

Computed tomography and patient risk: Facts, perceptions and uncertainties

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Abstract

Since its introduction in the 1970s, computed tomography (CT) has revolutionized diagnostic decision-making. One

of the major concerns associated with the widespread use of CT is the associated increased radiation exposure incurred by patients. The link between ionizing radiation and the subsequent development of neoplasia has been largely based on extrapolating data from studies of survivors of the atomic bombs dropped in Japan in 1945 and on assessments of the increased relative risk of neoplasia in those occupationally exposed to radiation within the nuclear industry. However, the association between exposure to low-dose radiation from diagnostic imaging examinations and oncogenesis remains unclear. With improved technology, significant advances have already been achieved with regards to radiation dose reduction. There are several dose optimization strategies available that may be readily employed including omitting unnecessary images at the ends of acquired series, minimizing the number of phases acquired, and the use of automated exposure control as opposed to fixed tube current techniques. In addition, new image reconstruction techniques that reduce radiation dose have been developed in recent years with promising results. These techniques use iterative reconstruction algorithms to attain diagnostic quality images with reduced image noise at lower radiation doses.

Key words: Computed tomography; Radiation dose; Iterative reconstruction; Neoplasia; Carcinogenesis

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Core tip: The rapid increase in computed tomography (CT) utilisation has brought with it significant public concern with regards to the doses of ionising radiation delivered during scanning due to the fact that some experimental and epidemiological evidence has linked exposure to low-dose radiation to the development of solid organ cancers and leukaemia. It now seems that a threshold-model of risk might be more appropriate with the risk increasing exponentially once cumulative doses of 100 mSv or more are reached. Nevertheless, there is

an inherent responsibility on the medical community to keep radiation doses “as low as reasonably achievable”. Each imaging procedure needs to be justified and optimised and the minimum radiation dose possible used to obtain a diagnostic CT should remain the goal in each clinical scenario.

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INTRODUCTION

Since its introduction in the 1970s, computed tomography (CT) has revolutionized diagnostic decision making^[1,2]. It has resulted in better surgery, better diagnosis and treatment of cancer, better treatment after injury and major trauma, better treatment of stroke and better treatment of cardiac conditions^[3,4]. CT has many advantages over other imaging modalities in that it can be performed in minutes and is widely available which can allow physicians to rapidly confirm or exclude a diagnosis with improved conviction. It has had a major impact on the field of surgery where it has decreased the need for emergency surgery from 13% to 5% and has almost made many exploratory surgical procedures extinct. The widespread uptake of CT in clinical practice has been shown to decrease the proportion of patients requiring inpatient admission^[5,6]. The progressive year on year technological advances in CT have also helped to make it an increasingly appealing imaging modality with higher spatial resolution and shorter scanning times leading to vastly increased number of clinical applications, *e.g.*, CT colonography, CT angiography, CT urography, *etc.*

Given these advantages, it is no surprise that CT has seen an explosion in its utilization since its inception^[7]. In 2007, it was estimated that around 62 million CT scans were being obtained each year in the United States, compared with around 3 million per year in 1980^[8]. One of the major concerns associated with the widespread uptake of CT is the associated increased radiation exposure incurred by patients. A United States study in 2009 found that CT is now responsible for 75.4% of the effective radiation dose delivered from all imaging procedures, while it accounts for only 11% of X-ray based examinations^[9]. This increased reliance on CT scanning has resulted in the cumulative per-capita effective radiation dose received from medical imaging in the United States to increase almost six-fold between the years 1980-2006^[10] (from 0.5 mSv to 3.0 mSv) and medical imaging is now the largest source of radiation exposure to humans other than natural background radiation^[11] (in 2009, it contributed to over 24% of the United States population’s radiation dose)^[12]. Since

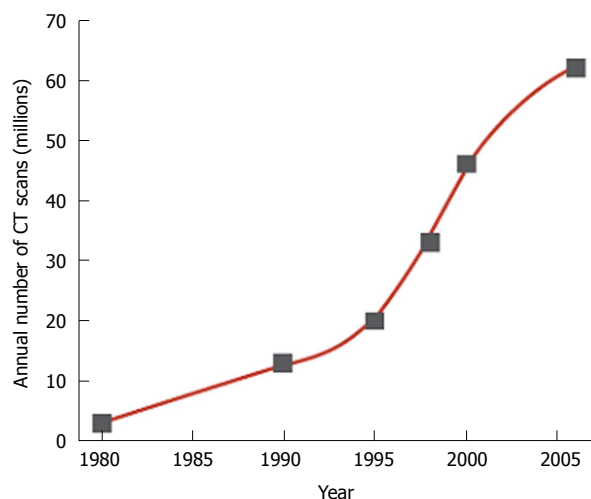


Figure 1 Estimated number of computed tomography scans performed annually in the United States (Image directly from ref.^[22]). CT: Computed tomography.

the mid-1990’s there has been an annual increase of almost 10% in the utilization of CT scanning^[7]. The rapid expansion in the utilization of fluoroscopic and interventional radiologic procedures has also helped to contribute to the increases in ionizing radiation delivered by the medical community^[13,14]. Combine these guided procedures with the potential advent of CT-based screening programs (*e.g.*, CT colonography^[15], CT lung screening^[16]) and there is an expectation that the reliance on CT scanning could continue to increase further in years ahead (Figure 1). This reliance on CT scanning is often further exacerbated by a lack of alternative imaging modalities, especially in smaller centres^[17].

RADIATION EXPOSURE AND CANCER RISK WITH CT SCANNING

The rapid increase in CT utilisation has brought with it significant public concern^[18] with regards to the doses of ionising radiation delivered during scanning given that some experimental and epidemiologic evidence has linked exposure to low-dose radiation to the development of solid organ cancers and leukaemia^[19]. It is widely accepted that large doses of ionising radiation increase the likelihood that an individual will go on to develop cancer during their lifetime but the association between low-dose radiation (of the order used in standard diagnostic examinations) and oncogenesis is unclear. The link between radiation and the subsequent development of neoplasia has been largely based on extrapolating data from studies of survivors of the atomic bombs dropped in Japan in 1945^[20] and on assessments of the increased relative risk of neoplasia in those occupationally exposed to radiation within the nuclear industry^[21]. Using this method of extrapolation where small hypothetical risks are multiplied by huge

patient numbers, Brenner *et al.*^[22] estimated that in the future 1%-2% of all cancers in the United States would occur secondary to the effects of ionising radiation delivered by medical imaging, while a similar study by Berrington de González *et al.*^[23] in 2009 predicted that 29000 additional cancers and 14500 additional deaths could be expected each year.

While there is little dispute that large exposures to ionizing radiation such as are seen in nuclear disasters place an individual at an exponentially increased risk of developing cancer (analysis of the fall-out from the Chernobyl disaster has also highlighted an increased risk in thyroid cancer in those children exposed in utero downwind of Chernobyl)^[24] there is widespread disagreement as to level of cumulative radiation dose delivered by medical imaging which increases the risk of cancer. While many authors argue that a linear no-threshold (LNT) model applies to the association between radiation and oncogenesis^[22,25,26] others argue that a practical threshold exists below which the risks of cancer are no greater than an individual's background spontaneous risk^[27,28]. A recent report has even suggested that exposure of individuals to low-dose radiation may elevate the immune response and thereby protect the individual from cancer, a concept known as hormesis^[29,30]. The assertion that radiation induces cancer is a very broad statement. Particular organ systems are distinctly radiosensitive while others have more robust defences against the effects of ionising radiation. For example, organs such as the oesophagus, breast and bladder are particularly susceptible while organs such as the rectum, pancreas and prostate are much less sensitive^[31].

The validity of the linear no-threshold model has come under even further scrutiny in more recent times^[32]. An analysis of the Radiation Effects Research Foundation (REFR) data (which has followed the victims of the Hiroshima and Nagasaki attacks) compared cancer incidence in these cities with other Japanese cities which were not affected by the nuclear bombings. The group specifically looked at the incidence of colon cancer (commonly used as a cancer indicator in the Japanese population) and found that its incidence was not increased in those who received doses of radiation less than about 100 mSv^[25]. It is suggested that ascribing cancer risks to radiation exposures of less than 100 mSv is confounded by other risk factors for malignancy within an individual population^[28]. The REFR data was more consistent with the threshold-quadratic model of radiation-induced cancer than with a LNT model. Another issue in extrapolating experience of atomic bomb survivors in Japan to those exposed to ionising radiation in the medical setting is the inherent baseline differences in cancer risk amongst Japanese individuals vs populations of a different ethnic distribution (for example, stomach cancer is 10 times more prevalent in the Japanese community compared with United States subject, while breast cancer is three times more prevalent in the United States than in

Japan)^[25].

The linear-no-threshold model was initially adopted to assess radiation risk not because it has a solid biological and scientific foundation but because of its simplicity and its conservative nature (*i.e.*, the model is more likely to over-predict rather than under-predict the neoplastic risk associated with imaging)^[33]. As far back as 1946, when Muller accepted his Nobel Prize for his work investigating genetic mutations in *Drosophila* generated by the effects of X-ray (proposing the LNT model as a basis for predicting oncogenesis), there has been disagreement with regards to this model^[34]. International societies are beginning to doubt its validity. The Health Physics Society concluded that at doses below 50-100 mSv "risks of health effects are either too small to be observed or are non-existent"^[35]. The American Association of Physicists in Medicine supported this view stating that at dosages less than 50 mSv for single procedures and less than 100 mSv for multiple procedures the "predictions of hypothetical cancer incidence and deaths in patient populations exposed to such low doses are highly speculative and should be discouraged". Most tellingly, the United Nations Scientific Committee on the Effects of Atomic Radiation, one of the foremost international authorities on the effects of radiation in health, have also supported this position and have detailed that "statistically significant elevations in risk are observed at doses of 100 to 200 mGy and above" and that at dose ranges less than this no definitive risk can be ascribed to ionising radiation^[31]. Doses of ionizing radiation delivered by common radiological procedures are outlined in Table 1^[36].

While previously it had been insisted that even low doses of radiation were associated with risk of oncogenesis with a linear increase in risk with increased exposure, it now seems that a threshold-model of risk might be more appropriate with the risk increasing exponentially once cumulative doses of 100 mSv or more are reached^[37]. This, however does not negate the danger associated with radiation or allow complacency when deciding on the validity of an indication for a particular scan. In patients with long-term chronic medical conditions, for instance, the requirement for repeated imaging makes them more likely candidates for incurring radiation exposure in the range of > 100 mSv. In a study of Crohn's patients (this patient subgroup have an increased risk of small bowel lymphoma at baseline)^[38] over a 15-year period, it was shown that 16% of these patients had radiation exposure of > 75 mSv^[39] and a similar study assessing maintenance haemodialysis patients found that 13% of this population experienced a cumulative dose of > 75 mSv over a median follow-up of 3.4 years^[40]. In critically ill trauma patients the cumulative effective dose delivered to each patient averages 106 ± 59 mSv^[41] (although in this patient group the risks of avoiding imaging usually far outweigh the potential risk of future malignancy). Given that most CT studies can average at two to three imaging phases per study the doses incurred by each

Table 1 Doses of common radiological procedures

Examination	Average effective dose (mSv)	Values reported in literature
Posterioranterior study of chest	0.02	0.007-0.05
Head CT	2	0.9-4.0
Thorax CT	7	4.0-18.0
CT Pulmonary angiogram	15	13.0-40.0
Abdomen CT	8	3.5-25
Pelvic CT	6	3.3-10
Coronary angiography	16	5.0-32

Annual effective dose from natural background radiation = 3 mSv. CT: Computed tomography.

individual exam can quickly accumulate, especially in the patient with chronic medical complaints requiring ongoing radiologic investigation.

PAEDIATRIC AND FETAL SPECIFIC ISSUES

A simple dismissal of the linear-no-threshold model has engendered controversy since the recent publication of prospective data involving a large cohort study of paediatric patients in the United Kingdom who had undergone at least once CT scan between 1985 and 2002, when they were younger than 22 years of age. This data, albeit within the paediatric population, has been the first to suggest that medical imaging and the associated radiation exposure does indeed predispose to the development of cancer^[42] and that the link is not just a speculative one based on extrapolation from prior disasters or occupational exposure in the nuclear industry. Pearce *et al*^[42] and his team highlighted a linear association between the radiation dose to the brain and brain tumour risk and a similar association between doses received by the bone marrow and the development of leukaemia^[43,44]. The authors chose to follow the incidence of these tumours following radiation therapy as these have been the malignancies which have been observed in irradiated children. These data were validated by the work of Mathews *et al*^[45] who found a 24% increase in cancer incidence in a paediatric population exposed to a CT scan at least one year before a cancer diagnosis and followed up for 9.5 years. While these reports have helped to clarify the situation in the paediatric population the effects of radiation exposure in the adult population is less clear and whether or not this data can be directly applied to adult patients is ambiguous given that: (1) for any given CT examination, the doses delivered to adults is smaller than their paediatric counterparts^[46,47]. The effective dose delivered to a neonate when assessing a particular anatomic site can be double those which an adult will receive for the same investigation^[48]; and (2) children have been shown to have an inherently higher sensitivity to the effects of ionising radiation^[20,48,49].

What is particularly concerning about the findings

of these investigators is that it is within the paediatric population the expansion in CT utilisation is increasing at the most significant rate^[50,51]. For example, between the years of 1991-1994 there was an increase of 63% in the utilisation of CT examinations in children less than 15 years of age^[52]. This has been driven by a decrease in the scanning time for CT which reduces the need for sedation in younger or uncooperative children^[53]. Conversely, despite the risks of radiation exposure in this sensitive cohort, the use of CT has had dramatic benefits in the paediatric population. Between 1990-2007, the expansion in utilisation of CT decreased the negative appendectomy rate from 23% to 1.7% with an associated decrease in the number of operations performed^[54].

While the dangers of radiation exposure in the extremely young have been highlighted by recent population studies the situation with regard to the foetus in pregnant patients remains uncertain. While physicians have been demonstrated to have a poor understanding regarding the risks of imaging in pregnancy^[55,56], this is likely due to the fact that there is no solid scientific evidence regarding the exact dangers. Data in animal studies has demonstrated teratogenicity but the doses used in these studies were much higher than those used in diagnostic scanning^[57]. Studies of individuals exposed in utero at Hiroshima and Nagasaki have demonstrated growth restriction, microcephaly, mental retardation and increased risk of seizures from high dose radiation exposure^[58,59]. While protocols exist which direct the need for scanning in pregnant or potentially pregnant patients these are primarily based on the linear no-threshold model rather than a specifically defined carcinogenic risk^[60-62]. These protocols advocate minimising the radiation dose to which the foetus is exposed and concentrating the dose on the anatomy of interest; for example in suspected appendicitis, the scan volume should be restricted to include only potentially diagnostic areas and dual pass studies should be avoided^[63,64]. Clearly, the use of imaging in pregnancy and particularly the use of CT always evokes enormous anxiety and is usually met with reluctance among radiologists and radiographers/radiology technologists. However, as in all clinical situations balancing of risk vs benefit is required based on best available evidence and considering how diagnostic information which may be gained by imaging may change management and improve clinical outcome vs potential risk to fetus and mother as a result of radiation exposure. The use of ultra-low dose protocols in pregnancy is therefore vital, until higher level evidence is available to inform decisions regarding imaging in pregnancy.

PERCEPTION OF RISK ASSOCIATED WITH DIAGNOSTIC SCANNING

Patient perception

While we know that ionising radiation confers certain

risks to a patient, news media can sensationalise and exaggerate the potential adverse effects of radiation on carcinogenicity^[65] which can induce anxiety in patients, particularly parents of children undergoing investigation^[66,67]. In most instances the benefits of performing CT completely outweigh the potential risks. Medical doctors are increasingly encountering difficult situations when patients refuse CT scanning in clinical scenarios when CT scanning is clearly required; an example of this would be when a patient with newly diagnosed cancer who requires a CT for staging, declines the exam based on perceived risks associated with radiation exposure. Despite media coverage, patient understanding of the exact risks associated with CT scanning can, at times, be poor. Popular media have a tendency to focus on perceived and sometimes sensationalized dangers associated with radiation exposure associated with CT scanning while ignoring the enormous benefits in terms of expeditious and accurate diagnosis. Occasionally, excessive focus or lack of balance in the reporting of very rare incidences of error leading to extremely excessive radiation exposures from CT scanning as happened when it was discovered that one centre had been erroneously exposing patients to radiation doses eight times of normal during CT perfusion scanning^[68].

On the other hand, patients have been shown to underestimate the relative amount of radiation delivered by CT scanning and, surprisingly given media coverage, underestimate the carcinogenic potential of exposure to ionizing radiation. In fact, one study has shown that patients will often have a higher degree of faith in their treating physician if they undergo computed tomography scanning as part of their work-up^[69].

There is no question that there is a requirement for better patient education by imaging providers prior to the performance of CT scans. For example, it has been shown that 93% of adults referred for abdominal CT did not receive any information regarding the potential risks of this procedure and that only 3% of adult emergency patients are even aware of the potential association between CT and carcinogenesis^[70]. Despite the inherent risks associated with paediatric CT^[71] there is often reluctance on the part of physicians to convey the dangers associated with radiation for fear of confusing or upsetting parents with this information^[72]. Striking a balance is difficult as the exact risk associated with radiation exposure in the range associated with CT scanning to patients, and particularly in children is unclear. However, informing parents about the slight risks associated with CT has not been shown to affect their willingness to allow their child to undergo scanning^[73]. A balanced discussion of risks vs benefits with parents about the risks is paramount^[74,75] as pressure is often exerted on physicians by parents encouraging the utilisation of CT in order to expedite diagnosis^[76], without a thorough awareness of the dangers associated with this scanning. There is a need

for multidisciplinary discussion involving experts in many disciplines (including radiology, radiation biology, medical physicist, public health physicians) so that a consensus can be agreed to guide physicians in providing advice to patients of varying ages with regard to risk associated with CT scanning. Proper counselling and education can help parents become more willing to accept a more conservative strategy^[73]. Despite limited knowledge amongst some physicians regarding the carcinogenic potential of CT scanning there are concerted efforts amongst radiologists and physicists to reduce radiation exposure through imaging to patients. Using newer technologies, and strategies such as iterative reconstruction, radiation exposures associated with CT scanning are diminishing incrementally^[77].

PHYSICIAN AND MEDICAL STUDENT PERCEPTION

Difficulty arises when balancing the immediate need for diagnosis with the unlikely potential for harm associated with a CT scan. To this effect, there tends to be a reliance on the individual health care providers to be cognisant of potential dangers and to minimize patient exposure to "as low as reasonably achievable". There can be a lack of recognition from health care workers, however, regarding potential dangers associated with CT. A United States study of health care providers found that less than 50% of radiologists and only 9% of emergency department personnel were aware that there was a potential association between CT and the development of malignancy^[70]. Data have also shown that many physicians are also unaware of the doses of radiation associated with individual examinations^[78,79]. A systematic review on physicians' knowledge of radiation exposure and risk found that there was often a "low level of knowledge and radiation risk awareness"^[80]. An assessment of American paediatric surgeons found that 53% of all respondents thought that the lifetime risk of cancer was increased from exposure to one abdominopelvic CT scan, although 75% underestimated the dose delivered by this scan compared with a chest X-ray. The report also found that the majority of paediatric surgeons did not discuss the potential risks associated with these scans with their patients^[81].

Poor physician awareness has also been observed in the United Kingdom and other parts of the EU^[79], where appreciation of the consequences of radiation exposures was similar to the United States with most underestimating the dose of radiation delivered by common radiological investigations^[78,82]. Similarly, in an Australian cohort of doctors, it has been shown that the "knowledge of radiation exposure from medical imaging is poor"^[83]. It has also been highlighted that not only is there deficient knowledge amongst doctors regarding radiation dose incurred through imaging but that radiation dose is often not considered to be an important consideration when referring for radiological

investigation^[84]. The reasons why there is such a poor understanding amongst clinicians regarding the dangers associated with radiation could be explained by a lack of training at undergraduate and postgraduate level^[85]. It has clearly been shown that there is a lack of awareness at undergraduate level^[86].

Research in the postgraduate population has found that there is often limited focus on radiation safety and radiation protection within training programmes and have highlighted the importance of increased education initiatives in this area, both within radiology and other specialities^[87]. Teaching of radiology at an undergraduate level and delivery of dedicated radiation protection education improves student's awareness.

DOSE REDUCTION STRATEGIES

While we may not be certain as to the exact oncogenic potential of ionising radiation there is an inherent responsibility on the medical community to keep radiation doses "as low as reasonably achievable (ALARA)". Each imaging procedure needs to be justified and optimised and the minimum radiation dose possible used to obtain a diagnostic CT should remain the goal in each clinical scenario. With improved technology, significant advances have already been achieved with regards to radiation dose reduction. The dosage delivered from a combined CT study of the abdomen and pelvis has declined by a factor of between two and three since the 1980s due to a number of different technological innovations^[88]. However despite these technological advances and emphasis on the ALARA principle, radiation exposure has been shown to vary over a tenfold range in clinical practice for the same investigation, depending on variable parameters^[23]. This type of variation can exist both within and between different institutions with wide discrepancies in average dose reported^[89]. While standards and limits exist for health care workers and those routinely exposed to radiation occupationally (*e.g.*, nuclear workers) there is currently no legal requirement for routine monitoring of cumulative effective radiation dose which patients may be exposed to during the diagnostic process^[90-92].

Integration of hospital PACS systems on a national and international level would help to allow cumulative radiation exposure for each patient to be tracked. This type of database is currently being developed by the scanning industry (GE healthcare's Dosewatch[®] system being an example of this). These platforms also allow optimisation tools which can be utilised by both radiographers and radiologists to try to minimise radiation exposure while, at the same time, maximising the clinical information which will be attained by each scan and limiting the risk of duplicating scans which have already been carried out at other institutions. Defined exposure limits can be stipulated for each type of scan and the technology will inform the physician if these pre-defined limits are exceeded. This would also allow departments the opportunity to audit and streamline

Table 2 Methods to try to optimise dose delivered during computed tomography scanning^[3]

Current dose reduction strategies in CT scanning	Dose reduction strategies gaining interest ^[92]
Solid state scintillating detectors	Manual/automated adjustment of scanner output according to patient size <i>via:</i> Tube current modulation; Selection of the most dose-efficient tube potential
Electronic circuits with lower levels of background noise	Iterative reconstruction methods
Multi-detector row arrays	Increased spiral pitch or non-spiral methods in cardiac CT
More powerful X-ray tubes and generators	
Beam shaping filters which vary the X-ray intensity across the patient cross section	

CT: Computed tomography.

their practices. Also, this online collection of radiation dose data associated with imaging procedures, will alert individual departments to sporadic incidences of high radiation exposures and allow immediate action to prevent large cohorts of patients from suffering very high radiation exposures as a result of diagnostic imaging.

Scanning techniques can be optimally adjusted (Table 2) in order to try to achieve an acceptable image at lower exposure level. Dose reduction can be achieved *via* a wide variety of means^[93] as below.

Tube current modulation and automatic exposure control^[94]

Different patients, depending on their size, will all require different radiation doses and the most basic feature which can be modulated in each patient is the tube current^[76]. For example, the amperage utilised in paediatric scanning should be significantly lower than that utilised in their adult counterparts^[95] (and needs to be higher in obese patients). The tube current should be modulated based on the overall attenuation of the anatomic area being assessed^[96]. Other techniques, such as ECG based current modulation can be used to help reduce the dose during cardiac CT^[94,97]. Automatic exposure control, is a relatively new technique, which modulates the tube current during an individual scan based on the different attenuations of different anatomic regions. This also has the added advantage of delivering the optimal dose to achieve the optimal diagnostic image^[98]. Radiologists can define the quantity of noise, which is acceptable to individual clinical scenarios, prior to the scan thus aiding the difficult task of balancing of image quality and radiation exposure.

Strategies to design an ideal tube potential for individual patient sizes and different diagnostic tasks have been published and these have been demonstrated to reduce doses by 70% for the chest and by 40% for the

abdomen^[99]. In the case of cardiac CT, electrocardiographic based tube current modulation can allow doses to be reduced by levels of between 30%-90%^[97]. Further advances using a dual source CT system allows dose reductions by a factor of up to 10-12^[100].

Iterative reconstruction

Iterative reconstruction has been one of the most significant advances in dose reduction technology in CT scanning in recent times. This type of technology, when used in conjunction with or in place of filtered back projection, may improve noise and spatial qualities within the image^[101]. Iterative reconstruction techniques allows images of improved quality to be acquired at significantly lower radiation doses^[102]. As technology and software continues to improve it is likely that iterative reconstruction algorithms will progress concurrently^[103].

Noise reduction filters

This technique has the potential to optimise quality of acquired image by eliminating noise and have been demonstrated to substantially reduce radiation dose^[104,105].

Low dose protocols^[106,107]

Low dose strategies for abdominal CT scanning in children and young adults have been shown to be non-inferior to standard dose CT with respect to negative appendectomy rates^[108,109]. These low dose strategies can use up to four times less radiation than the standard dose protocol.

Spacing of CT slices

Using a large number of thin adjacent CT slices can result in significant increases in radiation dose to the patient. Multi-slice CT scanners also deliver considerably more radiation dose due to scan overlap, positioning of the CT scanner in closer proximity to the patient and increased scatter radiation^[110]. There is therefore an important balance to be met when selecting a slice small enough to achieve the optimal diagnostic image and large enough to ensure that the radiation dose delivered is acceptable^[111].

Maintaining the limits of radiation field within anatomy of interest

All too often during image acquisition in CT the area being scanned includes extra images which are outside the field of original interest. For example, one study found that when assessing the utilisation of abdomino-pelvic CTs that extra images above the diaphragm were obtained in 97% of cases and that images below the symphysis pubis were obtained in 94% of patients^[112]. This equated to an additional 1280 images in 106 patients and while the images provided additional radiation exposure in each patient there was little additional diagnostic information in the majority of these cases. Maintaining the field to only the area of interest can

allow smaller cumulative dosing and potentially improved images *via* focused imaging^[113].

Decision support at the time of ordering a scan

Automated prompts and advice as part of online radiology ordering systems can help to reduce the number of low utility examinations carried out^[114] (one study demonstrated that this type of system can reduce the number of low utility examinations threefold)^[115].

Split bolus techniques for urological studies

Typical CT urography protocols have required multiple image acquisitions to obtain the unenhanced, contrast-enhanced nephrographic, and contrast-enhanced excretory phase images. This method of multiple image acquisition requires a significant radiation burden (quoted between 15-35 mSv)^[116,117]. However, the utilisation of split bolus protocols can significantly reduce this burden and exposes the patient to doses similar to that experienced in standard unenhanced and contrast enhanced abdomino-pelvic CT^[118].

Virtual non contrast CT from dual energy CT

Rational scanning: The strategies outlined above can play a huge role in minimising the dose administered to the patient during various scanning procedures. However, the best dose reduction strategy is to avoid needless scanning. Unfortunately, it has been shown that large numbers of scans are undertaken each year which are lacking in a valid clinical indication^[119]. In fact, it has been suggested that perhaps 20%-40% of all CT scans could be avoided if decisions to scan were based on available guidelines^[120,121]. In the paediatric population it has been shown that one third of all CT scans could be replaced by alternative approaches or not performed at all^[122] and questions have also been raised regarding the routine use of CT for diagnosing appendicitis within the same population, despite its impressive results in reducing negative appendectomy rates^[123]. There is scope for replacing or reducing CT in favour of other diagnostic modalities. Magnetic resonance imaging and ultrasound have the benefit of not exposing the patient to any ionizing radiation but their utility is compromised by availability [in the case of magnetic resonance imaging (MRI)]^[124,125] and image quality (in the case of ultrasound)^[126]. Also in some clinical scenarios, MRI does not offer equivalent diagnostic information when compared to CT. Decision support software programmes which rate the appropriateness of a CT scan as it is ordered by a physician, are difficult to develop, but have shown impressive reductions in the expansion of CT scanning^[114]. Given that between 20%-40% of CT scans are ordered inappropriately as per evidence based guidelines^[127], the introduction of these types of initiatives to encourage physicians to re-assess the clinical necessity for each scan is encouraging. The American College of Radiologists have recognised the need for thorough guidelines to assist physicians in

deciding when particular scans should be utilised^[128]. However, a caveat to the introduction of these types of decision support is that the application of a no-denial policy on radiological imaging, surprisingly, did not result in increased utilisation of imaging modalities^[129].

Of course when imaging is clinically indicated then the benefit-risk balance is almost always overwhelmingly in favour of imaging^[128,130]. However, all too often the decision to image is based on time constraints, medico-legal concerns or patient preference. There is, as yet, no study which attempts to quantify and assess the risk-benefit ratio for radiological investigations and responsibility lies with the referring physician and radiologist^[131]. The need to optimise clinical decision making with regards to imaging therefore needs to be guideline based as this alone has the potential to reduce the influence of convenience factors^[132]. The risk/benefit ratio is individual to each patient. The following factors contribute to oncogenic risk from radiation.

Genetic considerations: Certain populations and individuals may be more radiosensitive and have more of a propensity to develop cancers post radiation exposure^[133]. For example, some patient groups with a genetic abnormality which predisposes to cancer have been shown to be more sensitive to the effects of radiation^[134,135].

Age at exposure: The BEIR VII report demonstrated the relationship between the life-time attributable risk of cancer incidence and age at exposure, showing that the risks of carcinogenesis was much higher the earlier that patient was exposed to high doses of radiation^[21]. Older patients undergo the majority of medical imaging but limited life expectancy reduces risk of radiation induced cancers^[21]. Criteria for imaging in these patients should not necessarily be the same as for those for younger patients with curable disease^[136]. The longer post-radiation life expectancy in the paediatric population allows greater scope for the generation of malignancy and this fact has been borne out by recent population based studies from the United Kingdom^[42] and Australia^[45].

Sex: There appears to be a trend towards a higher incidence of cancer in females post exposure to radiation as opposed to men (even with similar exposures to radiation)^[137].

Illness: Many patients who undergo repeated imaging while being treated for illness likely to reduce life expectancy. Oncogenic effects of this imaging radiation are unlikely to materialise^[136].

Fractionation and protraction of exposure: In general, it is believed that there is a greater risk from high doses of radiation delivered over a short time period in comparison with the same (or lower doses)

delivered over a protracted course due to the influence of DNA damage repair^[138]. However, the influence of the cumulative dose being delivered over a longer period has been suggested to be, surprisingly, small^[139,140].

The reality is that rational scanning will rely on the appropriate knowledge base amongst physicians and trainees. Therefore, the role of education of medical staff, both at undergraduate, postgraduate and even more senior level cannot be underestimated given the shortcomings in knowledge of radiation exposure identified above. These types of educational initiatives have previously shown to be successful in reducing scanning numbers when implemented appropriately^[141].

CT SCANNING: RECOMMENDATIONS FOR THE FUTURE

Clarity regarding the association between radiation exposure and oncogenesis is, as yet, not fully elucidated. However, despite this, the goal when imaging patients should always be to use a dose that is “as low as reasonably achievable”. Imaging, irrespective of the risk, should only be used when the potential clinical benefit outweighs the potential risk. The three fundamental principles of radiation which are laid out by the International Commission of Radiologic Protection include^[142]: (1) justification; (2) dose optimization; and (3) dose limitation.

There is a responsibility to adhere to these fundamental principles. Given that it has been shown that low-dose protocols do not impact diagnostic yield, such protocols need to become the standard^[108]. Recent data has shown that a single scan has low risk but given CT expansion cumulative doses can escalate. The extrapolation of small carcinogenic risks in the individual to cumulative cancer figures in the population is often sensationalized by the popular media resulting in significant distress and anxiety amongst the public, which can make patients and their families reluctant to undergo scans which may be in their best interests.

The future of radiation optimisation will include education of physicians and patients. Such initiatives include the Image Gently[®] and Image Wisely[®] campaigns. Image Gently[®] provides information regarding paediatric population radiation safety to parents and physicians and guides dose optimisation^[143,144]. The Image Wisely[®] campaign promotes radiation safety in the adult population and has developed an honour roll for facilities and associations who have pledged to “image wisely” within their practice^[145]. The Image Gently[®] initiative has been further developed to include specific guidance on paediatric interventional procedures under the title of Step Lightly[®]^[146,147]. In response to the Cedar-Sinai controversy in the United States, the Food and Drug Administration has also launched a national initiative to reduce unnecessary radiation exposure to patients^[148]. It is apparent that physicians are not effectively discussing the potential risks of radiation exposure with

their patients, however small^[149]. When potential radiation dose exposure is substantial, for example, during interventional procedures, radiation risk needs to be a component of consent prior to the procedure. With increased prevalence of radiologic investigations, patient education regarding the risks of radiation exposure needs to be tackled by the medical community in order to accurately convey potential risk. The Interventional Radiology Patient Safety Program among others have issued guidelines resulting in practice modifications where excessive radiation doses were being delivered intra-procedurally^[150,151]. Incorporating audit as standard into radiology departments can also help to decrease the dose delivered to each patient^[152,153] and will also help when discussing these scans with our patients. The establishment of national reference levels for specific CT examinations will allow audit at a local, national and international level^[154-157]. While controversy still exists regarding the exact oncogenic risk associated with CT scanning simply ignoring the issue is not acceptable but audit, education and reassessment are key to improved understanding and safer practices.

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