Pediatric CT doses: where we were and where we are now

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INTRODUCTION

Since the turn of the century, there has been more public and media concerns on pediatric exposure to radiation. Extra effort in addressing those concerns make relevant information available, understandable and rectifiable. All that triggered national debate on the importance of ALARA in imaging, hence the introduction of image gently, image wisely campaigns.
In this presentation we revisit why limiting radiation exposure in children is so important in view of the history of pediatric CT radiation exposure concerns and children elevated risk from radiation as demonstrated in Figure 1 and Table 1. We explain the interventions that took place to address these concerns, and touch on the current school of thought on pediatric CT dose reduction.

BACKGROUND

Early studies showed that the doses being given to children from CT were unnecessarily high because of the suboptimal imaging parameters being used.

After 2003, the medical and industry experts efforts lead to significant CT technology and dose management developments. That included introducing machine specific technique charts and technological innovations like tube current/Dose modulation in 3D., lower kVp, using iterative reconstruction algorithm.

In 2006, formation of the Image Gently Alliance: to raise awareness in the imaging community of the need to adjust radiation dose when imaging children. The AAPM produced machine specific CT protocols based on Vendors feedback.

ACHIEVMENTS

- improvements in CT acquisition chain technology (industry)
- using pediatric-size-based CT protocols (radiology team)
- innovations in image reconstruction algorithms (radiology, vendors)
- study justification for the exam (referring physician)
- dose optimization at the exam time (radiology team)
- dose management, reporting and benchmarking after the exam (radiology team, industry)
- Significant pediatric CT doses reductions dose reductions over the years, Table 1.

Case Comparison 5-year old child dose change over the years: effective doses from pediatric body CT were 33 mSv in 2001 and 9 mSv in 2012.
With advanced dose modulation technology, our results show a 5-year-old effective dose from chest/abdomen CT to be about 0.4 mSv. These figures illustrate the remarkable achievements in pediatric CT dose reduction that have taken place over the years

RESULTS

Table 2 Sample of studies reporting CT scan parameters and effective doses to pediatric patients; note that the YNHH authors reported kV settings of 120, or a median close to 120

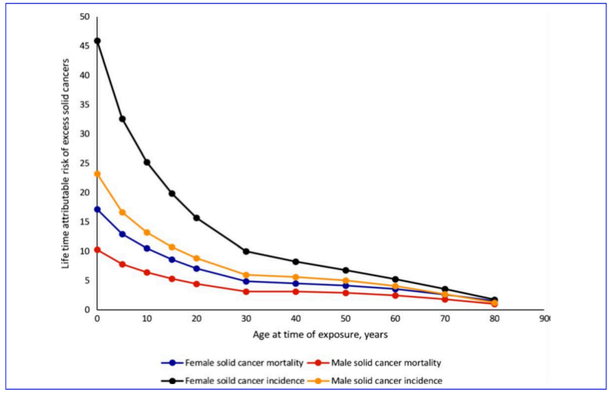
Authors	Age, years	Paterson et al. [23] 2001[a]	Brunner et al. [21] 2001[b,c]	Brunner [14] 2002[b,c]	Huda et al. [48] 2001[d]	Huda & Vance [37] 2007[d]	Hollingsworth et al. [49] 2003[e]	Arch & Frush [50] 2008[e,f]	Bernier et al. [51] 2012[g]	YNHH 2015–2018[b,i]
Head mAs	Newborn	...	Fixed 462 mAs for all age groups	Fixed 340 mAs for all age groups	300	160	...	...	...	31 at 70 kV[j] (120 at 100 kV)[k]
	2	...			...	...	...	...	...	44 at 70 kV[j] (100 at 120 kV)[k]
	5	...			380	200	...	...	...	40 at 80 kV[j] (125 at 120 kV)[k]
	10	...			400	230	...	...	...	42 at 80 kV[j] (125 at 120 kV)[k]
	Adult	...			400	300	...	...	...	80 at 120 kV[j] (275 at 120 kV)[k]
Head CT, effective dose, mSv	Newborn	...	130 (brain)	95 (brain)	6.0	3.6	...	...	1.4	1.17
	2	...			...	...	...	...	1.4	0.911
	5	...	70	52	4.0	...	...	...	1.4	0.9
	10	...	40	29	2.8	...	...	...	...	1.09
	Adult	...	25	18	1.5	0.9	...	...	...	1.9
Abdomen mAs	Newborn	140–300 for age range 0–16 years[l]	Fixed 404 mAs for all age groups	Fixed 240 mAs for all age groups	150	50	125	25–75	...	47 at 70 kV[j] (25 at 80 kV)[k]
	2				...	70	125	25–75	...	85 at 70 kV[j] (25 at 100 kV)[k]
	5				160	75	146	25–75	...	85 at 70 kV[j] (25 at 100 kV)[k]
	10				180	100	161	25–75	...	140 at 80 kV[j] (35 at 100 kV)[k]
	Adult	...			200	190	...	50–100	...	70 at 100 kV[j] (180 at 120 kV)[k]
Abdomen CT, effective dose, mSv	Newborn	...	50	29	5.3	2.5	...		10	0.39
	2	...			...	...	...		9.1	0.43
	5	...	33	19	3.7	...	...		9.1	0.38
	10	...	28	16	3.7	...	...		...	0.93
	Adult	...	22	13	3.1	3.5	...		...	1.36

[a] Reported mA only, no reference to scan time per rotation and no dose estimate
[b] Authors' risk estimates are based on assuming fixed mAs to pediatric and adult patients. Organ doses are approximates obtained from paper graphs
[c] Reported absorbed organ dose in mGy
[d] Calculated from model patient dosimetry and the author institution scan parameters
[e] Obtained from a survey of body CT. No dose reports. Authors assumed scan time 1 s, hence reported mA would be the same as mAs
[f] Recorded mAs in each age group is used for more than 60% of scanned patients
[g] Median effective doses based on Monte Carlo calculations from multi-detector CT

The table compares the evolving CT acquisition parameters used by several authors over the years and their consequent effect on CT effective doses [1-8]. Some authors reported using actual scan parameters on physical phantoms to determine organ doses, while others used synthesized data from computer-based models. Data from our institution are based on our departmental patient age- and weight-based pediatric CT protocols.

CURRENT THINKING ON PEDIATRIC CT DOSES : MORE WORK TO BE DONE

- Feel good about lowering doses significantly ?. Is that enough?
- Or, have we gone too far on pediatric CT dose reduction. Consider Image quality.
- Institutional approach to dose optimization and standardization: should consider variations in vendors, patient age, gender, weight and size.
- Develop better understanding of the wide range of dose reporting and dose managing software, still in progress.
- How to go about establishing, managing and responding to dose alerts and notifications
- Benchmarks for pediatric and adult dose?. What is that "sweet" number for acceptable minimum that does not compromise image quality
- Individual patients are more or less radiation sensitive depending on their unique genome, epigenetic factors, and confounding radiation sensitization at any given time. Shall individualized patient doses be a future consideration?



Ref: BEIR VII, Phase 2. National Academies Press, Washington, DC

Figure 1: Effect of age at time of exposure and gender on excess cancers
The lifetime attributable risk of solid cancer mortality by age of exposure and demonstrates the increased risk effect of age on radiation sensitivity.

Table 1: Effect of age at time of exposure and gender on excess cancers: based on figure 1

	Newborn compared to 30 years old		5 years compared to 30 years old		15 years compared to 30 years old	
	F	M	F	M	F	M
Cancer incidence	4.58	3.86	3.26	2.77	1.98	1.78
Cancer mortality	3.49	3.24	2.64	2.46	1.75	1.68

F female, *M* male

The table shows an increase in children's excess cancer risk and about a factor of two difference in sensitivity between girls and boys

CONCLUSIONS

- The linear-no-threshold model of radiation risk is a hypothesis.
- Is there a problem with using an unproven hypothesis as the basis for a worldwide patient safety campaign?
- It sounds like a rhetorical question, and indeed certain authors have aggressively attacked the idea, claiming that the ALARA concept is actively harmful to patients and even that the Image Gently Alliance should be dissolved
- New technologies and collective efforts of healthcare providers have helped reduce patient doses, children in particular, to significantly low levels below the 100 mSv with preserving image image quality.
- Some argue that the no increased cancer risk has been demonstrated at dose levels below 100 mSv, and to emphasize continuing dose reduction serves only to fuel public fear and unnecessarily compromise image quality

SUMMARY:

- Pediatric CT dose optimization is a work in progress and will continue to be for several years.
- Measuring dose to actual patients is not easy.
- Optimizing an entity that is hard to measure is harder still.
- shifted focus from best possible image quality to a balance of image quality with patient safety.
- On the way, partnerships created radiologists, technologists, medical physicists, manufacturers, referring clinicians and regulatory bodies.

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