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CT scanner design and patient radiation exposure

It's a pleasure to be allowed to speak with the physicists as a non-physicist. When we are looking at radiation risk, we've discuss in the literature the risk of low-dose ionizing radiation, the frequency with which CT scanning is used, and also the use of higher than necessary doses in many cases. One thing that I'd found was missing was a discussion on CT scanner design. We've just had a great talk that introduced this topic. I want to review some of the things that we've found in some simple experiments we've done and in our experience with CT scanners.

The impact of scanner design, I think, is really important, and I'm going to discuss three areas. The first area concerns design factors and the specific example of the effect of different collimator design, the second is comments on multi-slice units and, finally, the third is to compare different CT scanners.

Many of the same factors that occur with plain films are also important in CT scanning, but we don't think about them. Because it has digital data output, the scanner provides a good looking image no matter what we do. We don't burn it out or have a black image based on our technique, and it makes it in many ways harder to evaluate what we are doing with that technique. In looking at collimator design we compared three CT scanners and simply did axial sections through a phantom with a pencil ionization chamber. We used different slice thicknesses, and we normalized our exposures. We said that a 10-mm exposure value was 1 and if we look at the results that we got, you would expect a 10 mm would give 1 and 1 mm would give 1/10 of that exposure. These are the results that we got with the three different CT scanners (Table 1). The results were much higher than expected as we got down to the thin sections on two of the three scanners.

The GE CT/i tracks very closely to what we would have expected. The Siemens Somotome Plus tracks to the 0.2 level. The Toshiba (aquilion) in its single-slice configuration strays even further from that line.

CT scanners can collimate both before and after the patient. If you have the same pre- and post-collimation, then everything that you are exposing the patient to goes to make up your image. If you have a wider pre- than post-collimation, the patient is getting more than the expected radiation.

I will tell you that I have not been able to confirm collimator design. When we tried to contact the physicists in the different companies, we never got responses and I'm not sure why that is. Answers that ranged from "That's pretty much it" or "I guess that's about it" are as close as we got.

I think that examples of examinations where this is a factor would be for the posterior fossa where we use thin-section axial technique in our patients. We could well be scanning at that 3-mm level where we are giving overlapping greater than the expected dose. Temporal bone studies are another example with axial 1-mm sections. In high-resolution chest work at 1-mm sections at 10-mm intervals, we might be giving about three times what we might expect in the dose if we were to simply look at our 10-mm section and assume we were giving one-tenth of that dose.

When we look at multislice scanners, we get a whole new group of considerations. I'm going to use GE scanners, the LightSpeed and the CT/i, because those are the scanners that I've worked with. I'll also mention that the CT/i is a very low-dose scanner. It's a tough mark to beat and it's made things kind of difficult when you compare those two.

The good thing when you get a Light Speed is that it is much faster, and all kinds of things that were tough

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Table 1. Normalized exposures

Scanner Expected	Slice thickness				
	10 mm	8 mm	5mm	3 mm	1 mm
CT/i	1.0	0.8	0.5	0.3	0.1
CT/i	1.0		0.500	0.308	0.112
Somatom	0.800	0.494	0.296	0.148	
Aquilion	1.0		0.563	0.423	0.369

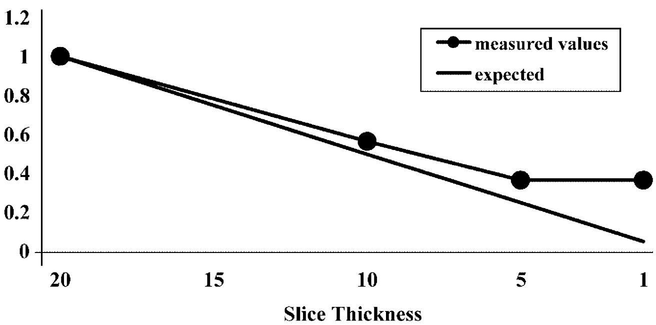

Fig. 1. GE lightspeed

are easy and things you couldn't do, you can now do. You can get slices from just through the patient without thinking about things like tube cooling, and depending on how you set up the scanner, you can go back and get thinner slices retrospectively, which we were never able to do.

When the scanner was delivered, however, we had some problems. There was no single-slice capability. I've talked about high-resolution chest CT that requires one thin section. As delivered, the system only had four contiguous 1.25-mm sections. We couldn't tilt the gantry and do helical scanning, so that for example our sinus CTs could not be done on that scanner. Particularly concerning was that if you use the same technique, the dose was much higher, but if you went to the same image noise, you still had a higher dose on the LightSpeed scanner. The LightSpeed now shares some of the problems that we have discussed. Figure 1 shows a straight line on an earlier version of the scanner when there was no thinner slice available than those 4 contiguous 1.25-mm sections. We do notice a straying from that ideal line that we didn't see with the CT/i (Fig. 1). The way that this scanner is being used some places even today is in this mode. If you want a 1.25-mm slice, you obtain 4 and throw 3 away. I've been involved with some high-resolution protocols for research, and within the last month I had to inform a radiologist that he could not use either of the CT scanners at his institution. He had to use his single-slice scanner because his multi-slice scanner was providing far higher radiation than was allowed for in the IRB approval.

I think the important thing here is not to snipe at GE or any of the manufacturers. Certainly this dose problem is one that has been described in several previous talks, that of the unused portion of the X-ray beam. This was the first time since I've been looking at CT scanners that a mainstream upgrade really required a trade-off – some things that were better and some things that were problems. I really wasn't used to that. Before this we got new, more efficient detectors, a faster scanner, more memory, and greater heat capacity. It was pretty much if you could afford it, it was a straight win, and it was an easy decision. Now, I think we are going to see more of this; we are going to have more trade-offs. In order to get the scanner to do more, we are going to have to give up some things that our other scanner may have done very, very well. Certainly, if we are replacing a single-slice scanner with a multi-slice scanner, there is going to be a dose penalty. One of the problems, and this comes back to the manufacturers, it is quite difficult to get information often on the limitations of the new scanners when they come out.

Let's talk about comparing CT scanners. I suspect that some people looked at those normalized values and said, "Wwhy normalize it? Why don't you just tell me that this scanner has this dose and that scanner had a lower or higher dose. If one scanner doesn't quite get as low, but starts off with half the dose, overall our patients are going to benefit." The reason that I didn't do that is that I think it is extremely difficult to compare CT scanners and dose. The reason that I say that is exposure really needs to be related to image quality. It isn't the question that if you set the scanner up in exactly the same manner what the dose will be. The question is, for an image of equal quality, what will the dose be? When someone says our scanner has a 30% higher dose if you set it to 0.08 s, 100 mA, and 120kVp, but you will get just a pretty of an image with 50 mA, well that's a win-win. That scanner is going to allow me to go down to 50% of the original dose and that would be a good situation. I don't think measuring the exposure for the same technique is really very useful, and image noise is the easiest factor to use, but it's only one factor in image quality.

Image quality has multiple components, and the importance of those different components really depends

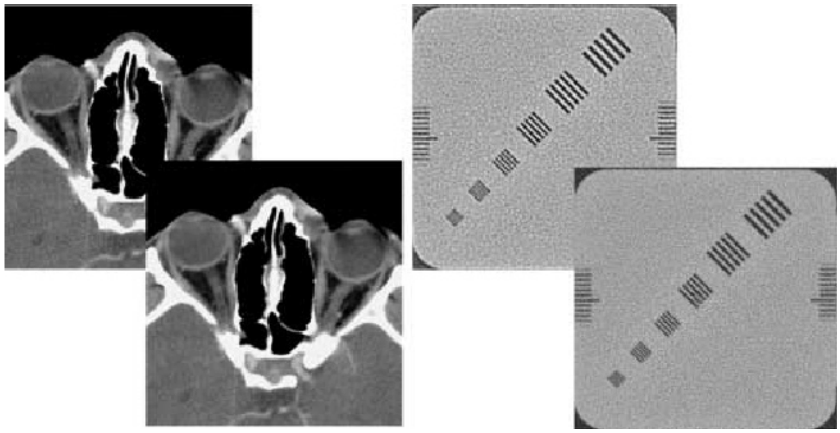

Fig. 2. Evaluation image quality

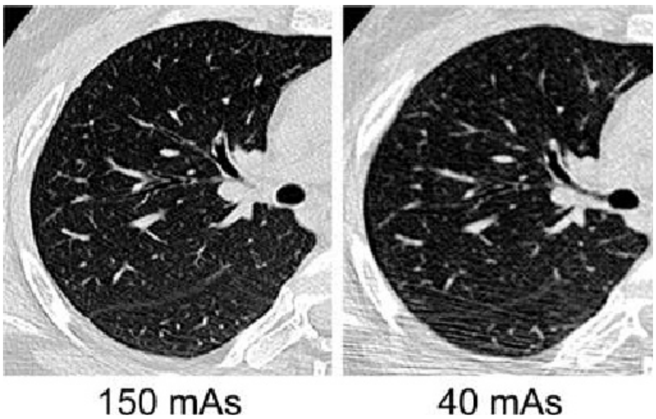

Fig. 3. 15-year-old HRCT

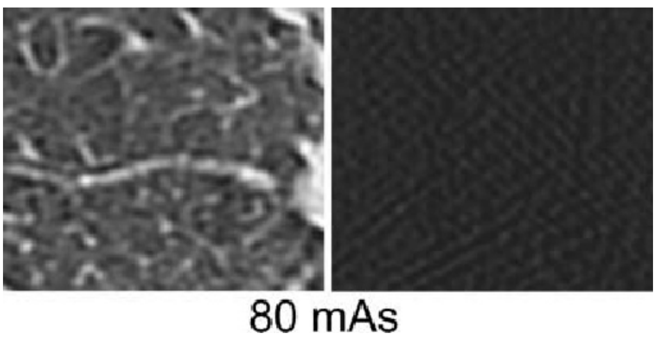

Fig. 4. 5-year-old HRCT

on our imaging task. I've done a fair amount of really simple experiments using patient scans and retrospective reconstruction (Fig. 2). Image quality has a number of components and they include noise, the artifacts that we get, high-contrast resolution, low-contrast discrimination, and accuracy. There are many others, but these are the kinds of things that we think about.

In Fig. 3, the question may be whether the resolution is good enough and particularly whether these streak

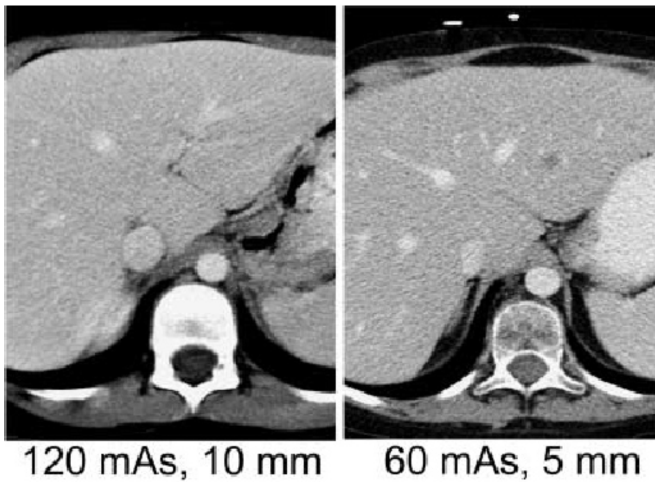

Fig. 5. 15-year-old liver metastasis

artifacts are too much. Our question might be high-contrast resolution and the presence of streak artifacts as we change our radiation dose.

Here in a smaller patient (Fig. 4), our concern might be the fact that we look like we have little, dark, maybe cystic areas, but if we simply look at the air around the patient, we see a very similar pattern. This isn't unstructured noise or resolution, this is a structured noise, perhaps there is some streak artifact here as well. However, this is a noise that is actually simulating pathology in our patient.

If we look at the abdomen, we are now looking for low-contrast discrimination. Is this lesion still there in this patient; is it hiding right in here in this somewhat noisier scan (Fig. 5)? Different situations, different requirements for our scanner. How do we say what is the image quality that we are going to compare in those different scanners?

We can use image noise. We can take the standard deviation of a homogeneous area of our scan and look at the standard deviation. It is available on the clinical

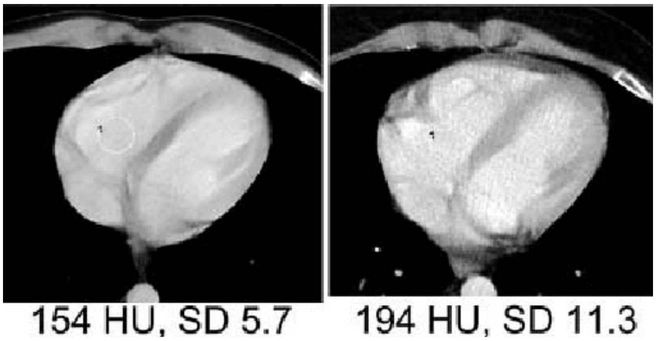

Fig. 6. 4× change in exposure

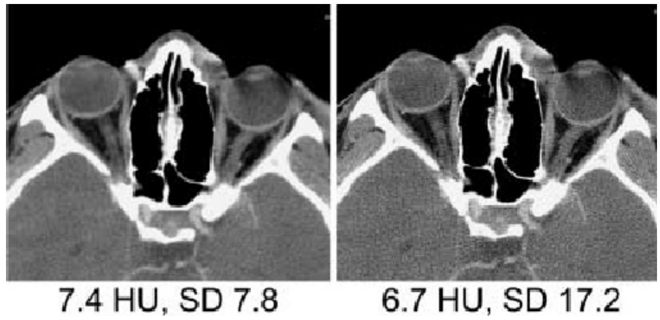

Fig. 7. Change of reconstruction kernel

console, very easy to do, and it's a very useful way to evaluate technique changes on the same CT scanner when we cut down or try different combinations, particularly, for example, if we are doing different slice thickness and different other technique settings.

We see a change in image noise when we look at the standard deviation going from 5.7 to 11.3 or approximately doubling (Fig. 6). As I said before, it's one factor in image quality and it's dependent on the reconstruction kernel, and this is important. I think that there is a limited value in comparing noise among different CT scanners for that reason. In Fig. 7 we've got a little more than a doubling of image noise, but it's the same image. This is a comparison of two image reconstruction kernels on the same CT scanner. The reconstruction kernel is giving us the difference in noise that we can see here. If we use one scanner, we can say we'll use the same reconstruction kernel and eliminate that factor,. but we don't know if the reconstruction kernel in one company's CT scanner is a little nosier or a little less noisy than the one in our other CT scanner. It's a very difficult comparison.

Figure 6 was a four-fold change in exposure, and Fig. 7 was a change in reconstruction kernel. I found that manufacturer's information is limited. It's very, very hard to compare CT scanners. There are requirements for the CTDI for an average head study, but unfortunately, there are a lot of different ways to interpret that. When you get that number, what image noise are you talking about? What other factors are there in the image quality that you are looking at? Because one scanner does an average head that pleases one set of radiologists, it may be very different from the next company and the people that they use.

An independent assessment is possible, but it requires a complex set of measurements. Many of those factors I mentioned are part of image quality. One of the questions for discussion is: should a standard reporting method be developed that would allow us to compare those CT scanners?

In summary, the CT scanner design is an important factor in patient dose. Trade offs such as faster scanner and lower dose need to be considered when we are choosing a CT scanner, and I think that the information needed to make this decision is not available to most radiologists.

Dr. Walter Huda: Speaking as a physicist, I found it all crystal clear, Alan.