females [1].

We should know whether the CT dose is optimal by looking at CT dose parameters. However, it is confusing when talking about dose parameters because different X-ray modalities have different dose parameters and a single modality may have more than one parameter. Dose parameters for CT are “CT dose index - CTDI” and “dose length product-DLP”.

On newly released MDCT machines, CTDI is displayed on the monitor console, so that the technologists performing the scan will see it before and after the scan. It is also used to detect whether the radiation dose is within the diagnostic reference levels (DRLs). DRLs, using the third-quartile (75 percentile), of the CTDI and DLP values have been proposed as guidelines from the European commission [24, 25]. Many countries have or are going to have CT DRLs of their own [26-29] while others use the DRLs of the European Commission and of the United Kingdom [30] for comparing and adjusting the CT doses **(Table 3)**. However, CT doses seem to be lower in updated reports, because of concern for radiation and advances in CT technology [31]. Technologists and radiologists should produce and interpret images of acceptable quality, not of the highest quality from very high dose scans, which would only increase the radiation dose. Therefore, physicians need to understand that it is not necessary to get the highest quality image, but it is necessary to obtain good enough quality for making a reliable diagnosis and not expose the patient to unnecessary additional radiation and cancer risks.

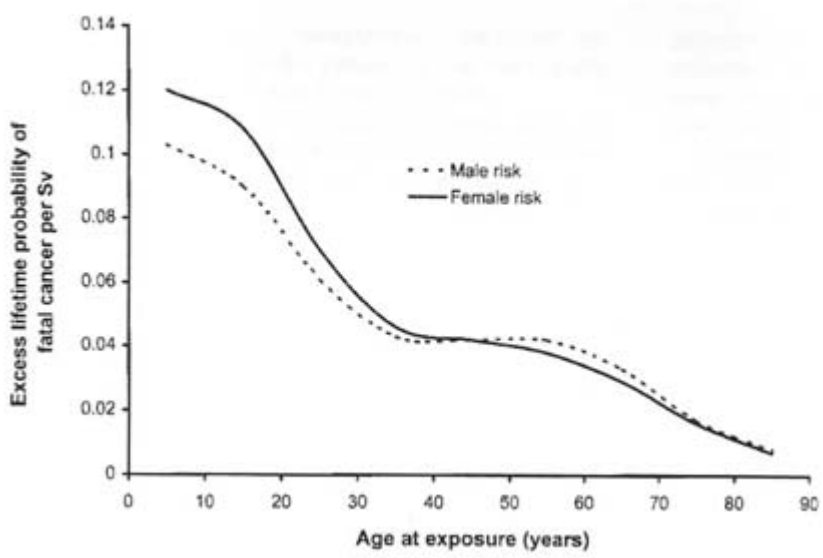

Fig. 1 Age and sex effect on risk of cancer when receiving ionizing radiation [22].

Table 3. Diagnostic reference levels (DRLs) for MDCT in adults.

CT examination	scan region	$CTDI_w$ (mGy)		$CTDI_v$ (mGy)		DLP (mGy cm)	
		UK MSCT	European SSCT	UK MSCT	European MSCT	UK MSCT	European SSCT
Head (acute stroke)	posterior fossa	110	-	100	-	-	-
	cerebrum	65	-	65	-	-	-
	whole exam	-	60	-	60	930	1050
Thorax general	lung	18	30	13	-	-	-
	liver	19	-	14	-	-	-
	whole exam	-	-	-	10	580	650
Thorax HRCT	whole exam	50	35	7	10	170	280
Abdomen (liver metastasis)	whole exam	20	35	14	25	470	900
Abdomen&pelvis (abscess)	whole exam	20	35	14	15	560	780
Chest, abdomen & pelvis (lymphoma)	lung	16	30	12	-	-	-
	abdomen & pelvis	20	35	14	-	-	-
	whole exam	-	-	-	-	940	-

Diagnostic reference level from United Kingdom in 2003 reported in 2006 [30]
Diagnostic reference level from European guidelines published in 1999 [24]

CTDI and DLP are dose parameters for QC. However, for assessment of cancer risks, an individual organ-specific absorbed dose is more appropriate. The effective dose is another dose quantity that is used for protection purposes [32], and it allows comparison across different types of CT studies and between CT and other imaging studies. So it is frequently mentioned in medical literatures.

To obtain the effective dose, there are many methods. It must be understood that most commonly used methods calculate effective dose to a phantom rather than a patient. The most accurate but sophisticated methods need the help of medical physicists. Most of developing countries have not enough medical physicists. The easiest way to calculate the effective dose for practical purpose is to multiply the displayed value of DLP by the conversion factor (conversion coefficient, or effective dose per DLP). The conversion factor is area-specific and age-specific, so we need a set of conversion factors **(Table 4).** However, to make sure of the result, the displayed DLP needs to be verified by the QC process that needs scanning a cylindrical acrylic phantom. These conversion factors are derived from a standard patient size (70kg man), from the estimated radio-sensitivity of each organ (tissue weighting factor), and from the assumed organs being included in the scanning volume. These numbers are estimate valid for a patient matching phantom and thus, will have large error when applied to patients with higher or lower body weight.

Table 4. Conversion factors specific for scanning area and age group [30].

Region of body	Effective dose per DLP (mSv/mGy·cm) by age				
	Pediatrics				Adult
	0 year old	1 year old	5 year old	10 year old	(70 kg)
Head	0.011	0.0067	0.0040	0.0032	0.0021
Neck	0.017	0.012	0.011	0.0079	0.0059
Head and Neck	0.013	0.0085	0.0057	0.0042	0.0031
Chest	0.039	0.026	0.018	0.013	0.014
Abdomen and pelvis	0.049	0.030	0.020	0.015	0.015
Trunk	0.044	0.028	0.019	0.014	0.015

Many authorities worry about the application of the effective dose [11, 21, 32, 33]. They suggest that it is used for reference values for protection purposes, not for detailed assessments of dose and the risk to an individual. As the ICRP revised tissue-weighting factor in 2007, there is a suggestion that DLP to effective dose conversion coefficient should be reassessed because it underestimates the effective dose [34].

The King Chulalongkorn Memorial Hospital (KCMH) performed CT examinations on 1286 patients at 1,402 visits for 1576 scanned areas between June 1 and 30, 2010. Mean age of the patients was 55 years. Males and females were nearly equal. Sixty subjects (4.7%) were under the age of 15.

In 1225 adults with 1504 scanned areas, the five major types of performed CT were whole abdomen (abdomen and pelvis) in 351, chest in 278, upper abdomen in 260, brain without contrast enhancement in 241, and brain with contrast enhancement in 142. These accounted for 84.6% of all CT.

$CTDI_w$ (sequential scan for brain CT), $CTDI_v$ (helical scan for body CT), DLP, and scanning parameters from adult patients between June 1 and 7, 2010 were retrospectively reviewed from Picture Archiving and the Communications System. The effective dose for each type of CT was calculated. The mean values of dose parameters in KCMH were compared to four university hospitals **(Table 5)** in Thailand and DRLs of the UK and European Commission **(Table 6-9).**

Table 5. CT dose data from five university hospitals in Thailand.

Hospital	University	Hospital size (beds)	CT exams in 2009	CT scanners
King Chulalongkorn Memorial Hospital	Chulalongkorn University	1439	15800	Somatom Sensation 4 Somatom Sensation 16
Siriraj Hospital	Mahidol University	2232	31035	GE Light speed Somatom Definition
Maharaj Nakorn Chiang Mai Hospital	Chiang Mai University	1475	16118	Somatom Definition
Srinagarind Hospital	Khon Kaen University	808	13379	Philips 128
Songklanagarind Hospital	Prince of Songkla University	853	17855	Brilliance 64

Table 6. Mean values of CTDI, DLP, and E from CT scan in adult CT brain from five university hospitals in Thailand, comparing with DRLs for MSCT of UK and European commission.

CT brain		A	B	C	D	E	DRLs	
							UK	EC
NC	Number	43	14	10	7	9		
	$CTDI_w$	60/47	59	56	60	45	110/65	60
	DLP	817	998	974	1526	1089	930	
	E	1.7	2.1	2.0	3	2.3		
NC+C	Number	35	5	10	19	27		
	$CTDI_w$	61/47	60	56	60	46		
	DLP	1665	2653	1948	2700	2045		
	E	3.5	5.57	4.1	5.67	4.2		
All	Number	78	19	40	26	36		
	E	2.5	3.0	3.1	5	3.8		

Table 7. Mean values of CTDI, DLP, and E from CT scans in adult CT chest from five university hospitals in Thailand comparing with DRLs for MSCT of UK and European commission.

CT chest		A	B	C	D	E	DRLs	
							UK	EC
C	Number	48	-	14	-	32		
	$CTDI_v$	8.0	-	9.8	-	8.6	13	10
	DLP	306	-	410	-	355	580	650
	E	4.3	-	5.74	-	4.97		
NC+C	Number	11	6	13	19	16		
	$CTDI_v$	8.2	10.11	9.3/11.2	6.6/13.2	11.77		
	DLP	636	711	156/450	718	742		
	E	8.9	10.0	8.5	10.1	10.4		
All	Number	59	6	27	19	48		
	E	5.1	10	7.1	10.1	6.8		

Table 8. Mean values of CTDI, DLP, and E from CT scans in adult CT upper abdomen with intravenous contrast material from five university hospitals in Thailand comparing with DRLs for MSCT of UK and European commission.

CT upper abdomen		A	B	C	D	E	DRLs	
							UK	EC
	Number	70	24	33	43	16		
Venous phase	$CTDI_v$	12.4	13.8	11.7	15.6	10.4	14	25
	DLP	380	395	323	-	316	470	900
	E	5.7	5.9	4.8	-	4.7		
No. of phases		3.4	2.7	3.5	2.8	3.1		
Whole exam	DLP	1294	1132	1011	1149	1064		
	E	19.4	17	15.2	17.2	16.9		

Table 9. Mean values of CTDI, DLP, and E from CT scan in adult CT whole abdomen from five university hospitals in Thailand comparing with DRLs for MSCT of UK and European commission.

CT whole abdomen		A	B	C	D	E	DRLs	
							UK	EC
	Number	77	3	63	39	77		
Venous phase	$CTDI_v$	12.3	13.9	11.9	17.9	11.3	14	15
	DLP	608	600	544	-	552	560	780
	E	9.1	9	8.2	-	8.3		
No. of phases		3.5	3	2.4	2.7	2.65		
Whole exam	DLP	1662	1507	971	1742	1131		
	E	24.9	22.6	14.7	26.1	18.4		

These data show a wide range of CT doses between hospitals in Thailand for each type of CT scan. The effective dose of CT brain ranges from 2.5-5 mSv, CT chest from 5.1-10.1 mSv, CT upper abdomen from 15.2-19.4 mSv, and CT whole abdomen from 14.7-26.1 mSv.

With multiple scans to the same area (pre contrast and post contrast scans) in one examination, the patient dose increased to double when the same scanning parameters and same scan length were used. Single series of non-contrast CT brain may be adequate for patients with specific clinical indications. This was applied in more than half of CT brains in Hospitals A and B. As non-enhanced CT chest usually gives inadequate information, Hospitals A and E prefer post enhanced CT chest, and Hospital C performed a limited length of pre contrast scan to reduce the unnecessary radiation.

The high total dose is more obvious with CT abdomen, where the scanning area is long (25 cm for upper abdomen and 45 cm for the whole abdomen). There is a high conversion coefficient (many organs with high tissue weighting factors in the abdomen) and multiple phases of scanning (depending on clinical query). The high dose setting is seen in high CTDI of CT abdomen in Hospital D. Multiphase scan explains high dose for CT abdomen in Hospital A.

Comparing dose parameters in Thailand to DRLs from the UK and European Commission, we found that mean CTDI values in Thailand were not above their level. However, mean DLP value of some types of CT scanning in many hospitals was above the levels. This is likely from greater extension of the scan length. Orbits and maxillary sinuses are mostly included in brain-scanned areas including the sensitive eye lenses.

Patient's information is a necessary part in planning a proper CT scan, particular the numbers of scanning phases. Discussion between physician and radiologist beforehand may obviate unnecessary scanning phases or may move the patient to another more appropriate imaging modality. With inadequate communication between attending doctor and radiologist, there is a tendency to over scan, because the radiologist does not want to miss an important finding or to reschedule the patient for additional scanning.

CT dose data in this article were limited to five university hospitals but showed substantial variation in doses across institutions. The authors suspect that results would be even more variable if hospitals of Ministry of Public Health and private hospitals were included in this survey. This implies need for optimization to ensure that patients are given only the dose required for obtaining image of diagnostic quality and no more.

CT parameter settings in Thailand are usually performed by specialists trained from CT vendors with the acceptance of image quality by radiologists as a foremost consideration. General radiologists may have limited knowledge regarding radiation dose calculation. A national survey of the condition of the CT scanners and patient dose data by the authorized agency (Department of Medical Sciences, Ministry of Public Health) is needed. Medical physicists in diagnostic radiology are not readily available, even in some university hospitals. Radiology professional organizations, such as the Royal College of Radiologists, Society of Medical Physicists, and Society of Radiological Technologists, should take part in continuing educational courses and help to standardize CT dose throughout the country as well as assure quality of the machines. Above all, the inappropriate utilization of CT for diagnosis that can be arrived by other methods must be discouraged.

Conclusion

CT scanning provides a great benefit in medicine but it also becomes the major source of X-ray exposure. Radiation doses from a CT scan are much higher than most conventional radiographic procedures. This raise concerns about the carcinogenic potentials. Therefore, we encourage every CT unit to adhere to the International Guidelines of CT dose parameter references. It is comforting to learn that the radiation doses of CT scan procedures from some university hospitals in Thailand are within acceptable standard ranges. We encourage the development of a mechanism in every CT unit to ensure that the justification for utilization of CT scans is required and monitored.

The authors have no conflict of interest to report.

Appendix Radiation protection glossary

Radiation dose*	General term applied to the quantity of radiation received by a body where the radiation interacts.
Absorbed dose*	The quantity of energy imparted to unit mass of matter (such as tissue or organ) by ionizing radiation. Unit Gray (Gy). 1 Gy = 1 joule per kilogram.
Equivalent dose*	Different types of radiation have different radiation qualities resulting in different degree of biological damage. Equivalent dose is obtained by multiplying the Absorbed Dose by a Radiation Weighting (quality) factor. Unit Sieverts (Sv).
Effective dose*	Different tissues/organs have different degree of sensitivity to radiation stochastic effect. Effective dose is obtained by multiplying the Equivalent Dose by Tissue Weighting Factor. The resulting quantity can be used to express detriment to the whole body as a summation of several organ doses. Unit Sieverts (Sv). Collective
Collective effective dose*	It is derived from summing the individual effective doses within an exposure population. This quantity has been used to assess overall detriment and therefore as an aid to decision making techniques in optimizing radiation protection.
Tissue weighting factor*	The factor takes account of the different sensitivities of different organs and tissues for induction of probabilistic effects from exposure to ionizing radiation (principally induction of cancer).
Stochastic effect*	It represents radiation harm for which there is no threshold. Even the smallest quantity of ionizing radiation exposure can be said to have a finite probability of causing an effect, and this effect being either cancer in the individual or genetic damage.
Deterministic effect*	It describes ionizing radiation induced damage where a dose threshold exists and for which the severity of damage increases with increasing dose above that threshold. Examples will include radiation burns, hair loss, cataracts, and radiation sickness.
Linear dose response*	Linear dose response in radiation protection relates to the zero-threshold model that predicts that every small addition of radiation exposure contributes to an increment in the probabilistic / stochastic effect. The response relies on the assumption that even one photon has the ability to cause an ionization event in DNA which may initiate cancer (or other genetic effect).
CTDI (CT dose index)**	The CTDI represents the radiation dose of a single CT slice and is determined using cylinder acrylic phantoms of a standard length with diameters of 16 cm and 32 cm. Unit mGy.
$CTDI_w$ (weighted CTDI) **	The $CTDI_w$ reflects the weighted sum of two-thirds peripheral dose and one-third central dose in a 100-mm range in acrylic phantoms.
$CTDI_v$ (volume CTDI) **	The $CTDI_v$ is defined as $CTDI_w$ divided by the beam pitch factor. It is the most commonly cited index for modern MDCT equipment
DLP (dose length product) **	The DLP is the $CTDI_v$ multiplied by the scan length in centimeters. Unit mGy cm.

* http://www.ionactive.co.uk/glossary_search.html (access September 9, 2010)
** http://www.medscape.com/viewarticle/572551 (access September 9, 2010)

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