Introduction to Biomedical Imaging Systems
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Lecture - 16
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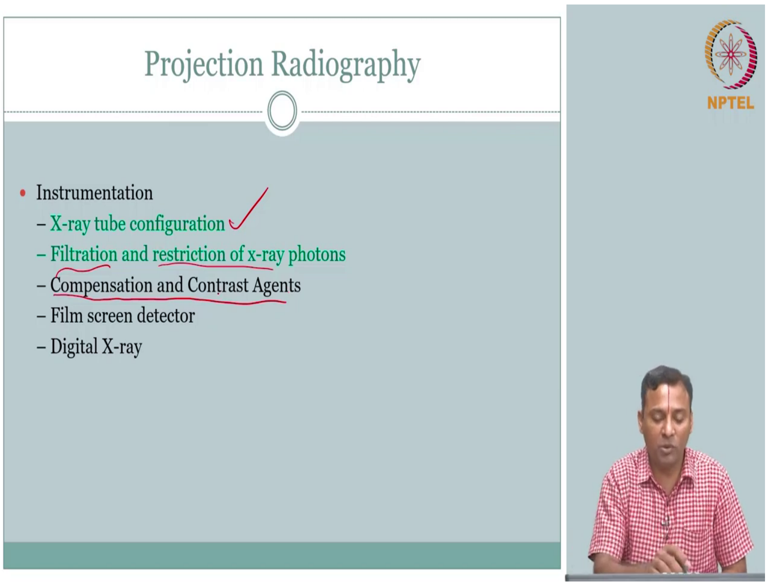

So, in the instrumentation, we started with the X-rays right, the X-ray tube configuration and then, just after the x-rays come out of the x-ray tube which is going to be a spectra of energy, we wanted to do two things; one is do the filtration so that only the energies that have maximum probability to give you signal right.

You do not want too higher signal, you do not want too lower signal and so, there is idea of filtration and we can just concluded restriction. What is restriction? It is just to cover the field of you, you do not want to send the x-rays to regions that are not going to be part of the imaging. So, as to avoid dosing the patient ok.

So, after that, so we had the source part right, just outside the source we talked about filtration restriction. Now, what about the instrumentation? Should we, are we going to instrument the patient or should we go to the detector side, what is your guess? Well, really speaking, its it is how you when we talk about instrumentation, you think about there is the physics, there is a concepts right, the physical phenomenons and other things and then instrumentation is trying to achieve. So, it is part of engineering right. So, you want to achieve make use of this knowledge make use of this understanding to realize something.

So, in some sense, even though the interaction of the x-rays that are coming with the tissues right which the object that itself is governed by physics; but our job here as engineers is to maximize the signal, minimize the noise right I mean. So, so that you can make a measurement that can be used reliably as an estimate of your underlying unknown.

So, in some sense, we need to also talk about in the instrumentation only about what happens with the humans, can we manipulate the material [Laughter] right to get good signal to noise ratio or contrast to noise ratio ok. So, we will probably the name we did talk about you know hint of contrast agents earlier.

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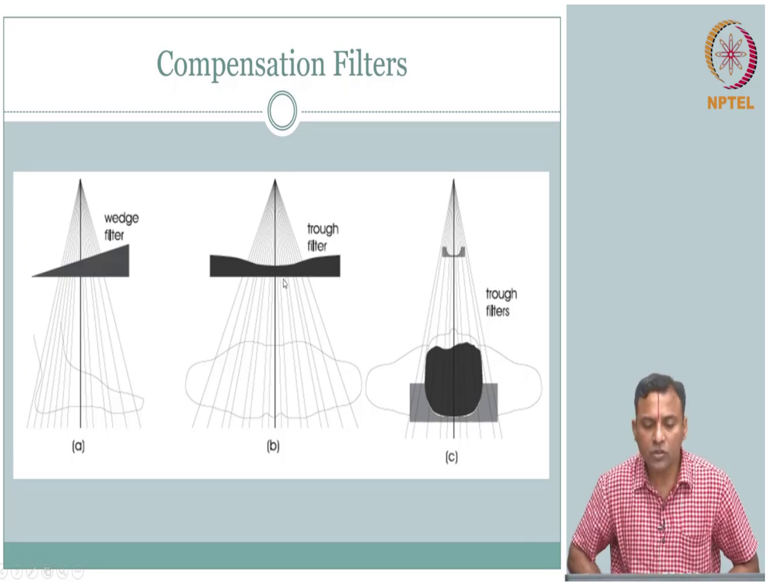

But we will go through the motions here ok. So, what do we mean by compensation filters right? So, this is essentially to think about I cannot really engineer the human being, I mean right I am going to go in my native state get an image; but what I can do is I can make this instrumentation to some extent customize it right so that for me, the signal to noise ratio is good. For me when I say depending on the object of interest.

So; that means, if I go for a chest x-ray or if I go for a head and neck or I go for an arm or I go for leg right or my foot each organ is different. So, depending on which organ you are doing, can we compensate for some losses that we know the physics has told us. So, when we built our material, we used a thickness right of a slab as delta x. So, we just use the thickness.

So, the thickness was same throughout the height. In our context narrow beam. So, the thickness across the slab was same with respect to at in the region, where your detector is seeing. That is what we did, but in reality that we need not be the case and therefore, based on that, we develop this signal and the photoelectric effect, Compton scattering. And we said the signal attenuation is dependent on the material property mu and length of the material. So, mu delta x e power minus mu delta x right.

So, now the question is ok that means, what we developed the material that we interrogated had a uniform slab thickness across. So, all are equations were right. For that, we did not really make it a point that the length changes you know across, we did not we did not encounter that. But really if I go stand right when you have a object which is a 3 D object like a human body, it is the thickness is not same throughout. The thickness is changing. What is our objective? Our objective is to find out the mu that is deferentially distributed right.

But the what is the attenuation loss tell you? I send some n photons in, some reduced photons come out and hit the detector. So, this loss is proportional and we said we modeled it as a exponential loss right; e power minus mu delta x and therefore, we can infer about the material mu through which so the loss is proportional to the material.

But we said material into delta x. So, the loss, so you could have a highly attenuating material, but delta x could be small or you can have a weak attenuating material, the mu could be low; but your delta x could be large. In either case you will get the same see that is a problem with the projection right.

So, you in either case get the same loss. So, material is not changed, it is only the length that has changed. So, therefore, the concept of compensation filter is if I know apriori right, if there is a difference in the material length delta x because mu I do not know. If I know mu, job done. I do not know the delta x, but if I can know the delta x, make a guess on the delta x which is not difficult right. I mean I have a thickness, I know that probably I have fat at the center and as I go towards the side I am less thin, thin alike the depth, depth is reducing

So, you know you can have a rough idea on how it is or if I go for my foot right I cannot show the foot here, but you know you look at your foot, you know I will have a sketch next time; but the idea is you can have scenarios, you can have parts that you are going to image, where you know upfront that the depth through which the x-ray is going to go is going to be different.

So, may be instead of sending the same number of photons and the differential instead of differential attenuation is the path length that is different that is giving you the lower signal, then the then your differential attenuation is not captured. So, what I can do is maybe if that is the scenario, then I can my objective is to make the path length same right; but then, I cannot change the path length.

So, what I will do is instead, I can send the photons so that irrespective of the length that is normalized. So, I can send more photons, when does go through some delta x. I can send right, I can send the same photons here, but then when it goes in I could have some material that is shaped to observe the photon. So, when it hits the material, the same number of photon goes through the thickness.

So, depending on the thickness, I can have additional compensation filter right that is going to allow proportionately same number of photons go through the thickness, per length you can normally see per length ok. So, where are the scenario? So, this is straightforward.

So, if I show you some examples, you will get the point. So, here for example, the photons come here right. If I did not have this wedge tape wedge shaped filter, what would happen? Here the x-ray is going through lot more path length of the tissue. Here it is going through very little. So, if you can relate this to your delta x that we derive.

So, delta x is more here, delta x is less here. If this material is same even if this material is same, mu is same, you can clearly see the loss is more on this side because the path length is more than this side. So, if I do not have any ways to tell that the compensate for this difference in path length, your plane interpretation would be there is more attenuation in this side, less attenuation in this side.

So, the material is more attenuating here than this side, which is not true, material is same. It is just that the path length is more on this side path length is less on this side right; the path length. So, the length of this line that is passing through the material right, that is what clear?

So; that means, in this case we apriori know that there is a path length difference because of the shape of the object and therefore, you could come up with a compensation filter, where you are essentially increasing this right. This length and this length put together, this length and this length put together, more or less the path length is same.

Therefore, whatever loss you are getting right is going to be proportional only to your differential material property, certain material property correct. So, this is why it is compensation filter? Because you are compensating for this change in path length through the medium so, you are trying to compensate for that.

So, there are two variables in your attenuation; one is mu, the other is delta x. By using this compensation filter, you are trying to make sure that delta x variability is reduced. So, whatever differential signal that you get is only because of the mu that is along the path and not the length of the path itself right. So, here is one typical example.

Here like I said for when you go for chest you know the front to back distance right, the depth at the center of your body is more compared to your sides right. So, that is your delta x in your slice thickness that we talked about when we slab thickness right. So, you could have wedge that is having through filters right. You have a less length here, more length here; therefore, the path length more or less is similar, likewise here around the neck.

So, you could really think about this. So, very application specific. We are not engineering the patient, but then it is still to do with the patient. So, depending on the patients, I should not mean your target right, your object or your human. So, based on that, so this is part of instrumentation in that sense right. So, you had the source side, this has to do with the object side right. So, that is with respect to your compensation filter.

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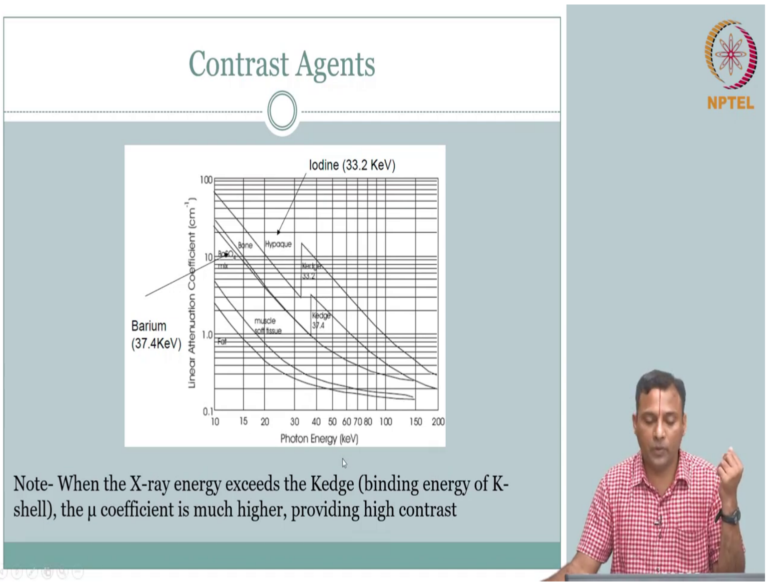

So, next is your contrast agents. What did we talk about contrast agents? In the brief intro that I said when we talked about contrast right. So, here again, we are not engineering. So, why is this part of instrumentation?

So, there is a inherent contrast, the 3D distribution right and the instrumentation of generating the x-ray and detecting it at all on the outside; but why is this part of instrument covered part of instrumentation? Because you are talking about capturing the inherent contrast right of the f of x y, contrast in the f of x y that needs to be captured.

So, here is a way. It is not natural, but there is a way, where we can increase the manipulate the inherent contrast that is why this is part of instrumentation. So, what do we mean by contrast agent? We talked about this before. So, some agent, so some trace quantity that you can send it into your body and that has a mu, specific mu right.

If it turns out the that mu is different from rest of the body parts like your soft tissue fat bone, if that is different from your body part, then wherever contrast agent is in the line of the x-rays that are going through, you will be able to detect it or contrast it out. So, the idea of introducing contrast agents is to increase the contrast of those locations where the agent is sitting ok.

So, we talked about this curve before, but there is a subtle addition in this. So, this is your previous curve, where we talked about photon energy and attenuation coefficient. Last time when we had this, we had only bone, muscle and the fat; only the three curves were like this and that time, we talked about you have to choose an energy, where you can have very good separation between the different tissue material. However, we said if it is too lower energy, the attenuation is high like the differential attenuation is also there.

But the attenuation is high that it won't come out. So, that is why we are going and if it is too large right, the photon energy is too large, then the inherent contrast between the various material of bone here for example, bone, muscle and fat is reduced right. So, there is a switch spot in between that is why our x-ray energy remember the waveform rather the spectrum that we plotted outside the x-ray all the filtering that you have done.

So, we have carefully come up with the x-ray energy that can maximize your interaction. So, now, what is added here is you suddenly see this sharp edge right, the sharp edge that you see; what is the sharp edge? It is called as a Kedge. Why is it Kedge, any guess? Of course, this is not your muscle or fat or anything, here is one material right. You have a plot for your barium, the other is for iodine compound.

So, there is a barium compound, iodine compound and this is its characteristic curve of the energy and linear attenuation. Why is it called Kedge? Any guess? Well, remember the interactions that we talked about, photo electric. When we talked about photo electric, when we talked about the probability of photo electric interactions right, we talked about this energy levels.

At that time, we mentioned that if it turns out that the energy that is coming in is close to K shell binding energy of a material. There is a sudden increase in probability of your photoelectric effect. Go look back at the probability of interactions that we talked about.

That time, we mentioned that it is noticed that suddenly when the x-ray energy is close to a materials K shell binding energy, then clearly there is a maximization of the effect ok and it turns out that if you so choose your compound so that there as a material property, the K shell energy binding energy is close to your diagnostic x-ray energy.

So, here are the examples of a iodine compound and a barium, where the K shell binding energy falls within the x-ray energy of interest. Suddenly, you see the attenuation coefficient just at K increases. So, this is your Kedge because of that reason your K shell binding energy is so positioned within your a diagnostic x-ray range that you are operating that there is a rapid or edge right increase in the attenuation coefficient ok.

And clearly, you can see what does this help? This helps suddenly you have your attenuation coefficient of the material that you introduce is very different to the other soft material that you are having here bone or a muscle or a fat. So, clearly, if the inherent contrast between the material that you have engineered which has a Kedge which pushes the attenuation coefficient high and the native material right, native soft tissue, the difference between their attenuation coefficient is increased.

In other words, you can increase the contrast in the image right because the spatially wherever this material is there, the attenuation going to be way higher compared to where the soft tissue. So, you can easily tease out, where this compound is in the path ok. So, when the x-ray energy exceeds the Kedge right, that is what that is why it is Kedge, binding energy of the K shell.

The mu is much of mu is your attenuation coefficient is much higher providing a high contrast. So, we can maximize the contrast inherent contrast. So, in some sense, this is not instrumentation, but this is part of instrumentation because you have to choose your energy levels and you have to choose the compound carefully right so that you maximize the inherent contrast ok.

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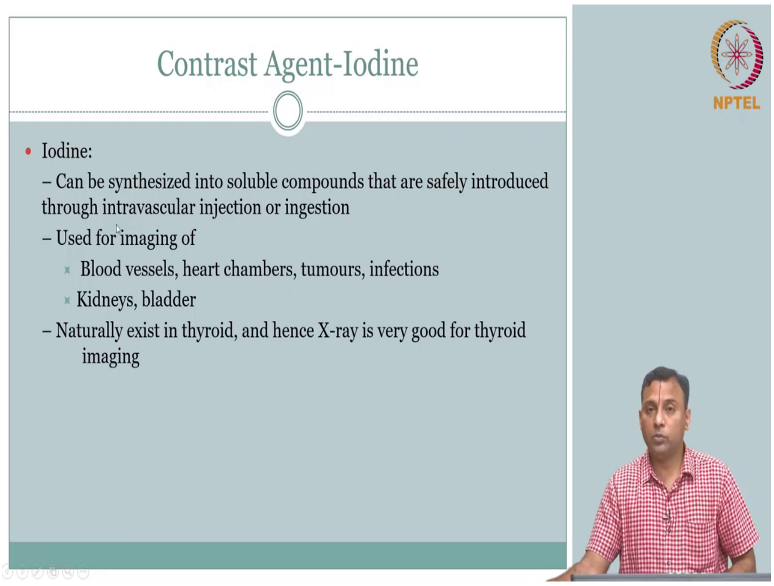

So, what are the typical compounds? Say for example, iodine you might know from basic knowledge, that iodine you know your thyroid is a natural center for iodine right. You would have seen maybe 6th standard, 7th standard text books Goiter and you know iodine, salt all these things you would have been familiar.

So, iodine has a activity in the thyroid. So, naturally, if you want to do a thyroid imaging right, you send x-rays because iodine is there and you saw the Kedge. So, it is a natural the contrast of thyroid will be very good because of this reason because iodine is already there ok.

So, thyroid imaging, it gets natural benefit. You do not have to inject the contrast from outside ok. So, what about other places? Other places, maybe I can come up with. So, this is a natural material which is biologically safe right iodine. So, I could create some compounds of iodine. So, it can be synthesized outside and into say soluble compounds and then, injected right.

So, essentially, I want to give it into the body send it into the body. So, if I send it into the body, what happens? It is going to go through a circulatory system. When it goes through the circulatory system, what happens? Wherever this iodine is going to go, when the x-ray is crossing path, it is going to attenuate that.

So, in some sense, when it goes to the circulatory system, you can then capture send the x-rays through and say ok, this is where the iodine is going right. So, you can track even like in fluoroscopy that is what we do right. It basically tracks in real time you see where all this iodine compound is going in the circulatory system.

Of course, you can also see where it goes and settles right. It has to go through your for example, circulatory system and it goes remember it will go through kidney. So, you could also do kidney imaging, then from kidney bladder right, it is trying to be sent out into bladder imaging. So, all there where you can have a very good contrast.

So, there are huge number of applications, where your contrast agent using iodine is very useful and very standards. So, for example, blood vessels right, its going through the circulatory system, wherever it is going, you can start to see them. So, if you have a block in the vessel right. So, blood will have only small region, where it is going. So, the vessel cross section will be reduced because of this flack or whatever obstruction. So, you can clearly see when you send the die, when you send the iodine compound, you can actually infer that the vessel is reduced, correct.

Heart chamber, so wherever the blood goes; tumours, where the tumours because again if there is a tumour; that means, there is a blood supply is there, its growing aggressively. So, we can you can look at where the blood vessel is going. So, based on that, you can also see the tumour.

So, if you have unusual activity, unusual vasculature, we can start to see tumours infections. Kidneys, bladder right because circulatory system then it goes to the kidney and then, through the bladder and sent out. So, wherever if you give this into the system, it has to go through the circulatory system, wherever it is going you can look at it ok. So, this is one very common contrast agent.

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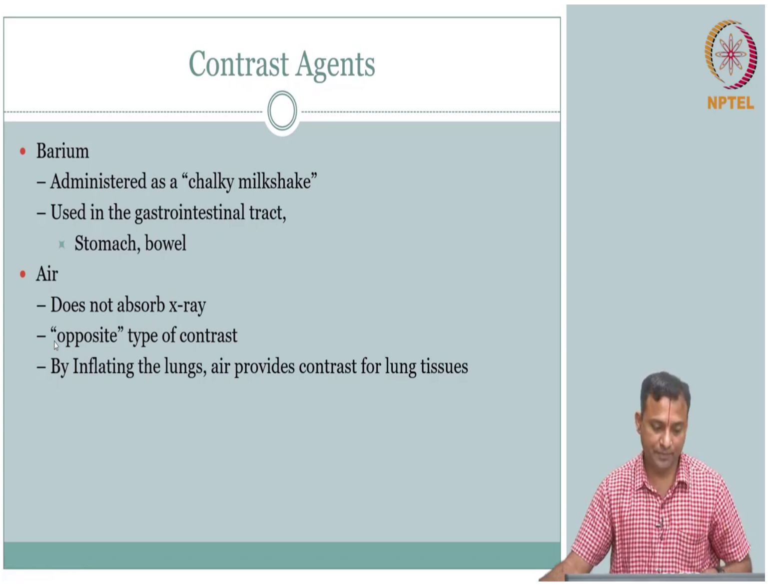

The other you can think about a barium that you saw right. There was another plot with barium. So, this is again a solution. It is administered as a milkshake, chalky milkshake. Essentially, what it is why it is chalky milkshake is if you shake it right, if you put chalk, it will look like a milkshake; never, I mean it is not going to be tasty ok and [Laughter] like your regular milkshake, where you might enjoy drinking it.

This is going to be not so enjoyable right not so tasty. But it serves a important purpose. Why? Because if you drink, a see there are ways to send it into the body. So, if I want to for example, image the GI track right is there are problem in GI track or if I want to see after GI track stomach and then bowel right, it is going through. So, what are the things I need? I need the milkshake wherever it is going right.

That time, if I send my x-rays, it is going to interact with the x-rays and attenuate. So, wherever it is going along that path right, when you project projection is what we are doing along that path, we will be able to do get higher contrast of your native material against what you are sending.

So, if there is a obstruction right, if there is an obstruction or there is a scar, if there is whatever, structurally whatever is changing, you will be able to look at it. Of course, one of the ideas of using this is it is even though it does not taste good, it does not take part in the activity. So, it is kind of a passive in that sense. It just goes through; it does not interact react. It just goes through the path and comes out.

That way functionally, it does not alter anything, it does not interact with you know. So, that is important aspect as well. You do not want to drink something and then, it starts to digest and create trouble right. So, this one essentially goes through retains the path and comes out and therefore, this is very useful in imaging the GI track, if there is any obstruction, growth, tumour, lesion whatever ok.

So, these are some compounds that you can prepare and routinely used, then we have something that is not really engineered from outside right. I mean you can use air also as a contrast agent. Can you now guess what that does mean? I mean, so what we talked about barium and iodine, it has higher mu right.

So, that means, there is going to be lot more attenuation, when x-ray energy is interacting with mu. So, compared to the soft tissue, the attenuation is going to be more. Our contrast is always a difference between two guys right; f max minus f min go right. So, or f background f target minus f background, it is a difference between the target and the background.

So, what have we done? I have by taking barium or iodine, if my target is where I want to see, the target mu is reduced. My background might be same, but my target is reduced. So, the difference is increased. So, the contrast is increased. But air, what does air do? Air also attenuates; but probably, it does not attenuates so much right.

So, probably, the air attenuation is less compared to your soft tissue. In other words, it in some sense this is having an opposite trend to the iodine and barium that we saw just now ok. That means, if air is in the path right, then compared to soft tissue air will have the less attenuation ok.

So, now, the question is ok air is having less attenuation, how does it how do we engineer that in the body? Think about, one is circulatory system; how else can we get something into the body? Breathing right. Remember our respiratory physiology that you would have covered in your you know anatomy, physiology kind of courses.

You can have air, you can inhale air, exhale air right. So, air is going. Air is going inside the body. So, if I want to do chest x-ray, I have lung sitting there, where appreciable volume is there in the path, where the x-ray is going to go. So, by you know inhaling, I can have more air. So, I can have path length change with more air or less air. So, in some sense, this is creating a contrast in a opposite sense right.

So, now, the attenuation is less here, compared to the surrounding tissue. So, the difference between your soft tissue and your air is going to be increased; that means, this will allow us to actually image with better contrast, the lung tissue. In some sense this is also a contrast agent, but it is doing the opposite effect right of having less attenuation.

So, does not absorb x-ray opposite type of contrast. So, you can inflate the lungs right to get in air that provides a good contrast for your lung tissue; clear? So, we have talked about increasing. So, if you talk about the target, I can either for the same background, I can reduce the target intensities; thereby; the contrast is increasing or I can do the opposite right.

I can do the opposite for a given background, the target is increased or I can have this same I can reduce this, for a right for air attenuation is less, it is going down. So, for given soft tissue, if air is in the path air is going to go down and therefore, a good contrast is going to be obtained.

In case of the other one barium and iodine the soft tissues here, barium or iodine is going to go up right. So, we can separate the difference. So, contrast is increased. Is there any other way to exploit? I could actually do both; I could do both right. I could give for example, if I want to do bladder or bowel or something like that, I can have air also right. The air is there; there could be air and you could have this barium.

So, if I take barium, attenuation is increased; if I have air in bowel, attenuation is reduced wherever the air is. So, in that image, you have very good dynamic range, very good contrast because you have both the effects ok. So, in some sense, you we might air is trivial, but then it could be used to your advantage if you know which target you are doing and what is your application ok.

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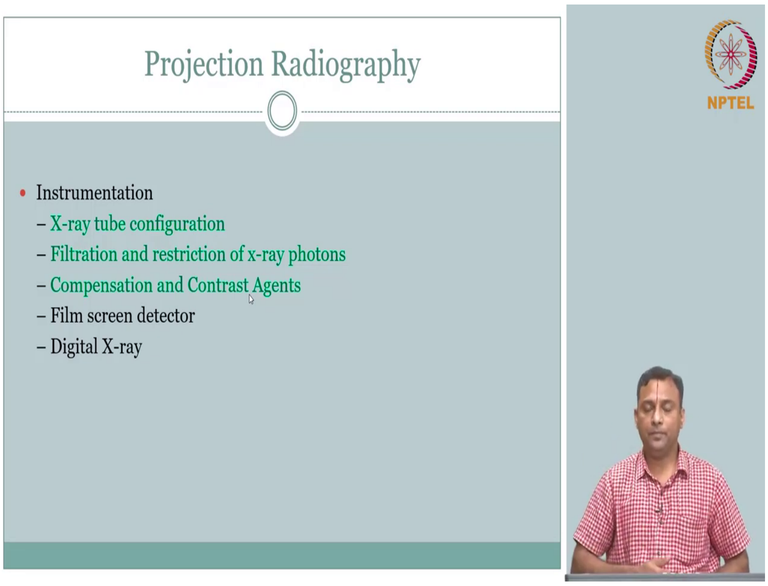

So, so much for compensation and contrast agents right. So, now, comes the you have source body right. You have a compensation and contrast agents had to do with the engineering the or maximizing the signal part, involving some tweaking with the object in place and then, you have your detector side.

So, whatever goes in interacts with the body comes out. So, now, it is time for us to do two things; one is the instrumentation so that we can catch whatever is coming back, not only catch whatever is coming through the body right, it has to it has to have good signal to noise ratio or contrast noise ratio right.

So, what is our signal? It is coming through the body, having interaction and then coming out number of photons x-ray photon. What is our noise or detrimental interaction? The Compton scattering what is going in, but then because of the interaction, it is scattered out right. So, when I stand at the detector behind I have to catch the signal, I have to minimize the photons that are coming due to Compton scattering ok. So, two things we need to understand in the instrumentation.

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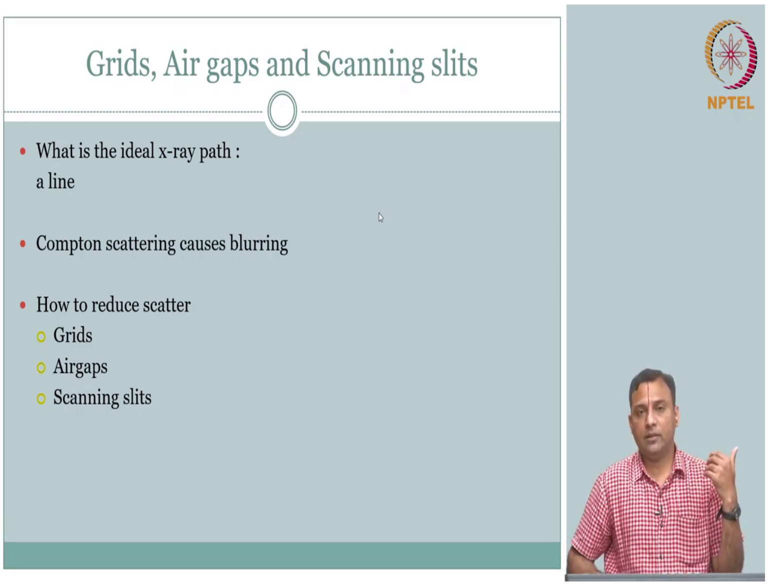

One is how do I accomplish this of maximizing my signal, minimizing the Compton scattering, next is after I know that is the signal let us come through the path, how do I convert it into a image right; what are the; what are the sub modules the instrumentation that is used to convert this into a image ok.

So, first is what is the ideal path? What do I mean by ideal path? We have the x-ray source and we talked about x-ray source as a cone right. It is sending out. So, source itself is small and it is travelling the distance and it is diverging. No matter what even if it diverges, it is always travelling along a line.

So, if I have a detector. So, if it is travelling at an angle right simple case if it is travelling straight, I expect it to come out straight that is going to be by signal, along the path length there is been interaction. So, it is hitting if it is diverging, it is going to hit at an angle and it has to come at the same angle.

So, it will take the straight line path. So, ideally you want only the straight line path in which sense, I can say if I have my detector it is hitting right, I can say that it actually came through the line that is ahead of it; in front of it. The interaction took place along the line in front of the detector.

So, the line collecting the detector point to the source point. So, the material was along the line that is our ideal scenario right that is the ideal signal. So, we expect the path to be a line clear. So, naturally, you have to do two things; one is if that is the case, I want to ensure that whatever came through scattering right, I can say that it is not my signal. So, if it does not come along the line connecting the detector to the source, that is something that I do not want, that is something that I want to avoid right.

So, essentially, your grids, air gaps or scanning slits will quickly run through each of them, their objective is to enable this; enable minimizing the signal that is entering from scattering, Compton scattering and maximizing the photons that are entering through the straight line path right. So, in some sense, you are trying to get very good signal to noise ratio right.

In order to get that, you have these instruments to first increase the chance of your signal and minimizing the chance of picking scattered. So, what does Compton scattering do? We talked about this briefly is Compton scattering essentially causes blurring right. So, I am looking at the straight line path, but then something Compton scattered is coming in getting hit at the detector.

So, my model, I will I can only say because I do not know. So, I am just sitting here. The detector is just receiving it. So, we will only pretend our model is it is coming from straight line. So, whatever came from here, we will we would assume we can only assume it came from the straight line. So, essentially, what happens is your blurring, your resolving capability goes down.

So, if there is a blurring because of Compton scattering. So, we talked about this before. So, it is a undesirable aspect and we need to reduce it. How do we reduce it? Maybe we do not want to collect that in the detector, before it hits the detector, we want to make sure that if there is a possibility we can make a kind of a filter again right, I would say some ways, where it is like a gating mechanism; I will only allow guys who are coming along the straight line, whoever is coming on the sides, I will not allow right.

So, that is what these grids or air gaps or scintillation slits, their job is before we hit the detector, how do we ensure? We get rid of scattering or at least the photons that are coming through scatter, minimize the photons that are coming through scattering. So, how to reduce the scatter that is the goal in this part ok. So, there are three ways to do it; we will quickly go through one each one of them. But in some sense, just by the problem proposition right and the name that is there, we can start to guess right.

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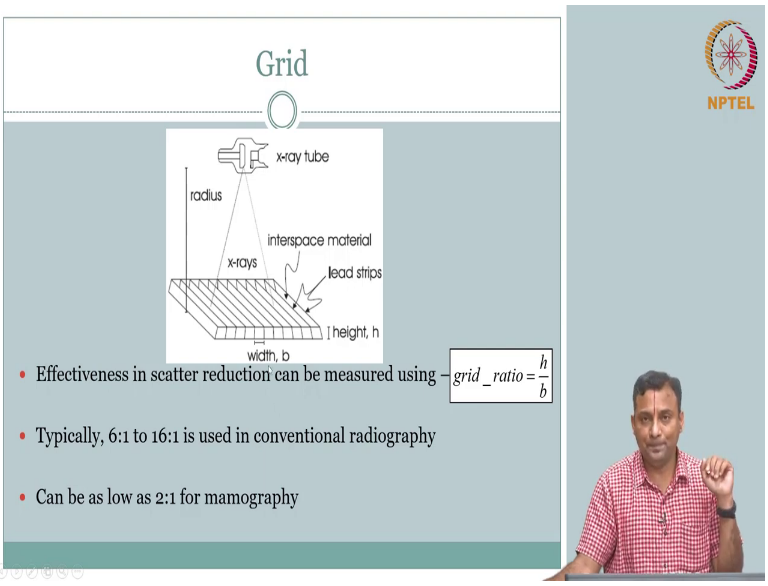

So, grid right. So, this is what we are talking about. You have your x-ray. The x-ray is sending at some angle right diverging and before it hits the patient or the object right, we cannot we are not that part is fine that part is done. But after, it comes out of the patient. So, there is an angle. When it goes hits the patient, there is a diverging angle that is fine.

Same line of sight is what we are going to use. But the problem arises because after it passes through the patient, the object 3D object, you are going to have scattering. So, that mean there is going to be angle. So, the detector is now going to not only have the line that you have from the source, but because of the Compton scattering you can have different angles that are coming in.

So, now the objective is how do I allow only the signal that was coming or the photons that are coming along the line of sight and minimize the ones that are coming at different angles.

So, how do we how do we. So, clearly it is gone through the patient, now we are talking about coming outside the patient with Compton scattered and coming out.

If it is Compton scattered and observed by the patient, we cannot do much right. Our interest now is assume we have sufficient signal that is coming out which we want to detect. So, that we can form an image. So, in such a scenarios something is coming out, how do we minimize that in the detector right minimize the Compton scattering in the detector so that the image quality is not compromised right.

So, there is a grid arrangement. So, in some sense, you can think about it as; that means, I is there a possibility where here for example, you have a grid of lead strips, what will lead do? If the x-ray photon hits the lead, it has more attenuation right. So, it will get absorbed. It if the length the thickness of your lead is going to determine how much is going to come out; but clearly, outside the body when it comes outside the body, all the x-ray photons you want to capture in the detector.

But then, I want to absorb. I do not want the detector to even receive Compton scattered photon. So, what can I do? I can have lead such strategically organized. What is strategy here? It is now a linear. It is organized in the linear grid fashion, not only that you probably can appreciate that it is not like parallel lead.

So, it is kind of having a focus, there is a tilt to the there is a tilt that you can see. So, it is focused. So, that this line of sight right it is kind of what they call as focused grid. So, because this is coming from diverging, this there is a tilt. So, that it is all focused; all the slits are focus. So, what will happen? You have lead and in between the lead, you have a transparent.

So, it can if it does not hitting this lead, it will go through. So, in some sense, if it is coming through the line, if it is only the photons that are coming through the straight line right will pass through without hitting the lead. If it is coming at a different angle, it is going to hit the lead and therefore, get observed by the lead right. Very nice way of thinking about it.

So, what are the factors; how can we ok it strategically arranged, but how can we engineer it? So, intuitively thinking, if I do not have any grid what is going to happen? Every angle, it is going to come and hit right. So, it is go detector is going to catch at every angle. So, when you look at this, the other extreme is I have lead right. I have lead that are next to each other right.

So, there are two factors; I can have lead next to each other which is controlled by the width which we call b and what is the thickness of or the height of your lead, height of your lead? Both of this is going to affect what is going through the. So, the width is going to dictate the distance between your lead is going to dictate because that is the transparent the distance between them is a transparent.

So, that is where you are going to go through right. So, in some sense, your b and height have a role right. So, if I have intuitively thinking, what factor what you know what relationship between h and b is helpful for you right. So, we could kind of think about this as your h right effectiveness. So, effectiveness of a scatter, how can we measure it? What is the effectiveness? I want only the straight line to come through, I want to abstract whichever is coming at an angle.

So, I want the lead to catch the ones coming at an angle, the Compton scattered one. So, how can I you know talk about effectiveness? I can talk about effectiveness by intuitively thinking about what is a favorable condition. So, I have one is h, the other is b. If I have very right.

So, if this is the direction, this is my source, this is my detector and I have this grid here. So, you can think the if the height of the grid is more, then there is a good chance that the more angles will be hitting the lead, it cannot go through. If the height is less, different angles can go in.

So, having a height tall or short which is favorable ok. Then what about your b right? b is the distance between the leads. Again, what is favorable? Well, if I have a height right, this is length is more, then in some sense that is going to have a shadow right. It can protects, it is all about the angles. So, it is more about the h by b; both of them right. So, grid ratio h by b.

So, I want to make sure that this ratio, I can manipulate to our advantage to talk about effectiveness. So, typically, you have about 6 to 1, you normalize it for b and report. So, you have about 6 to 1 or 16 to 1 in conventional radiography. So, this is a trade off right. So, but this is a range over which this h by b is used.

So, this is essentially to reduce the scattering. So, your tolerance, how much compton scattering you want to reduce this h by b that the angle right that is going to help dictate how much you can arrest. So, if you have a very large h right. So, the h by b ratio is large; that means, you are going to be very strict or I can be tolerant the h by b ratio can be small which means I can allow for little more angles coming in right.

So, you are essentially controlling how much of Compton scattering you want to arrest ok. This is something if you really think about it, when we talked about we did one simple calculation right.

Recall when we talked about number of photons that are last h mu and h mu dash and the energy and number of photons and the angle at which it can hit and still be considered straight line right; some 26.4 degrees, if it was hit, you still consider it as straight line path. Go recall that example that we did when we talked about Compton scattering ok. So, in some sense, your grid ratio tries to adjust for that angle.

So, you can be very tolerant or less tolerant of the Compton scattering depending on this ratio clear. So, this is fine. What are the other parameters? ok This ratio is important, but this is normalized right; one is normalized to width. So, to get a field for this what is this b, it is a distance between the two lines; instead of saying like that a common way of describing this specification is number of lines per centimeter right.

So, you can have say somewhere 60 lines per centimeter to 80 lines per centimeter; your instead of reporting it as b, it report at number of lines per centimeter. So, roughly you have 60 to 80 lines per centimeter in a typical system depending on the application either it is for mammography or is it for you know chest x-ray, depending on the application that can change vary in that region.

So, you have the ratio and the distance both of this are manipulated based on the application and level of noise that is tolerated or signal to noise ratio, contrast to noise ratio that the physician is ok with to make a reliable diagnosis. You see its always a tradeoff, that is the whole point ok. So, this is with respect to reducing the scattering. Yeah can be as low as 2 is to 1 for mammography ok, fine.

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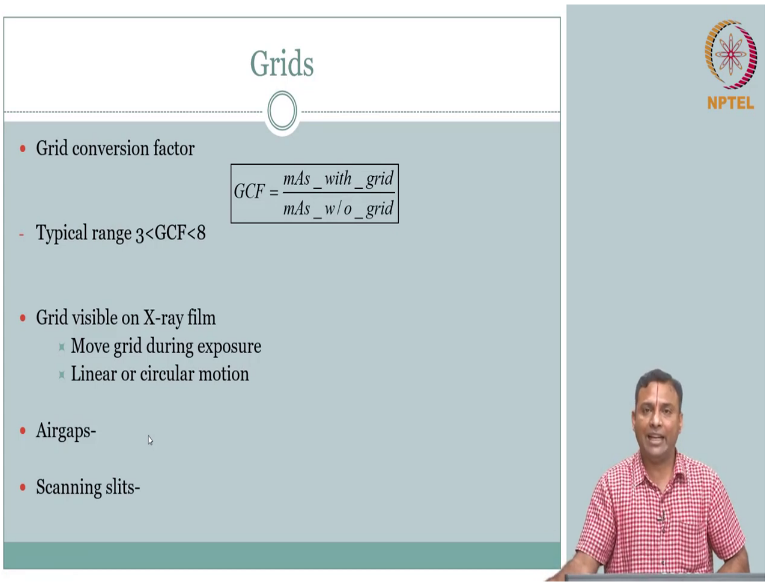

So, that is with respect to your grids. Now, the question is well you are talking only about reducing the scattering right. We talked about just reducing the scattering, but what am I interested? I need to have not just reduced the noise right scattering, I need to have increase the signal to noise ratio or contrast to noise ratio; but what happens when I use the grid?.

Whatever is coming at the angle I have reduced, but what happens when the lead; so, when the signal like the photon comes and hits the lead there is a grid of leads right or attenuating material what happens, when the photon is actually hitting that? Well, if it is hitting that that is also lost.

So, in some sense, you are getting the signal only through the transparent window that is adjacent to the leads right that is sandwich between the that the gap between the leads, not only you are hitting the you know the height of the lead controls which angle it is hitting that that is observed. But depending on the height when whatever is coming and hitting the lead itself that is also lost, your signal is also lost wherever the grid is actually physically where the leads are placed.

So, in some sense, I have reduced my noise, but I have also reduced my signal. What is of interest? Increasing signal to noise ratio one way of doing that is reducing the noise for the same signal, but if signal is also reducing; is it prudent? Clearly not. So, how can we increase the signal right for the given reduction in Compton scattering or the noise.

The only way is increase the number of photons, if you increase the number of photons for the same schematic right, then whatever is Compton scattered will reduce because of the grid, whatever the signal is lost due to the grid placement itself, you get more photons that are coming through because you have increased the absolute number of photons that as coming through; that means, your exposure is increased.

So, there is always a tradeoff. Your exposure is increased, but you get better signal to noise ratio because the grids have reduced the scattering. So, how do we talk about this scenario. So, for example, I want to increase the signal to noise ratio should I use the grid or not?.

Am I going to get better rewards for increasing that exposure because the quality is increasing or essentially, I end up with the same similar ratio of your signal to noise ratio that there is no point in increasing the dose, when your signal to noise ratio is about the same right. What do we do? So, we have what is called as grid conversion factor What is that grid conversion factor? It is the m A s. What is m A s? Current into time m A, milli Amperes tube current into s, your time that had to do with our exposure.

So, exposure with grid to exposure without grid, what does this convey? If I have if I do not have grid right, if I do not have grid, what is a scenario? I have some exposure without grid. So, there is some n number of photons that are coming, but then the scattering is also high. If I have grid, with grid your scattering is low.

So, what do you think this ratio is going to be? The moment I use grid right, the moment I use grid, my noise is going down, but my signal is also going down; whereas, without grid I have both signal is also there, noise is also there. So, now, what does this GCF do? GCF allows us to capture the sentiment via how much of the signal to noise ratio you are gaining because of having the grid right or rather if I do not have the grid and if I have the grid what we know already is if you have the grid, you may want to increase the signal; otherwise you are losing the signal also.

So, this grid conversion factor tells you how much you should increase the exposure if you have the grid compared to when you do not have the grid to compensate for the loss in the signal and of course, reduced in the noise ok. So, typically, a grid conversion factor is about 3 to 8. So, grid conversion factor into exposure without grid is equal to the exposure with grid.

So, if you look at this number here that is mean it is saying if I use grid, the exposure with grid is several times right. Because 3 to 8; 3 to 8 several times the exposure without grid clear. So, how much is it? This is the factor. So, you have to increase the exposure. So, that is a trade of dependent depending on the application, the doctor decides whether it is favorable, it is worth increasing the grid conversion, I mean increasing the signal to noise ratio by increasing the exposure or not.

So, if I increase this if I introduce this grid, then my quality goes down. So, I have to increase my exposure. So, this is where they make their domain knowledge expertise. So, think about when you maximize the signal, when you minimize the signal, your noise is Compton scattering.

When all can it happen well? So, you are introducing this grid to reduce the Compton scattering. When all can it happen? I can have it goes in I have Compton scattering. So, if the thickness is more right, if the thickness is more, then there is a chance of more Compton scattering coming out at angles are going to cause problems.

So, a rule of thumb that they have figured out is if it is less than 10 centimeters thickness that we are talking about. So, if you go for your arm imaging, you break a bone or suspect that you break a bone, maybe you know its very very its not that thick right the depth you can place it so that the its not much thicker you know 2, 3, 4 centimeters something like that.

You do not gain much at least they are found that it is not worth having a grid conversion factor and having the increasing the exposure; it is not worth. Because the Compton scattering itself is going to be less because the thickness of the material is less.

So, as rule of thumb the if it is a greater than 10 centimeters, then they want to consider introducing the grid that is when they believe that the benefit of introducing grid out west the cost that extra exposure that you need to do. The other way is that is one rule of thumb; the other is regarding the energy, when do you have Compton scattering at all energy levels and if you look at the signal right, there was a hill curve

So, if you are going to operate at a lower energy level, then you know you are not going to benefit much because even if you increase the exposure, the inherent contrast right the interactions is going to be limited and so, you are not really going to benefit much. So, another rule of thumb is whenever you want to have the grid, whenever they have greater than about 60 kilo electron peak when you are operating the x-ray tube with greater than 60 kilo electron volt peak, that time you want to introduce this grids.

So, these kind of domain specific, application specific experience based empirical rule of thumbs have been evolved whether to use the grid or not because of this grid conversion factor either you are you do not want to increase the exposure unnecessarily if you are not going to gain much in the signal to noise ratio or the reduction in the noise due to the introduction of the grid ok.

So, one another problem, this apart from the grid conversion because you have to increase the exposure the other problem with the grids is you are going to have shadows right.

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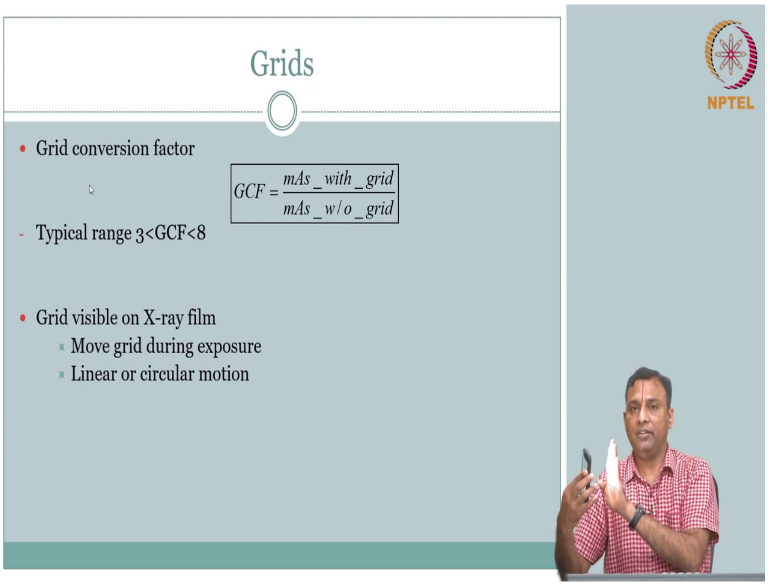

So, I mean it is difficult because when I camera is in front of me and I cannot show the shadow because the camera will obstruct it.

But the idea is if this is the grid right, if I do not have if I have the light coming in, there is a shadow behind right. If I move the grid, there is opening and the light can form. So, you can clearly see a shadow of my four fingers or this is the grid for example, right lead grid.

So, clearly if on one side you have photons come, the other side you have a shadow of the grid ok. So, that is not that is not the shadow because of the material having a grid light structure that is not because of material having a grid light structure. It is because of the grids that are there. So, it is an artifact. So, how do you reduce that? We can move the grid during exposure so that you can you know blur it uniformly.

So, there are there every location right in between the in between the grid. So, when you move, the location of the grid is also moving. So, you can have you can smear it throughout the background. In some sense, willfully you are smearing it, blurring it so that it is all homogeneous therefore, whatever differential you have is only due to the difference in the tissue ok.

So, you can do it like that. Last, but not the least air gaps air gaps is again not really an big instrumentation aspect. It is just using this knowledge that you have the line from the source to the detector through the object. So, there is an angle at which it is coming. The Compton scattering happens; the origin of Compton scattering is inside the object.

So, the distance between the object where the Compton scattering originates and the detector that angle is going to be different from the angle of your source to the detector. So, in some sense, if the detector is moved away from the object, then we could separate out these two angles ok.

So, in some sense, it is not really an instrumentation; the idea is to exploit this knowledge that if you have a gap between the detector and the object basically air gap, if you do that, you naturally reduce the Compton scattering. Of course, this is not so great because you will see that it also affects the signal and the contrast and the you know when we talk about imaging right the effect due to this distance between your object and the detector in terms of magnification will all come into picture.

So, it is ok; it is a slight maneuvering, but it is not that great. Again, scanning slits. We talk about slits; when we talked about slits in the contact or outside x-ray tube, when we wanted when we wanted to do the field of view right. So, we said slits is one thing. So, you can have actually slits here also. In some sense, what do we want? We have grid, now we are talking about the problems due to grid and what how we it arrested these Compton scattering.

So, why cannot we have slits right, in front of the object and back of the object. So, this is slit 1 right, slits you have openings, I have another slit openings. So, I can have one in front of the object, one in back of the object right and they both are aligned nicely. Then, what is going to happen? Instead of sending the x-rays, in the grid what happens? It goes through the patient right.

And the grid is behind the patient. So, the signal that came through the patient after the interaction, when it is hitting the grid that is lost. So, you have dosed the patient, but you are not exploiting that signal. Instead what we can do is we can have the slit also in the beginning, that way you do not even dose the patient where the grid is right.

So, you align these two perfectly, that way only through the transparent in between the slit locations, the signal is going through Every other angle even here, it is arrested and therefore, whatever comes out of Compton scattering, you can manipulate here and it can get arrested.

So, in some sense, you have reduced instead of sending the signal through the body and getting hit by the slits here or grids here, I can only send in at locations, where there is no slit; where there is no grid right. So, I can have a slit that is perfectly aligned. So, now, what will happen? Now we get best of both, but the only problem is the signal is lost, you do not get signal.

So, you have to increase the exposure right and also, here in this sense, you are not scanning; you are not going through certain locations wherever the slit is not allowing it. So, what we can do is have these two slits and move the slits right. So, what we call as scanning through the slits.

This way you can reduce the scattering, you can increase the signal as well. So, it is very effective in reducing the scatterer, but the only challenge is instrumentation is little bulky, you have to now synchronously move these two and exposure is also increased because you are you know getting more short circuit while it is moving different locations.

Of course, time is also little more because now you are scanning few location so that you do not have this shadow locations, that is the downside, but then you get good signal to noise ratio. So, this is again something that is used in higher end systems.

I think this is a good place to stop, before we hit the detector side of it that will be covered in the next lecture.

Thank you.