Do you know the radiation dose your patients receive from your CT scanner?

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Abstract

The number of computed tomography (CT) examinations and new indications for CT are increasing in frequency worldwide. While CT makes up only 4% of medical examinations, it might contribute as much as 40% of the total collective radiation dose to the population. Radiologists and referring clinicians should make sure that the CT examination is indicated. Doses can often approach or exceed levels known to increase the probability of cancer. This is especially relevant in children where dose reductions of up to 80% can be obtained by adjusting the exposure factors. The most important factors are decreased milliampere seconds (mAs) and increased pitch.

Introduction

Part of the work of a radiologist is to advise on the appropriate investigation for specific clinical problems. As radiation workers we are entrusted with the task of assessing whether the benefit from an investigation outweighs the radiation risk involved. Practically, however, most radiologists in clinical practice are not sufficiently aware of the relative risks of the various examinations that they routinely perform. This is understandable given the numerous confusing methods used and quoted in radiation physics. However, there is increasing awareness among clinical colleagues and the public that we should actually know and adjust our practice accordingly. [1-3]

The dangers of radiation have been known since the early days of its usage in clinical medicine. Every attempt should be made to reduce the exposure to harmful and excessive radiation. Most of the legislation is designed to ensure the safety of staff using ionising radiation. While clinicians are obligated to minimise doses administered to patients, strictly speaking there are no dose limits for patients. [4] While large radiation doses can also result from fluoroscopic studies and interventional procedures, this article concentrates on computed tomography (CT) examinations as CT might contribute as much as 40% of the total collective dose to the population, while representing only 4% of the total number of medical examinations. [5,6] In addition, newer CT indications and examinations, e.g. triple-phase liver studies, have also increased the radiation doses when compared with standard CT. [6,7]

None of the authors of this article is a radiation physicist, and this is not intended to be a specialised technical article on radiation protection. The aim of this article is to highlight for all our colleagues the significant radiation doses received by patients (especially children) undergoing CT scans and to discuss practical ways to reduce patient exposure.

Referring physicians should make sure a CT examination is indicated for a child and find out how it will be done. 'Ask: "What factors do you use on adults" and "what will you use on a child?" If they look the same, I would go elsewhere'. [2]
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The basic requirements are to adjust the mAs downward and increase the pitch. That's all there is to it. Get with it! [1]
Lee F Rogers
Editor in Chief
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REVIEW ARTICLE

Discussion

A brief overview of radiation physics

The old units for absorbed dose and absorbed dose equivalent were the rad and rem respectively; the currently used International System (SI) of units are the Gray (Gy) and Sievert (Sv) respectively. One Gray is equal to 100 rad and one Sievert is equal to 100 rem. The Gray is the unit of absorbed dose and is defined as the quantity of radiation that results in an energy deposition of one joule per kilogram within the irradiated material. The Sievert is the unit of absorbed or effective dose equivalent (H_T), and is equal to the absorbed dose in Gray multiplied by a weighting factor. Fortunately for radiologists, the weighting factor for X-rays is one, so for practical purposes a Gray is exactly equal to a Sievert. A Gray or Sievert is a large unit and as most doses received from diagnostic X-ray examinations are in the milliSievert (mSv) range (1 000 mSv = 1 Sv), these smaller units are more frequently used. To add to the confusion, the Sievert is also the unit for effective dose (E) defined as the sum of the absorbed or effective dose equivalents in the various tissues and organs, multiplied by their tissue-weighting factors (w_T), i.e. $E = '\Sigma' w_T \times H_T$. This takes into account the risk associated with a particular radiological examination depending on which organs are irradiated and the dose received by each of them. Though not exactly the same, the effective dose equivalent and effective dose are almost always of the same order of magnitude.[4] Since the above doses are calculated using estimated weighting factors that have been modified over the years by the International Commission on Radiological Protection (ICRP), the values for specific examinations quoted in the literature may not correlate. However, it is acceptable to make broad comparisons using these values.[8] Other frequently quoted comparable units used in radiation protection are air kerma, entrance surface or entrance skin dose with backscatter (ESD) and dose-area-product (DAP). The latter two are relatively easily measured in a radiology department, can be compared with published national guidelines and may well form part of a future quality control programme.[4,8-10] Other units of radiation dose in CT include CT dose index (CTDI), multiple scan average dose (MSAD) and dose-length product (DLP).[5,6,11] To avoid confusion these units will not be used in this article.

An overview of radiation protection

The ICRP guidelines state that a radiation worker should not receive more than 20 mSv per year over a 5-year period, and not more than 50 mSv in any one of those years. In comparison, to put this into perspective, every individual in the population receives approximately 2.5 mSv from background radiation per year from the environment.[4] Table I compares the typical effective dose equivalent (H_T) for several plain film investigations and also expresses them in terms of the number of chest X-rays and length of exposure to background radiation that would give the same dose.[4] This last method, which has been recommended by the United States National Council for Radiation Protection and Measurement (NRCP), is called background equivalent radiation time (BERT) and is useful when explaining radiation dose to a patient.[12]

Radiation doses received in adult radiology

There are a lack of published data on comparable doses for CT examinations. A chest X-ray is the commonest radiological examination (41%) and will be used as the reference value for the following comparisons.[6] The absorbed dose equivalents (H_T) for adult radiographs versus CT examinations are shown in Table II. It can easily be appreciated that the doses

Table I. Comparison of the typical effective dose equivalent (H_T) for several plain film investigations in adults expressed in terms of the number of chest X-rays and length of exposure to background radiation which would give the same dose[4]

Examination	Average effective dose equivalent (mSv)	Equivalent number of chest X-rays	Equivalent length of background exposure (BERT)
Chest	0.05	1	1 week
Skull	0.15	3	3 weeks
Lumbar spine	2.1	42	10 months
Barium enema	7.7	154	3 years 1 month

BERT = background equivalent radiation time.

Table II. Comparison of the typical effective dose equivalent (H$_T$) for several plain film and CT examinations in adults (mSv)[4,6]

Examination	Plain film[4]	CT[4]	CT[6]
Chest	0.05	9.1	7.8
Head	0.2	3.5	1.8
Abdomen	1.4	8.8	7.6
Pelvis	1.2	9.4	7.1

Table III. Comparison of effective doses (E) in mSv for chest radiographs in children

Reference	Examination	Newborn	1 - 4 years of age	5 - 9 years of age	10 - 14 years of age
Staniszewska[13]	AP	0.21	0.18	0.18	0.08
Own data	PA/AP	0.049	0.059	0.055	–
Own data	LAT	0.077	0.083	0.072	–

AP = antero-posterior chest X-ray; PA = postero-anterior chest X-ray; LAT = lateral chest X-ray.

from CT studies are significantly higher than those arising from plain film examinations. A CT of the chest is equivalent to approximately 180 chest X-rays.[4]

Radiation doses received in paediatric radiology

Table III shows the estimated effective doses (E) for chest X-rays in children from a Polish study[13] and from calculations performed at our institution, the Red Cross War Memorial Children's Hospital, using reference sources.[14,15] The typical paediatric postero-anterior (PA) chest X-ray has an effective dose of 0.02 - 0.04 mSv.[16] Our figures are slightly higher, probably as a result of our institution still using a Quanta detailed screen with an Agfa CPM half-speed blue film. An Agfa CPG+ green-screen system is currently being installed and is expected to lower the doses signifi-

cantly. But what about doses received from CT? The United Kingdom National Radiological Protection Board (NRPB) has stated that the effective dose will underestimate the detrimental effect of paediatric exposure by about a factor of two.[8] In addition, a study using abdominal CT showed that the effective dose was 50% higher in children compared with adults.[17] As of early 2001 there are no published reference figures available for children on the effective dose received from CT examinations.[6]

Radiation risks

The risks of low doses of radiation are tumour induction and genetic damage. However, these risks are difficult to calculate. The ICRP estimate of risk of death from fatal cancer of 5% per Sv was extrapolated from the higher doses received by Japanese atomic bomb survivors. The lowest

dose at which there was evidence of deleterious effects in the atomic bomb survivors was 100 mSv, i.e. about tenfold the dose from an adult chest CT scan.[18]

The advent of fast helical CT has been attractive in paediatric examinations where sedation and co-operation are often difficult. This is supported by American data which have shown increases in the number of paediatric CT examinations of 63% between 1991and 1994 and 92% between 1996 and 1999. It has been estimated that the lifetime cancer mortality risk attributable to the radiation exposure from a single abdominal CT examination in a 1-year-old child is approximately 1:550, and approximately 1:1 500 for a head CT examination. To put this into perspective, of the estimated 600 000 children under 15 years old who undergo CT each year in the USA, approximately 140 000 will ultimately die of cancer. The estimated projected 500 CT-related deaths, however, represent about a 0.35% increase over this background mortality.[19]

How to reduce radiation dose in paediatric CT examinations

In CT, patient dose is proportional to the X-ray beam thickness, tube current and exposure time selected for each slice or helical scan, and the number of such exposures per examination. Significant variations have been observed between individual scanners with regard to the typical dose for a given type of procedure: factors of 10 - 40 over all makes of scanners and factors of 5 - 20 when each scanner model was considered separately.[5,20] A low-dose chest CT can be performed at 20 mA rather than

140 - 280 mA.[7] A recent study has shown that low-dose spiral CT of the paediatric chest can reduce the radiation dose to 5 - 20% of standard-dose CT without affecting the image quality.[21] Similar results with reductions in dose of up to 80% have also been reported for high resolution CT scanning (HRCT).[22]

Unlike conventional radiography, CT allows considerable latitude in the exposure required to produce a diagnostically acceptable image. Over- and underexposure in conventional film-screen radiographs are immediately noticed. With CT the pre-programmed adult settings will produce an acceptable image for a child as well as for an adult — the computer will make the necessary adjustments in the post-processing stage.[1,23] These may not be the most optimal milliampere seconds (mAs) settings.[24,25] A review of techniques of paediatric helical CT examinations performed elsewhere and submitted for second interpretation showed that average tube current settings used exceeded those typically suggested for an adult and were not adjusted on the basis of the examination type or the age or size of the child.[26]

The most important factor that can be changed is tube current. A 50% reduction in tube current results in a decrease in radiation dose of 50%. The potential for increased noise caused by decreasing the tube current in younger patients is counterbalanced by the smaller size of these patients.[6,23] Table IV shows suggested tube currents by weight of paediatric patient for a single-detector helical CT. In the uncommon situation where very small lesions may be present, such as in an immunocompromised child with suspected fungal liver disease, the values in Table IV may be increased by 50 mA to decrease noise.[23]

The second most important factor that can be adjusted is pitch. For a one-second gantry rotation (the standard among most CT scanners), pitch can be calculated by dividing the table speed by the collimation width. For example, a table speed of 10 mm/second with a collimation of 10 mm gives a pitch of one. If the collimation was changed to 5 mm, the pitch would change to two. When the pitch is doubled, the radiation dose is reduced by half.[6,23] A recommended standard pitch for paediatric patients is 1.5, which can be increased to 1.7 or 2 for follow-up examinations. A change in collimation (with constant mAs) does not significantly affect radiation dose. A thinner collimation is preferred in children because of their smaller size.[23]

Most children do not need an uncontrasted CT scan when intravenous contrast is going to be given. In addition, inappropriate referrals for CT examinations can also be eliminated and converted to alternative examinations such as ultrasound and MRI.[6,23] CT chest examinations in girls and young females need to be justified in view of the higher risks of radiogenic breast cancer in this age group. CT scans through the base of the skull in children can give high doses to the thyroid and it is preferable to shield this organ. However, when the gonads are not included in the examination field the small dose received is due to internal scatter and hence external shielding is not effective. There are other methods that the manufacturer can use to reduce the radiation dose received during CT examinations, but not many of these have been introduced as yet.[6]

Conclusion

The radiation dose received by patients from CT scans is probably significantly higher than most radiologists realise. Instead of a knee-jerk reaction, of trying to reduce the number of indications for CT scanning, an effort should be made to publicise the fact that a reduction in dosage can be obtained by altering the exposure settings to optimum levels. Ultimately, while CT scanners will always have a significant role to play, advances in ultrasound machines, increased availability of MRI scanners and imaging with ^{18}F-fluorodeoxyglucose positron emission tomography (FDG PET)

Table IV. Suggested tube current (mA) by weight (weights in original table in pounds) for paediatric patients for a single-detector helical CT[23]		
Weight (kg)	Chest (mA)	Abdomen or pelvis (mA)
4.5 - 8.9	40	60
9.0 - 17.9	50	70
18.0 - 26.9	60	80
27.0 - 35.9	70	100
36.0 - 45.0	80	120
45.1 - 70.0	100 - 120	140 - 150
> 70	≥ 140	≥ 170

should result in a reduction in the radiation dose received by everyone — especially children.[25] We hope that this article provokes discussion, a change in day-to-day practice and further investigation into methods to accomplish this goal.

Acknowledgements

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