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Estimating cancer risks from pediatric CT: going from the qualitative to the quantitative

Being quantitative, I think, always focuses the mind in these discussions, and this is really our rationale – to get some sort of feel for the absolute risks that may be involved. Let me start with a bit of background. It is clear, and I think everybody in the audience knows this, that pediatric CT is different from adult CT and also from any other sort of radiological exam as our article [1] points out. The organ doses are clearly higher for children than for adults [2]. Pediatric CT is of course increasing in frequency quite rapidly and probably more so than adult CT [3], and as Eric mentioned children are much more sensitive to radiation-induced cancer than adults [4]. I will go through these differences in some detail. First, let's talk about the organ doses.

For a given set of machine parameters (including the mAss), organ doses are larger in a child compared to a (larger) adult. Consider, for example, an organ located on the proximal side of the body relative to the x-ray source. This organ will get roughly the same dose in both adult and child (Recall that dose is energy deposited divided by mass.). As the x-ray source rotates, that same organ will be on the distal side of the body relative to the x-ray source; now that organ is partly shielded by the body tissue proximal to it, reducing the organ dose. But this dose-reducing, partial shielding will be much less for a thin individual, such as a child, compared to a thicker adult. Thus organ doses for children are larger than for adults.

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Pediatric CT usage is rapidly increasing. The following are some very rough numbers, and it must be said there is still a need for more surveys on pediatric CT usage in the USA. In 1989, around 4% of all CTs were pediatric [5], and this rose to around 6% in 1993. Today that number is about 1 in 10, making an estimated 2.7 million pediatric CT exams per year in this country [3]. This is clearly a large increase in the use of pediatric CT.

CTs contribute disproportionately to the overall radiation dose from radiological sources. Perhaps 10% of all diagnostic radiological procedures are CT procedures, but their contribution to the overall collective dose is probably 67% simply because the doses are higher [3, 6]. These numbers are from a fine paper by Mettler and colleagues published recently [3]. Although CTs are not the most common radiological exam, they are the most important to the population in terms of the dose.

We also need to think about the issue of multiple CTs. Again quoting data from Mettler [3], 30% of patients who undergo CT have at least 3 scans, 7% have at least 5, and 4% have at least 9. Thus, we need to get a better feel for the average number of CTs that any given individual has, and multiply the dose by that number.

Finally, we should again discuss the issue that children are clearly more sensitive to radiation than adults [4]. Figure 1 presents more recent data from the A-bomb survivors which show an even bigger age effect. The graph indicates lifetime cancer mortality risk versus age at time of exposure. There is an order of magnitude increase in risk in children versus adults and a significant sex differential, a factor of 2 difference in sensitivity between girls and boys.

In general, the reason for the shape of this curve is twofold. One is that children have more time to express a cancer than do adults. Hopefully, they have their whole lives in front of them [7]. Second, it appears that children are inherently more sensitive to radiation simply because they have more dividing cells and radiation

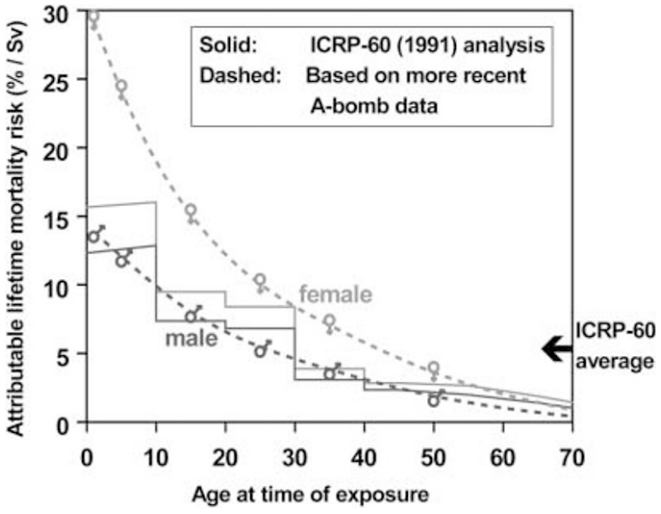

Fig. 1. Estimated lifetime risks based on updated (up to 1990) A-bomb data

basically acts on dividing cells. These two facts give us the shape of this graph.

How did we estimate the risks [1]? The answer is in three logical steps. First, we estimated the dose to each organ as a function of age, gender, and type of CT exam. Next we applied estimates of age-, gender-, and organ-specific risk-per-unit dose. We did not use the concept of effective dose (average over all organs) because the dose is so nonhomogeneous. Therefore, we did the risk estimates on an organ-by-organ basis, and finally, we simply summed up the estimated risks for all the different organs.

How does one estimate the doses? They can be measured in phantoms, or calculated with computer models in adults, in children, or in neonates. We did some relatively crude calculations for our dose estimates. Figure 2 shows the sorts of numbers we got. Of course, the actual values depend on what mAs setting is chosen, but the relationship between mAs and dose is linear. Thus, if the mAs settings were halved, the doses and therefore the risks would be halved. If the mAs settings were doubled, the doses and the risks would be doubled. One can simply scale the doses and the risks by the mAs setting. These numbers in Figure 2 are for 200 mAs, for head and abdominal CT. It is not surprising that the brain is the dominant organ in terms of dose from head CT, and stomach and liver from abdominal CT.

Rough ranges of doses for a single neonate CT are presented in Table 1. For an abdominal CT of 100 mAs, the estimated stomach dose is 10 mSv (millisieverts). For a head CT of 100 mAs, the estimated brain dose is 20 mSv. These are the sorts of doses one should bear in mind, though of course there will be variations from machine to machine.

Again for a single neonate, Fig. 3 shows the relevant dose range [8, 9], factoring in the variability in mAs

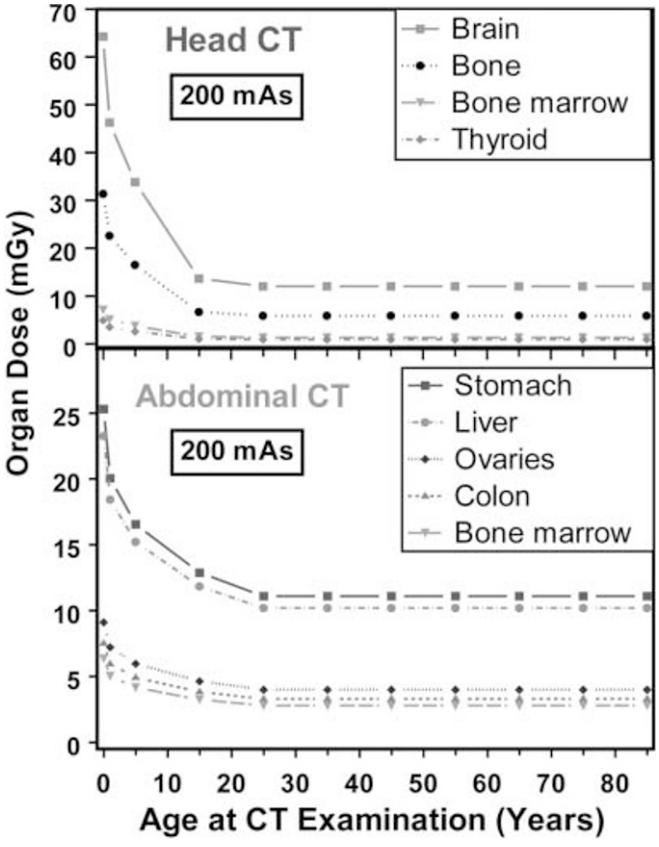

Fig. 2. Estimated organ doses for a 200-mA setting

Table 1. Relevant dose ranges for a single neonate CT

Abdomen CT (stomach dose)
300 mAs → 30 mSv
100 mAs → 10 mSv
Head CT (brain dose)
300 mAs → 60 mSv
100 mAs → 20 mSv

settings and the fact that many individuals get multiple CTs [3]. The range is roughly 6–100 mSv or 0.006–0.1 Sv. It is important to stress that this is the range for which there are direct epidemiological data. ''There is direct, statistically significant evidence of risk'' in this very dose range [10]. The individual risks are small but statistically significant.

Therefore, based on A-bomb derived estimated risks-per-unit dose and some data on the doses, we can produce the lifetime attributable cancer mortality risk as a function of age for a single CT exam. Figure 4 shows both a head CT and an abdominal CT. Again this is for 200 mAs, which can be scaled to any other mAs setting simply by scaling linearly. The plot is the estimated lifetime attributable risk in percent versus age at the time

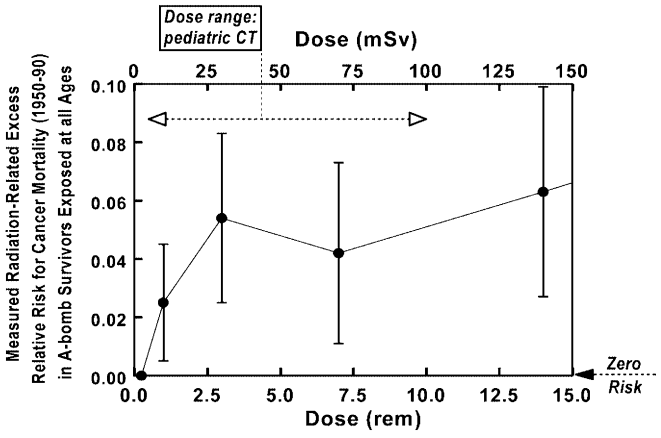

Fig. 3. Relevant dose range for pediatric CT: 6–100 mSv (0.006 = 0.1 Sv). "There is direct, statistically significant evidence for risk in the dose range from 0 to 0.1 Sv" [10]

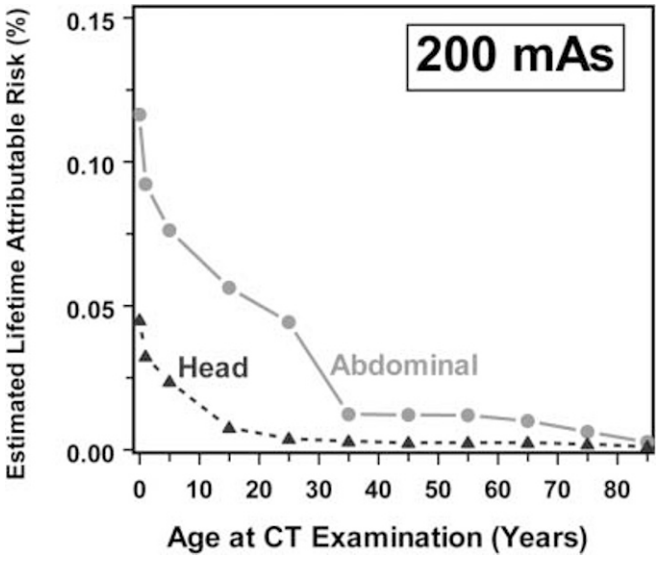

Fig. 4. Estimated lifetime attributable cancer mortality risk, as a function of age at examination, for a single CT examination

of the CT scan. Keep in mind that 0.1% is 1 in 1,000, 0.05% is 1 in 2,000. Again, a tremendous drop-off in estimated risk as a function of age is noted, which is why we are talking specifically about pediatric CTs though even here we are talking about fairly small individual risks.

If you break that estimated risk down into the different organs for head CT, you see that the brain and thyroid are the dominant risks, as might be expected (Fig. 5). If you compare boys with girls, there is not a huge difference in this case.

From abdominal CT, breaking down the estimated risks, you find that the digestive organs dominate, which again is no surprise. If you look at girls versus boys, you

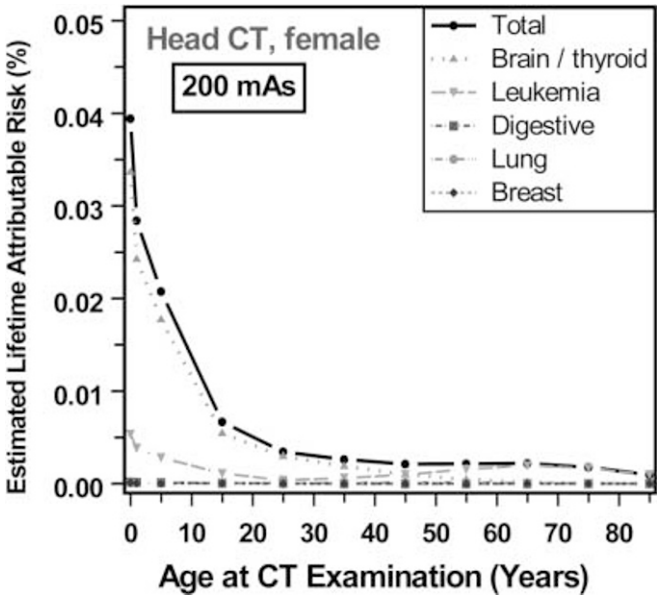

Fig. 5. Head CT: estimated lifetime cancer mortality risk (%)

see a fairly significant sex difference between girls and boys. The risks are twice as high in girls as in boys. These are estimated risks for a single CT exam at a given mAs setting. Again, our numbers for both head and abdominal CT are based on a setting of 200 mAs.

Using these rough risks and with our estimates of how many CT exams actually take place per year, we multiply one by the other and get the estimated number of predicted cancer deaths in the USA based on 1 year of pediatric head and abdominal CT scans. The issue here is that these estimated population risks are still small (of the order of 1,000/year), they are potentially reducible.

Let's finally discuss the risks and benefits of CT. It is obvious, and has never been in question, that for any individual the benefits will almost always far outweigh the risks. The issue is not whether an appropriate individual CT exam should be done – the benefits outweigh the risks.

However, the issue which is relevant is not individual risk, it is collective public health risk. It is the mean individual risks multiplied by the large number of people who are undergoing CT exams. So this is not an issue for an individual parent, for instance; it is an issue for radiologists. The individual risks are small, and so the benefit:risk ratio for any individual child would generally be very big. However, for a large exposed population, and our estimate is 2.7 million children a year in the U.S., that small individual risk is multiplied by a large and increasing number of children. This effect is likely to produce a significant long-term public health issue, and that's really the story – not individual risks, but public health risks.

Where should we go from here? Well, it's obvious that we could do better in our risk estimates – the doses are only fairly roughly measured. For example, we really need to understand more about cancer *incidence* as well as cancer *mortality*. We also need realistic confidence limits on the estimated risk. Most importantly, and this meeting is exactly what the doctor ordered, we really need improved communication about low-dose risks from researchers to radiologists. It has certainly been my experience, since this paper [1] came out last February, that there has been a real divide in terms of what is known. Radiation researchers have essentially said, "Well what's new? We've known this for quite a while." Radiologists have tended to say, "This is new stuff and probably not true." Information transfer between these two populations, I think, is really essential. Maybe there are areas where too many pediatric CTs are performed [7], which would give us potential for reducing the collective dose, as well as optimizing exposure settings for children. I am sure there will be a lot to discuss regarding standards for reduction in CT mAs settings for children.

Questions

Question: About the gastric cancer incident being a big part of GI cancer from abdominal CT: Since there is a very high incidence of cancer in Japan and an extremely lower cancer incidence in the USA, is that a relevant value?

Dr. Brenner: It is indeed true that cancer patterns between Japan and the USA, in general, are relatively different. There has been a major effort when doing risk transfer from Japan to the USA to take that into account. You could say it is a fairly crude way of doing things, but that's the best we can do. To answer your question, it has been taken into account as best as can be done.

Question: As a public health question, your estimate of 11% of CT exams being on children under 15: Where do you get that data, it doesn't seem quite right to us?

Dr. Brenner: It wasn't my estimate, it actually came from the paper published last year by Fred Mettler and colleagues [3]. It was a survey of the University of New Mexico radiology experience. They argued in that paper that it was relevant to the general experience in this country, but that is certainly something one might discuss. It's a very good general point that we simply don't know the numbers well enough at the moment – how many CT examinations are being done in this country and how many *pediatric* CT examinations are being done. We really do need better surveys.

Question: Why is it that a smaller organ has more dosage? I think it should be less dosage.

Dr. Brenner: One of the main reasons for this effect is that in adults, parts of the body between the x-ray beam and distal organs attenuate the beam and therefore reduce the dose to these distal organs. This effect is much smaller in children because they are in general thinner than adults.

References

1. Brenner DJ, Elliston CD, Hall EJ, et al (2001) Estimated risks of radiation-induced fatal cancer from pediatric CT. AJR 176:289–296
2. Huda W, Atherton JV, Ware DE, et al (1997) An approach for the estimation of effective radiation dose at CT in pediatric patients. Radiology 203:417–422
3. Mettler FA, Wiest PW, Locken JA, et al (2000) CT scanning: patterns of use and dose. J Radiol Prot 20:353–359
4. Pierce DA, Shimizu Y, Preston DL, et al (1996) Studies of the mortality of atomic bomb survivors. Report 12, part 1. Cancer: 1950–1990. Radiat Res 146:1–27
5. Shrimpton PC, Hart D, Hiller MC, et al (1991) Survey of CT practice in the UK. 1. Aspects of examination frequency and quality assurance. National Radiological Protection Board, NRPB report 248, Chilton, England
6. Shrimpton PC, Edyvean S (1988) CT scanner dosimetry. Br J Radiol 71:1–3
7. Berdon WE (1999) Editorial commentary on Roebuck DJ: "Risk and benefit in paediatric radiology." Pediatr Radiol 29:721
8. Paterson A, Frush DP, Donnelly LF (2001) Helical CT of the body: Are settings adjusted for pediatric patients? AJR 176:297–301
9. Donnelly LF, Emery KH, Brody AS, et al (2001) Minimizing radiation dose for pediatric body applications of single-detector helical CT: Strategies at a large children's hospital. AJR 176:303–306
10. Pierce DA, Preston DL (2000) Radiation-related cancer risks at low doses among atomic bomb survivors. Radiat Res 154:178–186