

CT and Radiation Safety: Content for Community Radiologists

Prepared by:

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Primary Objective: to provide a review of pediatric CT radiation dose and strategies to manage radiation dose.

Additional Objectives: After reviewing this material, the individual will be able to:

1. Understand scope of CT use
2. Be familiar with the basic measures of CT radiation
3. Learn the relevant amount of radiation resulting from CT
4. Be able to discuss the potential cancer risks of CT radiation
5. Know the fundamentals of CT regulation
6. Be able to develop or modify pediatric CT protocols to manage CT radiation dose

Additional Comments:

1. In general CT implies multidetector array CT (MDCT) although much of this material applies to any type of CT equipment.

1. Scope of CT Use

A. Number of exams

- i. Estimates as much as 65,000,000 per year for all ages in the U.S.
 - i. This number does not account for multiphase examinations. For example, a dual phase abdomen and pelvis CT at 5.0 mSv per phase results in a 10 mSv examination (if no parameters are adjusted).
 - ii. If one half of 68,000,000 exams have one phase, then there are 100,000,000 CT exam equivalents (or dose exposures)
 - iii. The number of multiphase examinations at all ages is unknown
 1. One investigation (Paterson, et al AJR 2001) noted that up to 31% of pediatric body CT examinations were multiphase
- ii. Estimates are one CT for every 3.5-10 people per year in the U.S.
- iii. U.S. highest number of CT examinations per year
 - i. Second highest per capita (#1 is Japan)
- iv. Up to 7,000,000 CT examinations per year in children
- v. Rate of growth estimated at about 10% per year
- vi. Some data from Arlington Medical Resources
 - i. indicates 40-50% increase in pediatric CT examinations from 2005-6

- ii. The frequency is fairly evenly distributed at all ages: 33% are performed in children ≤ 10 years of age
 - vii. Current numbers don't necessarily reflect applications over the past few years such as gated cardiac CT and screening in adults
- B. Factors influencing CT use:
- i. Appropriate clinical indications
 - ii. Scientific data
 - iii. Vendor marketing
 - iv. Business pressures: need to offer certain examinations or latest model
 - v. Public expectations
 - vi. Expectations of referring clinicians (facilitate triage and discharge of patients)
 - vii. Teaching Hospital, (high volume of trainees requesting studies, potentially increasing volume of unnecessary exams) Patient and physician expectations of rapid diagnosis and treatment decision

2. Basic Measures of CT Radiation *Absorbed dose*: This term refers to the radiation dose concentration applied to a given unit or volume, in Gray (Gy) (previously rad), and applies to gamma radiation and X-rays. Useful for general risk assessment but not practical for daily CT, because of the interaction among the multiple adjacent slices. 1 Gy = 100 rads; 1mGy = 0.1 rad.

Dose equivalent: This term, expressed in Sievert (Sv) (previously rem) refers to the biological effect of a given type of radiation in relation to the gamma or X-ray, and therefore takes into account the type of radiation; it is expressed as the product of the absorbed dose and a quality factor (Gy x QF). QF depends on the type of radiation (QF = 1.0 for X-ray modalities such as radiography and CT). Therefore, the value for Gy and Sv is equivalent when discussing diagnostic X-ray doses. This unit is useful for risk assessment but not practical for daily CT, as above and is not used much in discussions of medical imaging radiation dose.

Effective dose: This term, sometimes termed the effective dose equivalent, is a method of converting dose to specific organs to an equivalent risk to the whole body dose, as if the whole body had been exposed. Therefore, this dose is calculated by the sum of specific tissue-weighting factors, taking into account the radiosensitivity of each tissue irradiated. This is measured in Sv (or for the CT range of doses mSv) and therefore represents the sum of the individual products of dose equivalents (see above) and a weighting factor for relative susceptibility to radiation of the various organs in the radiation field.

CT dose index (CTDI): This is a measurement of radiation dose based on phantom (32 and 16 cm) analysis at a central point and at 4 points located intermediate from the center and the periphery of the phantom. This measurement takes into account the radiation dose (in mGy) within a slice, which in turn reflects both the specific radiation to that slice, and the additional radiation from detector configuration (penumbra effects) and scatter from adjacent slices. Therefore, CTDI values depend *only* on the selected CT parameters and do not reflect the dose to the individual

patient being scanned. The measure of volume CTDI, or $CTDI_{vol}$, is more standard and takes into account the contribution of pitch in that slice ($CTDI/pitch$). The CTDI for the larger phantom is a lower dose compared with the smaller phantom with constant imaging parameters. If the appropriate CTDI is not displayed when setting up a pediatric CT examination (eg the 32 cm is used for CTDI for an abdomen scan in a 1 year-old), then the estimated effective dose (see below-DLP) may be incorrect (in the example above, it will be underestimated). In general, the CTDI value from the 32 cm phantom can be converted to the 16 cm phantom by multiplying by a factor of two.

Dose length product (DLP): the radiation dose (in mGy-cm) is the product of CTDI and scan length. DLP increases with increased scan distance covered. As discussed above with CTDI, DLP values depend *only* on the selected CT parameters and do not reflect the dose to the individual patient getting scanned; an effective dose to the patient can be estimated using conversion factors (Tables 1, 2)).

3. Relevant amount of radiation resulting from CT

- A. Dose comparisons: See Table 3
 - i. In adults, one abdomen pelvic CT equivalent of 100-250 CXRs
 - ii. This is a reasonable comparison for children as well
 - iii. In multiphase CT, the dose is increased by the multiple of the number of phases (if no parameters are changed)
- B. How much radiation can a CT provide?
 - i. Investigations using anthropomorphic phantoms have shown that a single abdomen pelvis 64-slice MDCT examination with **parameters intentionally selected to maximize dose (e.g. highest mA, highest kVp, low pitch)** can result in an effective dose of more than 100 mSv (10 rem) which exceeds low level radiation and is in the range that has a clearly established risk of cancer
 - ii. New data from NCRP (April 2007) suggest that the amount of radiation contributed from medical imaging (especially nuclear medicine and CT examinations) is substantially higher than previously estimated and may approach background radiation dose ,
 - iii. CT the largest contributor to medical radiation dose in the U.S.
- C. Sources for Dose Estimations:
 - i. Measurements: air measurements do not represent patient dose
 - i. Various websites (eg ImPact: – Imaging Performance Assessment of CT scanners – www.impactscan.org)
 - ii. Effective Dose (ED) method (Shrimpton et al). $DLP \times \text{conversion factor} = \text{effective dose}$
 - i. DLP not well worked out for the spectrum of pediatric sizes
 - ii. DLP does not always reflect true (measured) effective dose

4. Potential Cancer Risks of CT Radiation

- A. What is low level radiation? Under 100 – 150 mSv
- B. Unique considerations in children
 - a. Lifetime to manifest changes

- b. Tissues are more radiosensitive
 - c. For similar CT parameters, the effective dose is higher for smaller cross sections (children) than adults
- C. Radiation dose is cumulative over a lifetime
- D. Most cancer risk discussion with CT is cancer mortality; risk of *incidence* is roughly double this
- E. Risk estimates
 - a. Based on linear, no- threshold model
 - i. This model is considered the best available
 - b. The risk of low level radiation may be zero, but has been reported to be as high as 1:500 in the literature. In general, from a single abdomen pelvis CT a reasonable life-time estimate across the pediatric age group is 1:1,000-2,000.
- F. Risk is higher for females and younger age groups
- G. Organizations supporting potential risk
 - a. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)
 - b. International Commission on Radiological Protection (ICRP)
 - c. National Council on Radiation Protection and Measurements (NCRP)
 - d. Food and Drug Administration (FDA)
 - e. Committee on the Biological Effects of Ionizing Radiation (BEIR) VII:
 - i. "...the risk of cancer proceeds in a linear fashion at lower doses without a threshold and ... the smallest dose has the potential to cause a small increase risk to humans."
 - f. Major radiological societies
- H. Pregnancy
 - a. A single CT abdomen pelvis CT can give up to about 30 mGy (3 rads) (dose to gravid uterus is an organ dose)
 - b. This dose provides essentially no (technically "negligible") risk for abortion, effect on organogenesis, or cognitive function
 - c. Accepting that low-level radiation dose have potential cancer risk (linear, no-threshold model), this dose does have slight risk of cancer in the baby but very low. Dose risks in general considered the same for fetus and baby for low-level radiation
 - d. Dose to fetus from maternal head, neck, or chest CT is negligible

5. Fundamentals of CT Regulation

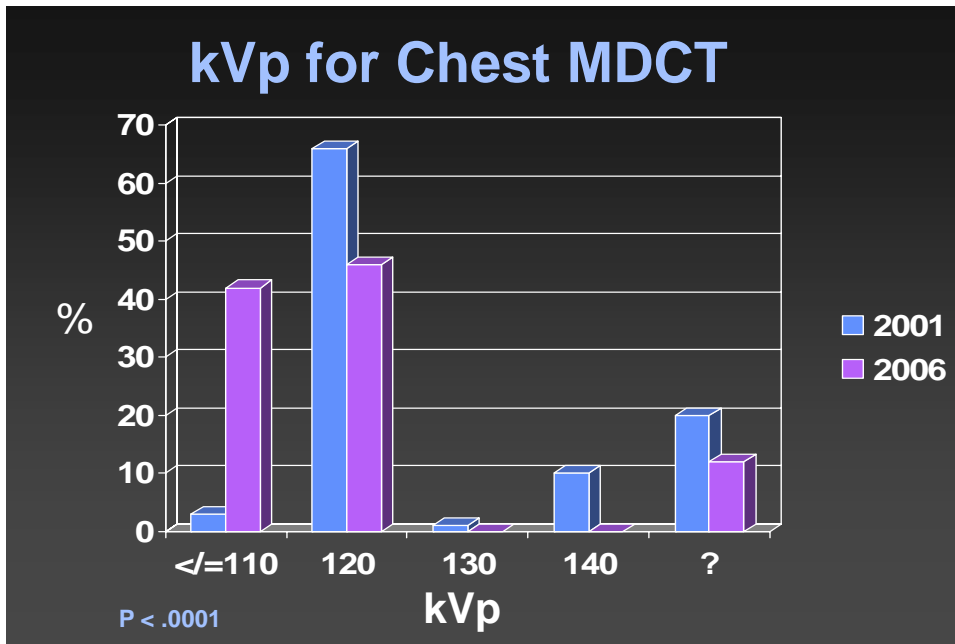
1. Currently no regulation of practice in the U.S.
 - a. FDA only regulates equipment
2. ACR CT accreditation is not as yet uniformly mandatory
3. There is no dose record standard or requirement
4. There is no requirement for manufacturers to display dose profile
5. There are no warning signals for high dose examinations on current scanners

It is therefore important for the radiologist to be aware, not only of the importance of CT in pediatric diagnosis, but also of efficient and appropriate methods for dose reduction.

Has CT Practice Changed in Children?

Limited evaluation but recent data at 2007 Society for Pediatric Radiology Annual Scientific Meeting for surveys of members of the Society indicate that parameters of kVp and mA used between 2001 and 2006 have significantly decreased kVp, and mA for chest and abdomen multidetector CT.

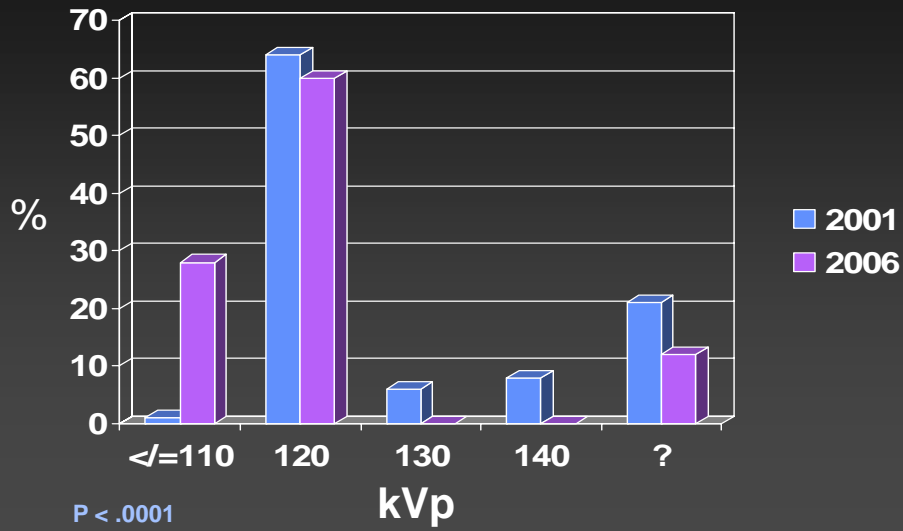
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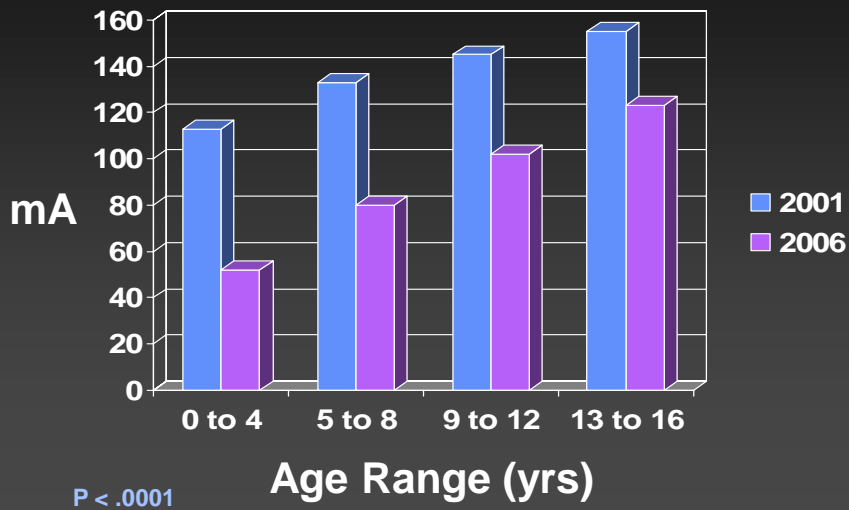
kVp for Abdominal MDCT



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Mean mA for Pediatric Chest MDCT



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Typical Medical Radiation Doses: 5 year-old (mSv)

		<i>CXR Equivalents</i>
• 3-view ankle	.0015	1/14 th
• 2-view chest	.02	1
• Tc-99m radionuclide cystogram	.18	9
• Tc-99m radionuclide bone scan	4 - 6.2	to 310
• FDG PET	15.3	765
• Fluoroscopic cystogram	<.33	16
• Brain CT	2.0	100
• Chest CT	up to 3	150
• Abdomen CT	up to 5	250

TABLE 1

Conversion factors for estimating effective dose from dose length product for adults
(From Brink and Goodman; RSNA Categorical Course in Physics 2006).

Body Part	Conversion Factor (mSv / mGy cm)
Head	0.0023
Chest	0.017
Abdomen	0.015
Pelvis	0.019

Example: if the DLP for an abdomen CT is 300 mGy.cm, then:
Dose estimate : 300 mGy.cm x 0.015 mSv/mGy.cm = 4.5 mSv
Permission Pending RSNA

TABLE 2

Normalised values of effective dose per dose-length product (DLP) over various body regions and (standard) patient age

Region of body	Effective dose per DLP (mSv (mGy cm) ⁻¹) by age				
	0 ^a	1y ^a	5y ^a	10y ^a	Adult ^b
Head & neck	0.013	0.0085	0.0057	0.0042	0.0031
Head	0.011	0.0067	0.0040	0.0032	0.0021
Neck	0.017	0.012	0.011	0.0079	0.0059
Chest	0.039	0.026	0.018	0.013	0.014
Abdomen & pelvis	0.049	0.030	0.020	0.015	0.015
Trunk	0.044	0.028	0.019	0.014	0.015

^aAll data normalised to CTDI_w in the standard head CT dosimetry phantom.

^bData for the head & neck regions normalised to CTDI_w in the standard head CT dosimetry phantom; data for other regions normalised to CTDI_w in the standard body CT dosimetry phantom.

Permission Pending www.msct.eu/CT_Quality_Criteria.htm

TABLE 3

EXAM TYPE	RELEVANT ORGAN	APPROXIMATE EQUIVALENT DOSE TO RELEVANT ORGAN (mSv)
Pediatric Head CT Scan Unadjusted Settings* (200 mAs, neonate)	Brain	60
Pediatric Head CT Scan Adjusted Settings* (100 mAs, neonate)	Brain	30
Pediatric Abdominal CT Scan Unadjusted Settings (200 mAs, neonate)	Stomach	25
Pediatric Abdominal CT Scan Adjusted Settings (50 mAs, neonate)	Stomach	6
Chest X-ray (PA/lateral)	Lung	0.01 / 0.15
Screening Mammogram	Breast	3

* "Unadjusted" refers to using the same settings as for adults. "Adjusted" refers to settings adjusted for body weight.

Permission Pending National Cancer Institute.
<http://www.cancer.gov/cancertopics/causes/radiation-risks-pediatric-CT>

TABLE 4

CT Parameters and Effect on CT Radiation Dose

<u>Variable</u>	<u>Relationship to dose (when other variables held constant)</u>
Tube current	Direct, linear
Gantry cycle time	Direct, linear
Kilovoltage	Direct, non linear
Pitch	Indirect, linear

6. General Strategies for Managing Pediatric CT Radiation Dose (see also specific protocols)

- a. Only perform examinations when appropriate
 - i. encourage clinical colleagues to consult radiologists for appropriateness of CT studies
 - ii. Utilize ACR appropriateness criteria for performing CT scans
- b. Consider other modalities (MR, sonography)
- c. Use multiphase scanning only when appropriate
 - i. Restrict multiphase scanning to body part in question. For example, evaluation of hepatic hemangioma can be restricted to the liver, or to the site of specific lesion.
- d. Adjust techniques based on:
 - i. Indication: For example, repeat evaluations for renal stones, or chest CT for pectus, can be done at much lower CT settings
 - ii. Scan region
 - iii. Size of child. For example, for given CT parameters, radiation dose will be higher in a smaller person or body part; therefore CT parameters can be lowered.
- e. Shielding
 - i. In plane shielding (shielding scanned region eg breast shields for chest CT, thyroid shields for chest and neck CT). Note that the benefit of in plane shielding with automatic tube current modulation will depend on the type of scanner and the technique employed—Coursey et al 2008)
 - ii. Shielding outside of scan field
- f. Automatic exposure control. This is available on many scanners, adjusting in-slice exposure factors depending on patient thickness and attenuation of tissues within the slice.