Good morning. I'm sure there'll be a few more coming up the elevator any minute now. Okay, so this is the third in a series four courses on the continuing education courses on CT Technology. Tomorrow morning Diana Cody from MD Anderson will be speaking on pediatric radiation doses and strategies to reduce and manage the dose in pediatric patients, which is going to be in this room at 7:30. My name is Mike McNitt-Gray, I'm a medical physicist from UCLA and today I'm going to talk about trade offs in image quality and radiation dose, and as, just as a preamble and background, image quality is a very complicated thing. I'm just going to speak about some of the simple components of it, but it has many components and it's influenced by many technical parameters as we all know, and it's always been a concern for the physics community, but that's been sort of an abstract concept brought home even more to clinically

acceptable image quality as we try to develop strategies to reduce radiation dose, especially to pediatric patients and that's the motivation behind this talk, is not the dose reduction strategies which you'll hear about tomorrow, but some of the trade offs you encounter as you implement some of these strategies. So that's the background here. So the purpose today is to describe several, certainly not all, of the components of CT image quality. I'm just going to focus on noise, the slice thickness, and its sister, Z-axis resolution. I will also talk about low contrast resolution and high contrast resolution. Just those limited aspects of image quality today and describe how each of these can be affected by technical parameter selection and then particularly paying attention to the trade offs that exist between different aspects of image quality. Sometimes there are competing aspects of image quality, so we'll talk about the trade offs

between them and especially when we talk about reducing radiation dose and the trade offs that occur in image quality from that. Okay, so here are the four components that I'm going to talk about today, just the noise, slice thickness, low contrast and high contrast. I'll define these in a very limited extent and then go through how they get affected by technical parameters. So as some of you have been hearing, noise has a very simple definition, it has a very much more complex definition which I'll talk a little bit about later, but in it's simplest definition it's just a measured standard deviation of voxel values in a homogeneous, typically water, phantom and it's influenced by many parameters, kVP, MA, exposure time, collimation, or reconstructed slice thickness which is mainly to cover a single detector scanning, but reconstructed slice thickness, the reconstruction algorithms such as the reconstruction filter, in some limited instances helical

pitch or table speed can influence this. Certainly the interpolation algorithm when it's a helical scan and some other parameters which we don't usually think of because we don't control them, but they do have an absolute, they have an effect on the absolute value which is focal spot to isocenter distance, detector efficiency and things like that. The only parameter I'm going to discuss right now about noise is the trade off between noise and MAS. So one of the strategies for reducing dose and we'll go through these a little bit later is to reduce the MAS, but clearly as been well documented and seems pretty straight forward that noise is proportional to one over the square root of MAS. So that is, if you reduce the MAS by half then the noise increases by the square root of two, so which is 1.4, so you've got about a 40% increase in noise. That's certainly if there's no other additional smoothing or if you're just in the linear portion of the

MAS curve there. So for example, here's a, and I'm going to try to illustrate a bunch of these concepts with phantom images and at the end we're going to go through some clinical images as well, just to solidify this. So here's an example of a water phantom scanned with a certain technique of 80 MAS and a 2.5 mm thick slice, and you know what, could we have the lights down just a little bit. So I want to make sure you can appreciate some of the differences in noise here, so let's see if we can do this. Here's 80 MAS, I'm going to reduce the MAS by half so here's a 40 MAS, and I hope you can appreciate the difference in noise. So I'm going to be your optometrist for a minute and say "here's a, here's b", so you can appreciate that a little more increase in graininess there, and in case you can't appreciate it visibly I'm going to take the same thing and measure and there's a standard deviation there and I think that says 13 and that's with 80 MAS. There's 100 MA and 0.8 second scan and now I'm going to reduce it to 50 MA and 0.8 second scan, 40 MAS and the standard deviation goes up about 40%. That's a standard deviation of almost 18 right there. So just reducing the MAS increases the noise and that's pretty visible and pretty appreciable and measurable. Okay, another aspect of image quality is the slice thickness and I'll give a broader term which is Z-axis resolution, but the reconstructed slice thickness has become well lets say, some more complex when going from axial, to helical, to multi detector scanning, and this discussion is going to focus only on the reconstructed slice within helical scanning and the factors that influence it. Which include, obviously, x-ray beam collimation. Certainly for single slice scanners where you have just one detector the beam collimation had a big influence on the slice thickness. Now when you go to multi detector slice thickness it's not so much that the beam isn't important but usually you're looking at detector width as the limiting factor or how you group those detectors together to make a channel. Then just to climb out on a ledge a little bit, the pitch and table speed and the interpolation algorithm, both have an influence on Z-axis resolution in some instances, okay? So for example, for some manufacturers' their multi detector scanners, the reconstructed slice thickness is independent of table speed and I'll give an example of this in just a second, and others are not independent of table speed. It depends on the interpolation algorithm, that's why I put these two together, they're very tightly linked and it depends on the implementation that's on the specific scanner, and specific models; and sometimes of the scanner that you have. So I'm sorry I can't give a general answer because there isn't a general answer out there right now. For single detector scanners, we first learned about the helical scanning and the interpolation algorithms either 180 LI, or 360 LI, 180 was implemented most of the time, and when you did 180 LI or 360 higher pitch scans produced a larger effective slicing, as we learned about this ten years ago when we saw the slice broadening due to increased table speeds. So at 180 LI you have a pitch of 1.5 the full width half maximum of that slice increased 10-15% over the full width half max at pitch one. So higher table speed, broader slice thickness. Again pitch two even broader slice thickness, full width half max would increase by 30% and it looks something like this. Here's a slice sensitivity profile from a single slice scanner and pitch one is in blue. Here we have distance along the X-axis and the intensity value so this is a slice sensitivity profile measured. This is with pitch one, okay so it has a certain broadening and then when you increase the table speed you would not only reduce the peak, but broaden that so the full width half max would increase by about 30%. Okay, so increased table speed typically increased your slice sensitivity profile, your effective slice thickness was broader, and certainly that would affect your Z-axis resolution. With multi detector scanners these simple trends were not quite so clear. This is because the interpolation algorithms are much more sophisticated; you have a lot more samples to choose from. Now you have instead of one detector to interpolate between, you have multiple detectors that you can collect data from and interpolate between, and so the number of different interpolation algorithms available as well, and different manufacturers have taken on different schemes of this. So there isn't a straight forward answer, it depends on the scanner. You might have to, as my colleague Tom Payne said yesterday, you might have to be a physicist and go out there and

measure it. So I encourage you to do so on your own scanner. But here's an example of a GE light speed QXI scanner. Same beam collimation, 5 mm same reconstructed nominal reconstructed slice with 5 mm, but two different table speeds. The HQ mode, which is 15 mm per rotation versus the HS mode, which is 30 mm per rotation and you measure the slice sensitivity profile. In the blue is the full at half max, the 5.3, that's for the slower table speed. The faster table speed again at peak is down a little bit and broader, full width half max at 6.2, so it's somewhere in the neighborhood of 15-20% increase because of the table speed doubled. So that's one example in multi detector where increased table speed gives you broader slice profile, decreased the Z-axis resolution. Here's a counter example. On the Siemens Sensation 16 they different interpolation algorithm and what happens it regardless of the table speed there's pitch

of 0.75, 1, 1.25, and 1.5 those profiles all line up, there's no degradation in terms of the peak, there's no broadening of the profile. It's basically their interpolation algorithm. So there's no difference in the broadening due to table speed and that's one of the trade offs that Siemens has incorporated. So here's some of the conclusions, one is just be careful, because it's not always generally true, but typically, I'm sorry these aren't the generalizations, this is another part. Just to summarize that last part, so single slice scanners increase table speed to full width half max usually goes up decreasing your Z-axis resolution and in some multi detector scanners that's true and some that's not. Okay, so what do people do to increase Z-axis resolution? Well you can just reduce the slice thickness by doing, going to a thinner collimation or a thinner reconstructive slice thickness in multi detector, but that's going to result in a trade off with increased noise, and

possibly dose. Now I'm going to try to illustrate that a little bit later but here's one of the conclusions, you can increase Z-axis resolution but just so you know there's no free lunch, you do have an increase in noise. One of the implications for dose is that by going to thinner slices means you increase the noise. The user may be tempted to increase the MAS to offset that increase in noise, which would then increase the dose, just by going to the same quanta level if you will. So there's that temptation when you go to thinner slices, nothing inherent in thinner slices in this particular item that says thinner slices give higher dose, it's just that they give higher noise which people sometimes go to higher dose protocols to offset that. Now that's out of one side of my mouth. The other side of my mouth a lot of times when you go to thinner beam collimations, then you get higher doses and I'll show that a little bit later. That's the

problem we often hear about called "Over beaming" when you go, in multi detector scanners when you go to thinner beam width sometimes there's a little bit of spill off, off the edge that ends up in a higher radiation dose. So lets illustrate this a little bit with the noise concept which is, here's a 5 mm thick slice and a standard deviation of 11 at a 50 MA, and 0.8 seconds scan and if you change that to the 2.5 the noise goes up and so to get to a comparable noise level, you'd be tempted to increase that dose level, but this is just to illustrate the point that going to thinner slices means increased noise and that's one of the trade offs. So here's what I am trying to get at. To compensate for the increased noise you may be tempted to increase the MAS to get back the noise levels equivalent to the original. So here's the 50 MA the 0.8 second scan 5 mm thick slice that's 11.8, now I go to, to get to the approximately same standard deviation or same quanta level

I have to go to 100 MA and 0.8 second scan. So I doubled my photon fluence, I reduced my collimation by half. The next aspect of image quality I want to talk about was high contrast or spatial resolution. Okay, and what I mean by this is high contrast or spatial resolution within the scan plane, typically determined using objects have a large signal to noise ratio. This tests the systems ability to resolve high contrast objects typically of increasingly smaller sizes or increasing spatial frequencies, trying to move to a higher spatial frequency object. There's been some quantitive methods described, scanning a wire or to calculate the modulation transfer function from the point spread function or scanning an edge to get it from the end spread function or estimating technique called the Droege-Morin method where you can scan a bar pattern phantom and do some calculations to estimate that. I'm going to do this visibly because I

think that'll be a little more illustrative to you and I'll do that in just a second. This is influenced by a number of factors including the system geometric resolution limits, focal spot size, usually not controllable at a user directly, though if you know enough about the scanner you can sometimes chose a technique that can go to the smaller focal spot size. That's usually a tube heating problem. Detector width, ray sampling, again usually things not under the control of the user, pixel size which is, and one of the dominant factors that is, is the properties of the convolution kernel. Okay, so let's take a look at that. So here was an estimate of the modulation transfer function, estimated from the Droege-Morin approach and this is from a GE LightSpeed scanner and it's got three of their common ones that we often look at. There's lung on the top, bone and standard. That's just the name of the protocols, name of the filters you'll see at the

scanner. Okay, and these all start at one, so what this is meant, in case you're not used to looking at this, this is increasing spatial frequency to the right, so larger objects that show up over here, smaller objects, finer spatial frequencies over here. The amplitude of modulation is essentially what's the amplification of the original signal is so this is output divided by input. So what you see here is anything that's above one is the signal or that amplitude of the original signal is actually amplified. Okay, so there's more difference between background and object in this region above one, than there is down below. This is where you would actually have less and so your limiting resolution is for example a lot of times people would use, some people use 50%, some people 10%, some use 5% and some just go all the way down to zero, but this is where you have basically no ability to resolve. We'll show this in a phantom, in the bar pattern phantom

injust a second, but so here's what the different algorithms would do. So this lung algorithm actually over enhances in this region, so structures in this spatial frequency range actually get over amplified, that is there edges actually appear stronger than they are in the original object. Bone tries to preserve those; this algorithm here is bone tries to preserves those edges out as far as it can and smooth basically smoothes those edges together and I'll try to illustrate that visually with this bar pattern phantom. Okay so here's the standard algorithm and you can see these lines, I hope you can see this pretty well, so I just want to compare and contrast this algorithm and also there's two things I want you to appreciate now, one is that you're going to see once again there's no free lunch, that we're going to get an increase in sharpness, but you're also going to notice if you will, the background, look a the noise or the heterogeneity within the

object and even in the water as we go from the standard to the bone. Now what we expect as I go to the bone, is that we should see maybe further down in this line pairs, but if not at least things, will be a clearer, but you may also appreciate a difference in noise there. Okay, so now I went to bone, so let's see that again. There's the standard, which is a little smoother and there's the bone. So again take a look at the background and you should be able to see these lines a little bit sharper and maybe able to resolve this group down here. Okay, now I'm going to take it to the next algorithm - lung - which should even amplify that more. You should be able to see these lines and it is sharper and the background noise will change again. So there we go. So you see a certain graininess there, but those lines look very very sharp. So trade offs are that you get increased sharpness, increased spatial resolution and the noise, well a year ago I would've said

increased now I'm just going to say changed, because well we'll talk about that in a second. Let me illustrate this in a couple clinical images. Here's an image of lung it's a reasonably thick slice so it won't be the best illustration, but here's a reconstructed under standard and bone. So hopefully you can appreciate a little bit change in sharpness and certainly you'll be able to appreciate a change in structure down here where there's a little bit of streak artifact and it's going to be amplified with that bone algorithm down there. And some of these fine structures in the lung should just look a little sharper. It's not dramatic but you can appreciate the differences and certainly radiologists can. So here's a different chest slice with standard, it's probably a five or seven mm thick slice and now these may look sharp to you but when I change it to bone it's almost like it really comes into focus here. Okay, so the edges become sharper. So this is what

the algorithms do to clinical images. The differences in noise here the standard again, often appreciated in the soft tissue it's a little hard to tell in this one which is a good thing, but if you take a look down here you might be able to appreciate a difference in some of the streaks that are being enhanced by that increased edginess there. Okay, so you increase the XY plane resolution via the reconstruction algorithm, it can result in a trade off with a nominal increase or certainly I will say a change in noise. Okay, so that's one of the trade offs. Now I would, a year ago or two I would've said let's measure the noise in terms of the standard deviation, I'm going to do that but I want you to appreciate there's something else going on here as well. You're changing not just the spatial frequency of the signal; you're changing the spatsial frequency content of the noise as well. So lets take a look, here's the phantom scan with the standard reconstruction

algorithm and it's got a standard deviation down there, I think it says 11.5. So now what I'm going to do, I'm going to change that to bone, and appreciate that difference in noise okay. Some people might say it's much noisier and the standard deviation would certainly bear that out. This is now 45.5 standard deviation compared to 11. But we've really done and we haven't changed the MA or the scan time, that's all the same. Okay, now, sorry, I did one more thing there, I wanted to back up and prepare you for that. Here's the 50 MA, here's the 0.8 second standard and bone. Now my original goal was let's get back to the original standard deviation. Now to do that you could do this calculation in your head, I'll do it for in just a second. You're going to have to increase your quanta okay, so 50 MA times 0.8 second is 40, we increase our noise by a factor of four. It goes by the square root, so we have to increase our dose by a factor of 16. So to get to 640 MAS, which we did here, 640, 160 times four, we got back to about the original standard deviations, but if you look at those two…. there's the original/ standard, there's the now, same standard deviation but different algorithm, they look really different, and there you can have them side by side, because what's happened is that they've got the same standard deviation but they have very different spatial frequency contents here, okay. That's what's happening with the noise. So that's why I use to say increase, now I'm going to say change. Because what we've done and - sorry we switched from one manufacturer to another, these are no reconstructions using Siemens equivalent of a standard and a bone, or something like that - but you have a smoothing reconstruction curve. Now I'm showing you the noise power spectrum. So here's the amplitude versus spatial frequency and noise power spectrum is really a two dimensional function, this is just a one D slice along the X-axis here, but just to illustrate that the power of the noise in this smoother filter is concentrated down in the lower frequencies and the power and the noise in the higher spatial frequency or sharper filter, what would have been a bone or lung equivalent is now concentrated in the higher frequencies and the result of that is this real difference in graininess.. This is where the noise power concentrated in the lower frequencies. The grain size is almost larger if you will and this is a much finer noise. So we've done this in some simulations and this may have a implication for detectability. We've actually embedded the same object with the same nominal signal to noise ratio, or same, sorry I said that wrong, the same nominal signal difference from background or contrast so there's an object there you might be able to see. The same object is embedded in this background over here. So the granularity or the spatial frequency content of the noise may have an issue, may have an impact in detectably. This is an ongoing research project, but I just thought I'd highlight that it's just not this standard deviation you're interested in here. So lets move on to one more thing, which is the low contrast resolution. Often determined using objects having a very small difference from background, typically 4-10 depending on the phantom and because the signal, that is the difference between the object and the background, is so small. In the high contrast or spatial frequency we were doing a very high contrast object, now we're moving to very low contrast object, where noise is a significant factor in this detectability test. Usually done subjectively. I know there's some people working on some object of measures of this. I'm just going to talk about, illustrate it with subjective measures, and it typically tests and measures, this testmeasures the system and sometimes the observers ability to resolve low contrast objects of increasingly smaller sizes. That is increasing spatial frequencies and it's influenced by a number of the same parameters as noise are. So I'm going to illustrate this with an example from the ACRCT accreditation phantom. This phantom consists of a single 25 mm rod, which is just for reference and measurements - everybody can see it -and then sets of four rods. So what you'll see is they all have the same signal, which is about 6 Hounsfield units for background but different diameters. There a group of four rod that are six mm then there's a group of four rods that are five mm, then four, three, and two typically you can't see that unless you really blast it and to be honest in scanners even when we blast it we can't see those two mm we just have to hope that they're in there and somebody saw them when they manufactured it. This is just going to illustrate that noise can influence the low contrast resolution. So I hope you can appreciate this. Here's a technique with, here's the phantom so there's the 25 mm and here's a group of four rods, I hope you can see that. These are six mm, the five, which should be about here, the four here, the three here, and the two there.. You may not be able to see all those. The 240 MAS technique with a five mm thick slice in the standard algorithm. Now I'm going to reduce the dose, reduce the MAS and increase the noise. So there's my 80 MAS. That may have influenced your ability to detect those objects, I suspect it did okay, but some people will still say I see six mm no matter what and as Phil Judy would say, is Phil here? He would say, "if I say I can see six mm you can't prove me wrong," and he's right I can't. If you say two I can't prove you wrong. So that's the downfall of this test. But I think you'll all appreciate that our ability to

detect low contrast objects is going to be influenced by noise. Okay, so there I influenced it just by changing the MAS, I'm going to influence it now go back to the original technique and change the slice thickness which is also, but holding the MAS constant so I know I'm going to change my noise again. So there's my 2.5, so I hope you can appreciate the difference in noise between those two and potentially the ability to detect especially those five mm objects there. And now just for, well because I had the data, I'm going to change the algorithm and just show you , appreciate the difference between the standard algorithm, the same techniques and then the bone, certainly a change in the character of the noise. I can't say for sure whether it's affected your ability to detect this or not. So those are some of the image quality aspects. Those are some of the issues about trade offs, and so now let's talk basically in the context of reducing

radiation dose and talk about how these are going to influence image quality. Because there are several mechanism that reduce dose in CT exams and each of them has implications for the image quality. So we're going to talk a look at some phantom and clinical images there as well, and some we already have effectively, haven't we? Okay, so almost three years ago now the FDA sent out a notice talking about dose reduction for pediatric and small adult patients, and I hope we've all paid attention to this. We've done some work at our institution probably could do more, but some of the things that were suggested were: reducing the tube current, increasing the table increment for an axial scan or increasing the table feed per rotation or for helical scan or pitch, developing MA settings. So both of these are going to have implications for image quality as we've already seen. Developing MA settings based on patient weight, very appropriate.

These are all very appropriate, but this is a very appropriate one, even more appropriate. Developing MA settings based on the patient weight or diameter. This has nothing to do with image quality but it's still very appropriate and worth stating. Reducing the number of multiple scans with contrast. Do you really need to do a pre and post scan on this patient or do you need to do all three phases post contrast? Sometimes you do if it's indicated and that's what's necessary then do it and if it's not then don't do it. Just be thoughtful about how these are being carried out and I know that we're talking to the physicist crowd and who aren't the ones dictating these studies, but these are the things that should be considered. Eliminate inappropriate referrals for CT altogether. Again these are things that should be discussed at the institution level,. So what parameters influence dose? Well a lot of them are the same things that influence

the image quality, KVP, MA and scan time, or MAS, pitch and table speed, so we're going to look at a number of these parameters, collimation and I put a question mark there and I'll show why in a few minutes. The dose reduction options, which I'm going to list here and just raises a question 'cause I don't have a good way of evaluating these yet. Scanner make and model also has an influence on radiation dose. Turns out when we went from GE CTI single detector scan to a LightSpeed QXI the tube moved in closer. It's a smaller rotation diameter. That wasn't really well advertised, but if you did this same technique, so if you just took your single detector techniques and transferred them to your multi detector scanner, you were getting higher doses. So scanner make and model has an influence on that even if all the rest of these things are constant and what I'm going to call the indirect effects of algorithm and collimation, which is

really that when you go to thinner slice your noise increases and people may be tempted to increase the techniques to off set those increases in noise. So let's take a quick look at some of these parameters. So let's look at the beam energy. So this is one, sometimes suggested as a dose reduction option and here's why. We made some measurements in a phantom and CTDI, I calculated the CTDIw, which is just the weighted average of the center and periphery and the CTDI 100 phantom, we did it for the head and for the body. We did it for a number of KVP's keeping everything else constant. So what you see is that as you, so you know a lot of times you say well 120, 140 KVP's what's the difference. Well turns out at least in phantoms it makes about a 40% difference in dose. Okay, so you're operating closer to the square of the KVP then you are just on linear difference in KVP's. So in other words if you were doing 300 MA, one

second, a ten mm scan you'd be doing about 55 milliGray on particular scanner. It's going to vary from scanner to scanner. If you reduced just the KVP and keep everything else constant, you're going to go down to 40 milliGray as your weighted CTDI in the head and you go from 25 to 18. So you get about 40% decrease going from 140 to 120. Now what's the implication? If you reduced the beam of energy alone it will increase noise. And so what some sites do and I don't encourage this but I'm just observing is that they may feel they have to increase MAS to get acceptable noise. Okay, so if you do that, then you're off setting some of the benefits of reducing your KVP to reduce dose. So there is an implication even when reducing the KVP will increase the noise. It may increase the signal contrast for some tissues and for those contrast studies or for high Z materials do to increased photoelectric effects when you reduce the KVP. It

may also comeback to back fire a little bit if you're doing this in certain environments 'cause it may increase the beam hardening artifact if the beam energy gets too low. So some people reported a good results doing pediatric heads with 80 KVP and some people say the beam hardening artifact kills us. So they don't do that, we go to maybe 100 KVP, but not down to 80. So these are all potential trade offs. Another aspect of reducing dose is reducing the MA, the two current time product MAS and this is just linear as you would expect. So we kept, this time we kept the KVP constant, the slice thickness constant, we measure the phantoms again and we just vary the MA pretty linearly and it's pretty linear. So and we already saw this before, dose decreases linear with MAS, but the implication there is going to be increased noise. You're not going to get around this one. Now I am talking about fixed tube current things, I'm just going to

lightly address that at the very end of this talk, but, okay. How about pitch and table speed? Well it turns out that there's a parameter out there, I was using CTDIw before. Now I'm going to tell you that there's a parameter called CTDI Volume which takes CTDIw and divides by pitch.

We have in the past and other people have shown that pretty much dose is proportional to pitch. So when you have a pitch of two, when all other factors are held constant, I'm going to give my caveat to that in a second…so when you have a pitch of two you get 50% of the dose at pitch one okay, and if you have a scanner that doesn't do pitch one here's what happens. You've got two choices 0.75 or 1.5 and I know there's some other discreet steps out there as well, but if you have a pitch of 0.75 it gives you an increase of dose, 133% compared to the dose at pitch one.. Again that's with all the other factors held constant. Now those of you with GE scanners will notice

that if you change the pitch from HS mode or from 1.5 to 0.75 or one of their modes, they tend to adaptively change to current for you, to try to preserve noise and now we're into other more suffocated techniques but in some of the other scanners you'll see this. But the message is that dose is proportional to pitch when all other factors are held constant. However as we saw earlier that when you increase the pitch in some scanners you can increase the effective slice thickness. That's true in all single detector CT scanners and some multi detector CT scanners and when you do that, when you get to increase in effective slice thickness you're going to increase the volume averaging and reduce your Z-axis resolution. You'll also get some increase in the helical artifact and I will mention that the reason there's a sum there is for example, you saw the Siemens where increase in the table speed did not increase your effective slice thickness. Okay, now here's one

of the ways Siemens gets around this, and I just want to let you know that are terms out there that are confusing - some manufacturers, Siemens and Phillips, use the concepts effective MAS that's Siemens term or Phillips, which is MAS per slice, which is not MAS. It is MA x time divided by pitch. So it's an interesting and useful concept but it can be confusing when people mistake this for MAS. It is not. It is MAS divided by pitch, and what Siemens does and maybe someone knows this about Phillips, I don't know that off the top of my head, 'cause I don't have many of their scanners. When the pitch is increased on the scanner, and by the way if you see a Siemens Sensation 16 or above you won't see the term pitch, they use table feed but there is pitch, and you can extract what the pitch is, but you won't see it on the user interface, what you'll see is table feed. So when the pitch is increased, when the table feed is increased, the MA

x time is increased proportionally, so you're increasing the denominator and you're increasing the numerator to keep the effective MAS constant. Now that helps them keep that slice profile constant and it helps them keep the noise level constant but it - just so you are not under the mistaken impression - increasing the table feed there does not decrease dose because the tube current has increased for you okay. You just don't notice it. You go to the user interface and you type in 40 MAS or 200 MAS and you think okay that's good, now I'm going to increase the table feed and save dose. The tube current has been increased for you. That's not MAS you're manipulating its effective MAS. So I hope that concepts gets across a little bit clearer. It is a little bit of a caveat there. Any dose you thought you were going to save from increasing the pitch is not realized because the tube current has been increased proportionately. Okay how

about collimation? In a single detector scanner we measured this several years ago. Here's the CTDIw and body again and we measured this for a couple of different slice thicknesses and what we saw was surprisingly little difference. There's some difference, 10%, okay ,10% difference and only when you get down to the thinnest slices. So my argument was that CTDIw at least is approximately independent of collimation except for the very thin slices. So did that impact dose by going from 10 to 5? Not really, if you keep everything else constant. It would've increased your Z-axis resolution and increased noise going from 10 to 5, but not the dose. Okay that was true for a single detector scanner. Here's a multiple detector scanner, in which this particular brand, I think it was a GE Light Speed QXI , does have a difference from collimation. So if you wanted a five mm thick slice you could get it a number of ways on this scanner. You could

make it a 1 x 5 mm collimation called 5/1i mode, 2 x 5, or 5/2i mode, or 4 x 5, what's called 5/4i mode and if you measure the dose CTDIw you'll get very different, 40% difference in dose depending on the exact collimation setting that you're using. Now this is, a lot of manufacturers have gone to, because of the pressures in Europe I think it's a requirement in Europe I don't believe it's a requirement in the United States that they actually report the CTDIw on the operators console. So you can see this, if you have a Light Speed at home try this, and try changing just the collimation as you'll see the CTDI numbers change. Alright, so you can change with beam collimation again, higher at narrow beam collimations, this is the over beaming problem that you often hear.. And the implications for image quality is when you reduce collimation or reduce the reconstructed slice thickness anyway, you can increase the Z-

axis resolution that's going to increase noise and in some instances depending on exactly how you do it with the beam collimation it can increase the dose. So now let me take a few minutes, I hope, I know we've glanced over a number of topics and we've covered a lot of things, by the way this going to be a PDF form on AAPM website after the conference in case you want to review this, but let me walk you through now some clinical tasks and talk about how these trade offs manifest themselves in tasks, and some applications and see for example some tasks can tolerate a high degree of noise and therefore can go to a low dose. Two of them that I could think of are lung nodule detection. Now this is for a research study not many people are endorsing this clinically, but if you wanted to detect lung nodules I'll show you that in just a second or coronary artery calcium, which again is a screening study if you're interested in doing

this in low dose, but these are examples of high noise tasks. A low noise tasks where you cannot tolerate much noise would be an abdominal scan, a liver scan where you're looking for low contrast liver lesions or diffused lung disease. Lungs we often think of these are white dots sitting in a black background, but diffuse lung disease can be quite subtle and so radiologists really think this is a low noise task and there's medium noise tasks as well, such as looking for in the brain sometimes you're just looking for bleed outs, peds applications sometimes, oncology, abdomen or chest. So I'm going to give a couple examples of these, but first here's an example of a phantom, just to set the stage. Here's an example of a high contrast object, this is the ACR phantoms high contract resolution object. Now here's a question, does reducing MAS effect your high contrast ability? Typically no, and so here's a sharp algorithm and why doesn't it

effect your high contrast resolution? This is such a high contrast signal and there is noise in there but your signal to noise ratio can withstand this kind of reducing the MAS. So the question is if you reduce the MAS is it going to effect your ability to resolve these line pairs. So I'm going to take this from 240 down to 80 and you can probably still see the same resolution that you could before because this is a very high contrast detection task. So is this. In a lung cancer screen you're looking for white objects in a black background. So this is a relatively low dose technique 40 effective MAS, it's moderately sharp algorithm, thin slice and a reasonably noisy image. Okay even though it may not look it to you, but it’s pretty noisy compared to what we would do clinically for a clinically indicated scan. This was from a research study. So let’s take a look at these images. How does that look? Pretty confident you can see all the little white things in the black background. Very high contrast object there but, there is this down here and this is what we call a ground glass nodule. I’ve got a couple more examples in a second, which have a little less signal to them and might be a little more difficult to detect especially if there was a little more noise in this. So if we reduce the dose a little bit more, this might have been harder to detect. Okay, how about this one? Thin slice, lots of stuff in there, you’re trying to figure out where the cancer is. That’s not it. That’s the dome of the diaphragm don’t get confused, but there are some very subtle things and I’ll show you the answer in a second. You can see lots of white spots, you’re not going to miss those, but what you might miss were these. Very subtle ground glass nodules. Are they cancer? To be honest we don’t know yet. This is why this is a research study. Are these the kind of things we want to detect in a research study, absolutely. ‘Cause we want to follow these and see if this is what cancer looks like in an early stage. So a little more noise and we might have missed this one too. Okay, but for the most part when you’re looking for solid nodules, which is where we started with the lung cancer screening you can withstand a lot of noise. Coronary artery calcium, another screening study. Reasonably low dose technique, you’re looking for little specks like this but not there. You are looking for it in the coronary arteries like right there. Now you’re not going to miss that if the dose goes down a little bit more and if the noise picks up. So these kind of tasks can withstand a lot of dose reduction and a lot of increase in noise. Alright how about this one, this is a pediatric chest. This was a before and after study that I found: 220 MAS, five mm thick, same algorithm. Now they reduce the dose and they used a thinner slice, so should be much noisier and you can tell especially in the shoulder where there’s lots of streaking from the photon insufficiency. You can see lots of noise and appreciate the difference between these two. Now, is this a high or low contrast detection test? Well it depends on what you’re looking for. Clearly this is a contrast study, I suspect it was post surgery and they’re probably just looking for patency of the surgical structure and make sure nothing is bleeding out. So I would say this probably is a pretty high contrast task especially with a good contrast injection. So it too can withstand a lot of dose reduction, okay. So the dose reduction there was appropriate and probably could’ve gone a little lower. Okay, but now just for the sake of illustration now because they just to be conservative went a little bit further into the abdomen and gives a good picture of the liver. Look at this, what if this was a liver scan?. How about this, would you be more confident with the left or the right?

I hope you’re going to answer the left, because this has lower noise and you can see the structures, especially those subtle structures much better there. You can see the structure but I think you’re going to have more confidence there. So it depends on the nature of the task. Here’s a little bit bigger patient a 12-year-old, abdomen 280 MAS again seven mm thick so thinner and lower MAS so good comparability for noise there and you can see, you know, if you’re looking for structures in the kidneys and its ssufficiency you’re probably going to do okay again, the liver where you’re looking for more low contrast objects, you know, you’re probably okay but you can see why people might be a little more conservative with their techniques for that kind of application, especially if they’re looking for something subtle. Okay, now how about the head? Now are technologists were really pushing hard and really trying to drive this one. We went from 120 to 100 KVP, 440 MAS to 100, and they went, so that’s going to increase your noise. They went from 2.5 here to 5 mm thick so this is going to offset that a little bit, ‘cause it’s a little thicker slice. Now what are they looking for. I don’t know what the clinical indication for the scan was, but all I know was the structures were much better defined there, so did we go a little too far here in reducing the dose? It depends. If all you’re looking for is, you know, this is a post contrast study so if you’re looking for bleed outs you might be okay, but if you’re looking for a little more subtle differences that might have gone a little too far.. Alright, so we can always lower the radiation dose, but my question is can we do it too low, can we reduce it too far and if we lower it so low that we can’t accomplish a diagnostic test then obviously we have not done well for the patient. So we would like to lower it just to the level where it can be accomplished. Alright, well this is a magic bullet, but we don’t know where this is yet, we don’t know where the threshold is and that’s going to be clearly task dependent as I’ve tried to illustrate. In the meantime, what we’re going to have to do is struggle through some of these trade offs and appreciate that as we try to reduce dose that we’re going to have some implications for image quality and just make sure we’re doing it appropriately. That we want to give just enough dose where we can get the task accomplished. In summary there’s many methods to reduce the radiation dose. Many of them have, well each of them basically has image quality implications of increasing noise, broadening our slices, reducing our resolution in the Z direction, or increasing artifacts. We want to find the appropriate trade offs. These may be diagnostic exam, or task dependent, and we have to be clear about what the requirements of the imaging exam are. And frankly, what may be frustrating is that this may not be driving the diagnostic test, but other things as many of talk about is things that may be driving it are, things like liability. You know if I miss something, am I going to be held liable. Not is this the appropriate imaging protocol for the test, for this exam and that I can reduce the dose, but if I miss anything am I going to be held liable, and that may be driving this more than anything else. That’s going to be hard to overcome, which is why I put how can we establish those requirements. Those are an open question. And finally, just wanted to throw out the tip of the iceberg which is that - okay so now the manufacturers have done a great job coming out with dose reduction technologies, very exciting, very appropriate, now the only problems is how do we evaluate these? How do we know that they’re working appropriately other than the clinical implementation and the evaluation of clinical images, because I don’t have phantoms that very well test how the tube current modulation works on noise. Manufacturers do, I have to take their word for it, but in the field how do I evaluate that. This is going to be a little bit difficult. It should reduce the dose but maintain the noise, but it’s going to be hard to verify for a little bit, until we come up with some techniques to do that. So questions are open, how do we assess this in the field, how do we assess the dose reduction, and how do we ensure that the noise is maintained. Clinically we can see this, but in terms of physics testing this is still a little bit of an open challenge. And I think I’ll stop there, Thank you.