# The computerized tomography scans and their dosimetric safety

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## Abstract

In recent years the volume of diagnostic procedures involving the use of ionizing radiation has rapidly increased. Technological advances in computed tomography (CT) equipment, with the availability of multi-slice acquisition and the introduction of hybrid systems, have made this modality extremely popular among other diagnostic procedures, especially in pediatrics and as a screening procedure for asymptomatic adults. Physicians' major radiation-related concern regarding diagnostic imaging, is possible iatrogenic malignancy. According to major national and international organizations responsible for evaluating radiation risks, there is no low-radiation threshold for inducing cancer. This means that no amount of radiation should be considered absolutely safe. Although, the risk of radiation-induced cancer is much smaller than the risk of cancer from natural sources, it can become a public health concern if large numbers of the population undergo increased numbers of CT screening procedures that may even be of uncertain benefit. In order to reduce the overall radiation dose from CT procedures in the population, it is important to keep radiation dose as low as reasonably achievable, by adjusting scanner parameters separately for each individual. In addition, it is crucial to eliminate the inappropriate referrals for CT tests and choose other diagnostic modalities, such as sonography, magnetic resonance imaging systems, or nuclear medicine procedures. While CT remains an important diagnostic procedure, it is important for health care community to reconsider the indications of a CT scan, especially in children and asymptomatic patients. Physicians who prescribe CT could assess its use on a case-by-case basis. When used prudently and optimally, CT remains a very valuable imaging modalitiy for both children and adults.

*Keywords:* Computed tomography's usefulness – Radiation absorbed dose – Effective dose – Lifetime cancer risk – Minimizing radiation dose of CT

## Introduction

There is no doubt that computed tomography (CT) is a powerful diagnostic tool. Since CT was first used in the late 1970s, to support medical diagnosis, this modality continues to evolve. A 64-plus-row multi-detector CT and recently the introduction of a 128-slice scanner, produces images of detailed anatomical display even in a 3D model. Results from a 256-slice scanner are also available [1]. Due to these multi slice systems we have obtained a better diagnostic aspect of vascular and cardiac diseases, of perfusion imaging and screening tests mainly for the heart, chest and colon. Additionally, the introduction of hybrid positron emission tomography/computed tomography (PET/CT) and single photon emission tomography/computed tomography (SPET/CT) systems during the last years has increased the number of CT examinations. Radiation risks of performing CT scans must take into account the diagnostic benefit for the patient.

More than half of the diagnostic CT examinations in adults are whole body scans, 75% of them obtained in a hospital setting and 25% in a private practice [2]. The main increase, in the use of CT scans, is in paediatrics [3, 4]. In adults, the major reason for increasing CT tests is screening asymptomatic patients for gastrointestinal [5, 6], pulmonary [7], cardiac [8] and other diseases [9]. The use of CT equipment continues to grow up to 10% or even 15% per year [4, 10].

## Medical and especially CT radiation exposure

Medical radiation exposure contributes about 20% to the overall average annual dose that the population receives from natural radioactivity, derived from earth, food, water, radon and cosmic rays [9]. The importance of radiation-absorbed dose from X-rays from various CT tests has been highlighted lately [11-16]. Dose levels from CT tests surpass those from conventional radiography and fluoroscopy. Unlike radiography, where over-exposure results in blackening of the film, in CT better image quality is obtained with higher exposure. The fact that the same exposure factors are used for children as for adults and for pelvic (high contrast region) as for the abdomen (low contrast region), leads to increased absorbed dose to the patients. In addition, modern helical CT involves scanning a larger volume of the body, with no inter-slice gap, thus delivering higher dose to the patient. Nearly 62 million of CT examinations were performed in 2006 in the USA, both in hospitals and outpatient clinics [17]. Thus, CT contributes a significant portion of the total collective dose delivered to the public from all medical diagnostic procedures.

Spiral CT may administer to patients higher or lower radiation dose, depending on the choice of performance factors. Although it is possible to perform a spiral CT with radiation dose lower than with the slice-by-slice CT, in practice the patient receives higher doses due to the improper factor settings, like the scan volume, the mA used, the pitch (which is the degree of overlap between the adjacent CT "slices"), the slice width etc. In practice multi-slice CT may attribute 10%-30% more radiation dose to the patient than the conventional CT scan [18].

Many doctors including radiologists may think that the modern CT scanners, which are very fast, give a lower radiation dose to the patient. Unfortunately 'speed' and 'radiation dose' are not proportional in these cases. Nowadays, X-ray tubes are becoming more and more powerful in a way that they can produce high bursts of X-rays, and thus accomplish high quality images in a shorter time of exposure.

Organ doses from CT scans are also much higher than those derived from conventional radiographs, as shown in Table 1 [19]. For example, a typical dose to the lung from a conventional chest X-ray ranges approximately 0.01-0.15 mGy, whereas a typical dose to the same organ examined by CT may vary from 10-20 mGy and can be as high as 80 mGy for a 64-slice CT coronary angiography.

**Table 1**. *Typical organ dose from various radiological examinations [19].*

| Examination | Relevant organ | Relevant organ dose [mGy] |
|---|---|---|
| Dental X-ray | Brain | 0.005 |
| PA* chest X-ray | Lung | 0.01 |
| Lateral chest X-ray | Lung | 0.15 |
| Screening mammogram | Breast | 3 |
| Adult abdominal CT | Stomach | 10 |
| Barium enema | Colon | 15 |
| Neonate abdominal CT | Stomach | 20 |
| CT coronary angiography | Lung | 40-100 |

*PA, posterior-anterior

Radiation dose to particular organs from any given CT scan depend on a number of factors: the product of tube current and scan time, the number of slices, the patient's size, the axial scan range, the scan pitch, the maximum tube voltage, the particular scanner design and the applied technique [2]. Most radiologists should be able to adjust the above parameters according to the individual examination type and the individual patient size, in order to get low-noise images using low radiation dose.

The most common and useful method for expressing the dose administered to the patient from CT scans is the "effective dose", which represents an equivalent uniform whole-body dose. The Sievert is the metric system unit of radiation equivalent men dose (1 Sievert = 100 rem). The dose for a CT examination is equal to the dose per slice multiplied by the number of slices. For X-rays exposure, the equivalent dose in Sievert (rem) is numerically equal to the dose in Gray (rad) [20]. Effective dose from CT scans is much higher than from conventional radiography, but comparable to the effective dose interventional fluoroscopic, diagnostic coronary catheterization or some nuclear medicine examinations, as shown in Table 2 [17].

According to EANM/ESC procedural guidelines for myocardial perfusion imaging in nuclear cardiology published in the Eur J Nucl Med Mol Imaging, 2005; 32:855-897, the typical effective dose (mSv) for $^{99m}$Tc-sestamibi myocardial perfusion is, 6-9 and for $^{201}$Tl myocardial perfusion is, 17-34.

**Table 2**. *Typical effective dose (mSv) from common imaging examinations [17].*

| Non-CT effective dose | | CT effective dose | |
|---|---|---|---|
| Hand radiograph | <0.1 | Head CT | 1-2 |
| Dental bitewing | <0.1 | Chest CT | 5-7 |
| Chest X-ray | 0.1-0.2 | Abdomen CT | 5-7 |
| Mammogram | 0.3-0.6 | Pelvis CT | 3-4 |
| Lumbar spine X-ray | 0.5-1.5 | Abdomen and pelvis | 8-14 |
| Barium enema exam | 3-6 | Coronary artery calcium | 1-3 |
| Coronary angiography (diagnostic) | 5-10 | Coronary CT angiography | 5-15 |

The American Association of Physicists in Medicine (AAPM) states that, organ dose from CT tests are well below the threshold for the induction of stochastic effects such as erythema or epilation [16]. Patient radiation risks in CT are therefore those related to carcinogenesis. Ionizing radiation causes numerous types of DNA damage not only by the production of hydroxyl radicals from interaction with water molecules, but also by direct DNA ionization. It is assumed that multiple damaged sites, such as double-strand breaks, are oncogenic [21]. According to the US Food and Drug Administration, medical X-rays are already listed as a known carcinogen [22]. It is widely accepted that the radiation effects may not be evident until 5-20 years after the exposure.

The relationship between dose and lifetime risk of cancer, as far as low levels of low linear energy transfer ionizing radiation like CT radiation is concerned, is controversial. Linear no-threshold model provides the most reasonable description of this relationship. According to this model, the risk of cancer proceeds in linear fashion with no lower threshold [23].

## Estimated risks associated with CT scans

The estimated risks associated with CT are small but not hypothetical. These risks are based on models or major extrapolation of the administered dose. They are also directly based on measured excess of radiation-related cancer rates among children and adults, exposed to the same range of organ doses as those delivered during the actual CT studies. There was a statistically significant increase in the overall risk of cancer in the subgroup of the 1945 atomic-bomb survivors in Japan, who received low doses of radiation. In this subgroup the mean dose approximates the relevant organ dose from a typical CT study involving two or three scans in an adult [24]. The same significant association was also observed in a large-scale study of 400,000 radiation workers in the nuclear industry who were exposed to an average dose of approximately 20 mSv, almost equal to a typical organ dose from a single CT scan for an adult [25, 26]. Radiation risks may also be compared to the risk of heavy smokers to die or the risk of dying in a car accident

[17]. For patients, older than 60 years, the effective dose of a cardiac CT angiogram may be estimated to have a risk comparable to the risk of dying from lung cancer after smoking ~300 packs of cigarettes or the risk of dying in a car accident after driving for ~12,000 miles [27, 28].

Although this risk from a CT examination is very small, it is not zero. A CT examination with an effective dose of 10 mSv may be associated with an increase in the possibility of fatal cancer of approximately 1 chance in 2000, when the natural incidence of fatal cancer in the US population is about 1 chance in 5 [22]. In other words, the risk of radiation-induced cancer is much smaller than the natural risk of cancer. Nevertheless, this small increase in radiation-associated cancer risk of an individual can become a public health concern if large numbers of the population undergo increased numbers of CT screening procedures of uncertain benefit ("collective dose" augmentation). While the benefits of CT are well known in diagnosing diseases and also in the guidance of interventional and therapeutic procedures, these procedures are not without some risk.

Multiple scans present a particular concern. More than one-third of all children having CT scans had at least three scans [14]. Three scans are expected to triple the cancer risk compared to a single scan. Therefore, unnecessary radiation exposure during medical procedures should be avoided. Children have more rapidly multiplying cells than adults and a longer life expectancy. The odds, that children will develop cancer from X-ray radiation, may be significantly higher than adults. Children of less than 10 years of age are several times more sensitive to radiation than middle-aged adults [15, 29, 30].

On the basis of risk estimates and data on the use of CT from 1991 untill 1996, it has been estimated that, about 0.4% of all cancers in the U.S. may be attributed to radiation from CT studies. By adjusting this estimate for current CT use, it may be in the range of 1.5% to 2% [31].

According to Brenner et al. (2007) an asymptomatic 45 years old person who undergoes a full-body CT screening has an estimated lifetime cancer mortality risk of approximately 0.08%. On the other hand, the risk-benefit equation, changes dramatically for adults, who are referred to CT exams for medical diagnosis, because diagnostic benefits are estimated to overweigh the risks [32].

Einstein et al. (2007) stated that the estimated lifetime risk of cancer incidence linked to radiation exposure from a 64-slice CT coronary angiography scan, depends on patients age, sex and the scan protocol. This risk varies from 1 in 143 for a 20 years old woman to 1 in 3261 for an 80 years old man. A computer-simulated ECG-pulsing protocol reduces risk estimates to 1 in 219 and 1 in 5017, respectively [16]. The same ECG-pulsing strategy for a 60 years old woman and a 60 years old man bring down the risk to 1 in 715 and 1 in 1911, respectively. The study across patients groups of both sexes pinpoints the lungs as the organ with the highest lifetime cancer risk and in younger women pinpoints the breasts. It is clear therefore, that risk decreases with age and is higher in women [16].

Benefits of CT scanning are undoubtedly of crucial importance in patient management but radiation risks must also be discussed. Semelka's (2008) most recent communication in his continuing series of articles on Medscape Radiology, aimed at informing everyone about the risk of carcinogenesis from diagnostic radiation, indicates 4 pillars for "doing the right thing" [33]. The first is referring physicians and patients' information, the second is avoiding unnecessary CT scans, the third involves reducing radiation dose for each CT procedure, and the fourth is seeking alternative, non-radiation based imaging when feasible.

In 2004, a survey involving radiologists and emergency-room physicians [34], showed that about 75% of the entire group significantly underestimated the radiation risk from a CT scan; 53% of the radiologists and 91% of the emergency-room physicians did not believe that CT scans increased the lifetime risk of cancer [31]. It is true that nowadays many clinicians refer their patients for CT examinations without knowing the possible effect of medical radiation. Of course the patient should be asked if he or she had undergone other high radiation inducing examinations. Thus, the physician would consider the benefit and risk of a test adding a radiation dose to a patient, especially if the patient had already received several other radiation doses from medical examinations [9]. Such an implementation is not practically feasible, because most patients do not keep medical records. Therefore, as proposed by Professor P. Grammaticos few years ago, it may be practical to issue a "dosage card" for each patient, where every radiation emitting procedure and its specific parameters would be listed [personal communication]. This card would be most useful in the follow-up of the estimated attributable lifetime cancer risk, if issued for every individual on the time of his or her birth. All physicians who prescribe CT should re-evaluate the indications of a CT scan and assess its use on a case-by-case basis, especially when children and asymptomatic patients are concerned.

Major national and international organizations responsible for evaluating radiation risks, agree that there is no low-radiation dose threshold for inducing cancer [22, 29, 30]. This means that no amount of radiation should be considered absolutely safe. In order to reduce the overall radiation dose to the population from CT scans, it is important to keep radiation dose during this procedure as low as reasonably achievable, by adjusting scanner parameters appropriately for each individual patient. Specifically, exposure parameters should be adjusted to the patient's weight and size, as well as, to the region and organ system scanned [29, 30]. Lower mA settings should also be considered for skeletal and lung imaging. On the latest generation of scanners, automatic exposure-control mode option is also helping to reduce the radiation dose to the patient [35]. As far as scan resolution is concerned, there are cases where scans of lower resolution are also diagnostic. Furthermore, the number of scans performed with the use of contrast media materials should be reduced. These multiphase procedures are rarely necessary, especially in the chest and the abdomen imaging, and result in a considerable increase in the absorbed dose. Replacing CT scans, when possible, with non-ionising examinations, such as ultrasonography [36] and magnetic resonance imaging [37] is also of great importance. In some cases, other modalities are just as effective as CT and of much lower radiation. For example, in case of suspected pulmonary embolism in reproductive-age female patients whose chest radiograph is likely to be normal, it is preferable to proceed to a lung perfusion scan with $^{99m}$Tc-macroaggregated albumin ($^{99m}$Tc-MAA), than to a spiral CT [38-40].

*In conclusion*, while CT remains a crucial tool for diagnosis, it is important for the health care community to reconsider the indications of a CT scan, especially when used for children and for screening purposes. Evidently, when a CT scan is justified by real medical needs, the associated risk is small compared to the information achieved [31]. Hence, CT as all other medical procedures involving ionizing radiation should be performed only when a net patient benefit is anticipated. The amount of radiation administered to the patient used should always be kept as low as reasonably achievable-ALARA [17].

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