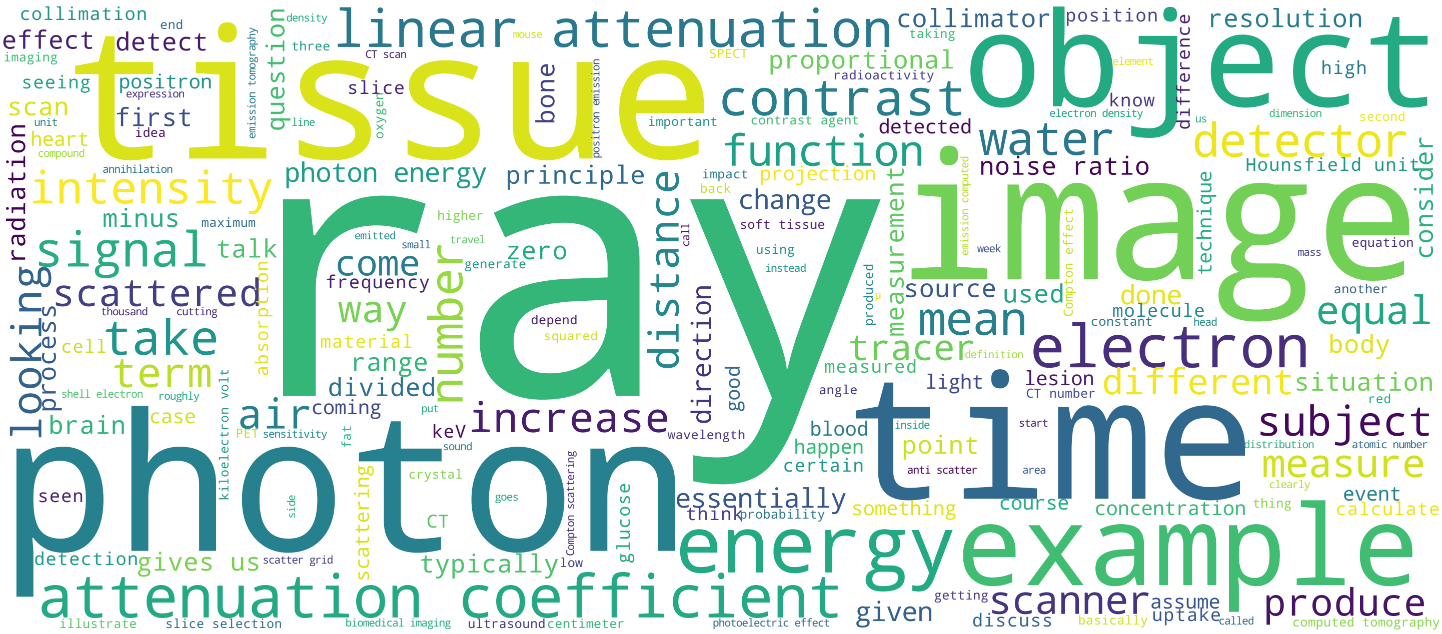
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

4.2 CNR in Computed Tomography

Fundamentals of Biomedical Imaging

Prof. Rolf Gruetter



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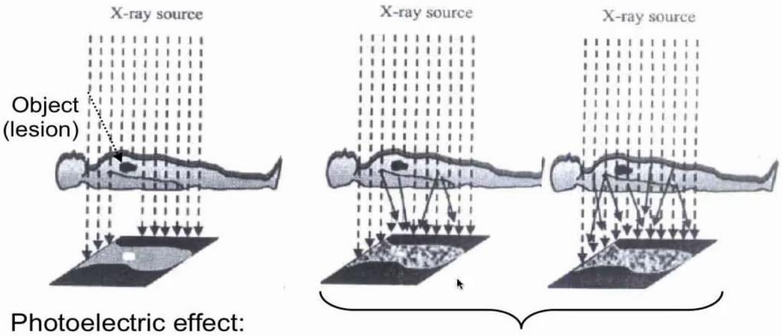
Video

EPFL

4-2. How does x-ray scattering impact CNR ?



Photoelectric effect: complete absorption of photons → Object (lesion) easily detected

With E_γ ↑: Compton scattering → increased masking of object.

4-7

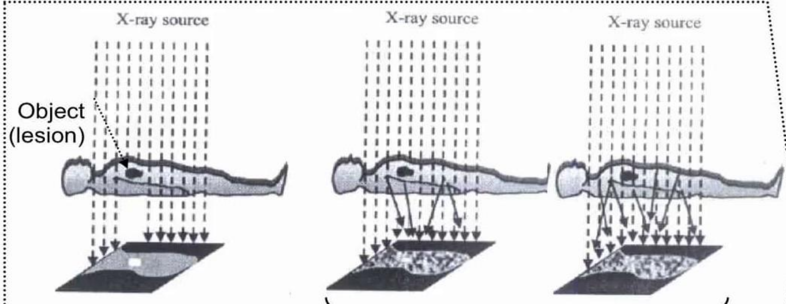
We have seen that the size of the object has an impact on contrast. There's a second consequence, and that is the impact of scattering on contrast to noise ratio. And I want to address this question-- how does x-ray scattering impact the contrast to noise ratio. Let's look here at an idealized situation. We have an x-ray situated-- x-ray source. And for simplicity, assume that we do for the entire course, that the x-rays are coming in in a collinear, coplanar way. We have the subject here, and the subject here has a lesion. This is the lesion here. And now we will assume that this lesion is such that it is producing complete absorption of the photons, through the photoelectric effect, and this complete absorption, obviously, means that the object, the lesion, is easily detected. Now, let's consider the situation where we increase the photon energy. As we increase the photon energy, as we have seen, Compton scattering becomes increasingly predominant, and this produces an increased masking of the object, as follows. We have the film that we detect, here-- here's the idealized object, here. You see it very clearly, here.

Notes

Summary

0m 04s

4-2. How does x-ray scattering impact CNR ?



Photoelectric effect: complete absorption of photons → Object (lesion) easily detected

With E_γ ↑: Compton scattering → increased masking of object.

Scattering increases with FOV (field-of-view) of irradiation
⇒ Further reduction of image contrast

Solution: Anti-scatter grid (collimator)

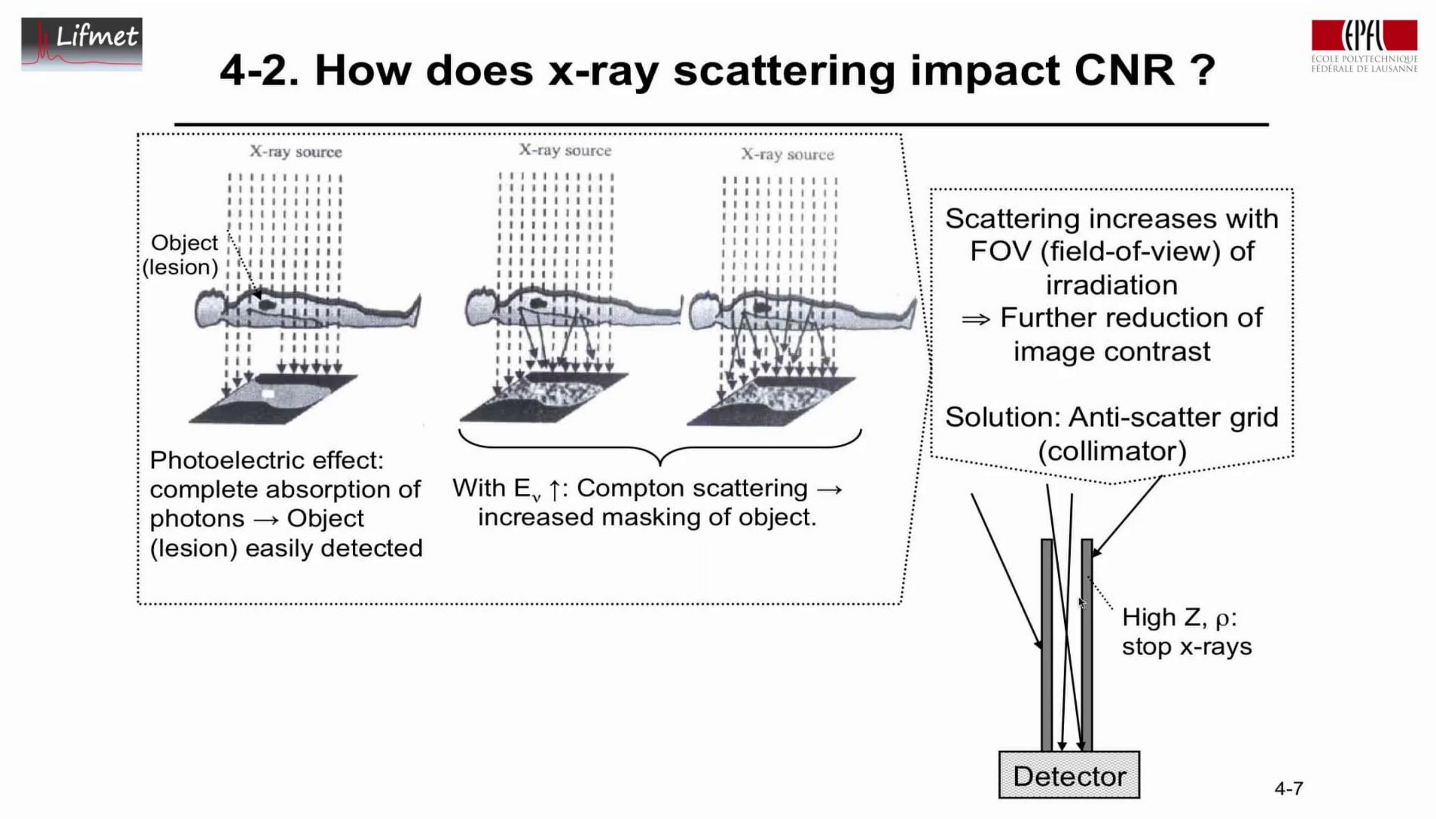
4-7

But now, we can have photons that are being scattered by the Compton effect, that are detected at this location, even though they have come this path here, and then they are coming through here. As we increase the photon energy even further, Compton starts to completely dominate the mechanism of x-ray interaction with tissue. We have increased Compton events, and this leads to a near complete masking of the object. So, this scattering, the probability of this scattering, obviously, increases with field of view, as the object is bigger-- so we can have a photon scattered here at the lower abdomen, and up here at the level of the heart, because it has been scattered. So, with a larger field of view of a radiation, we have an increased reduction of image contrast. And the solution here is to mitigate the effects of scattering by using an anti-scatter grid, which is actually the same thing as a collimator, and collimators are something we are going to talk about next week, when we talk about emission computed tomography. So, let's look at schematically, what this anti-scatter grid or collimator is doing. We'll presume we have a detector, here, at the bottom.

Notes

Summary

1m 27s

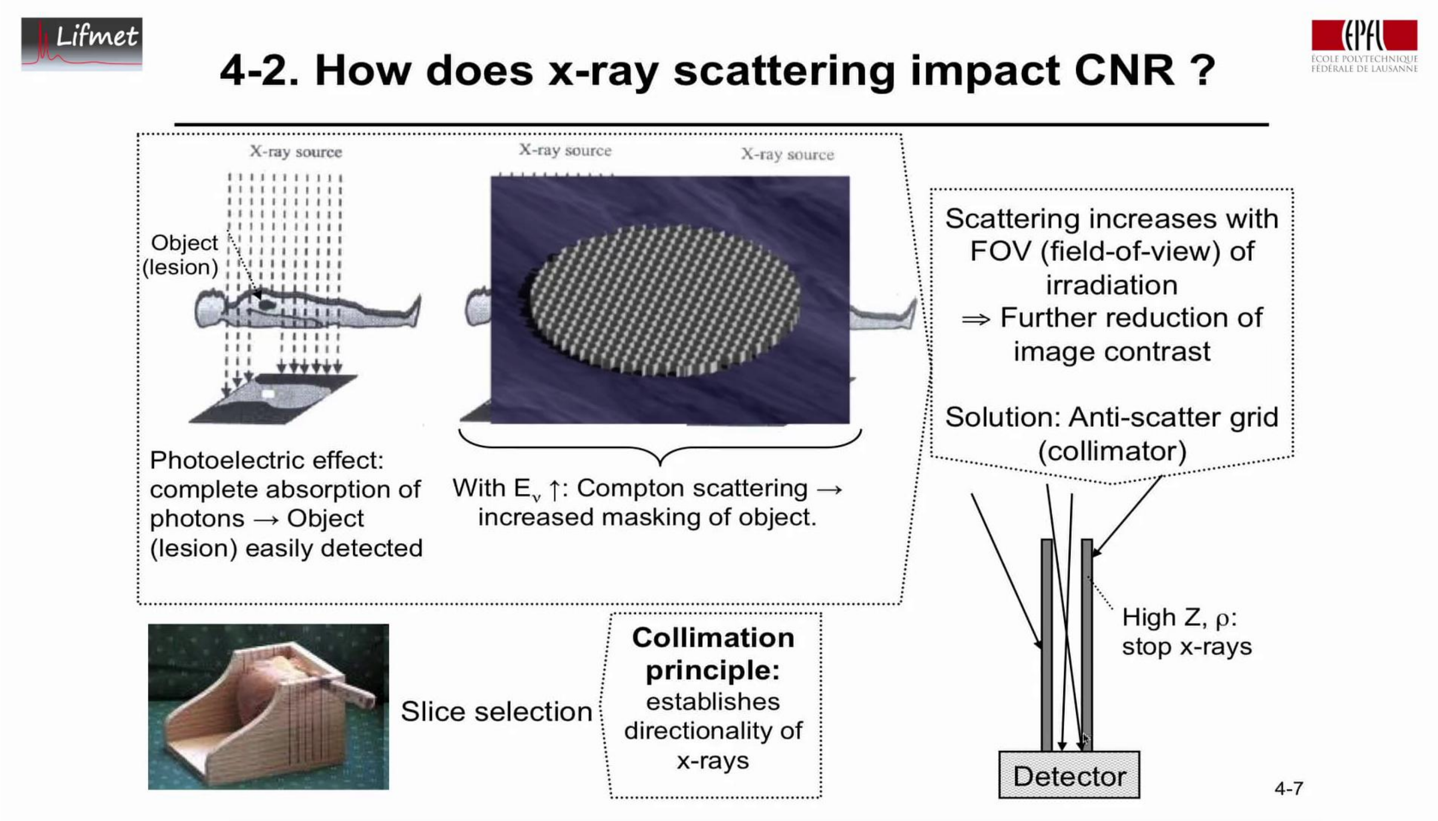


And then we have two thin stripes-- in this case we'll idealize it. This is not the complete situation, but doing it idealized the principle-- this is a material that has a very high atomic number set, and a high electron density. We can idealize it, it's not a perfect situation, but this a material that is capable of stopping the x-rays. So, the x-rays are coming nearly collinear, as we would like to have it, here. They come in, they're still passing in the detected-- by the detector. For x-rays that are being scattered by Compton, that is these x-rays here, here, and here-- they don't have the proper angle-- so, they are not coming in a collinear fashion. They hit this collimator material, here, and they are being stopped, so they cannot penetrate, and so they are being eliminated.

Notes

Summary

2m 53s

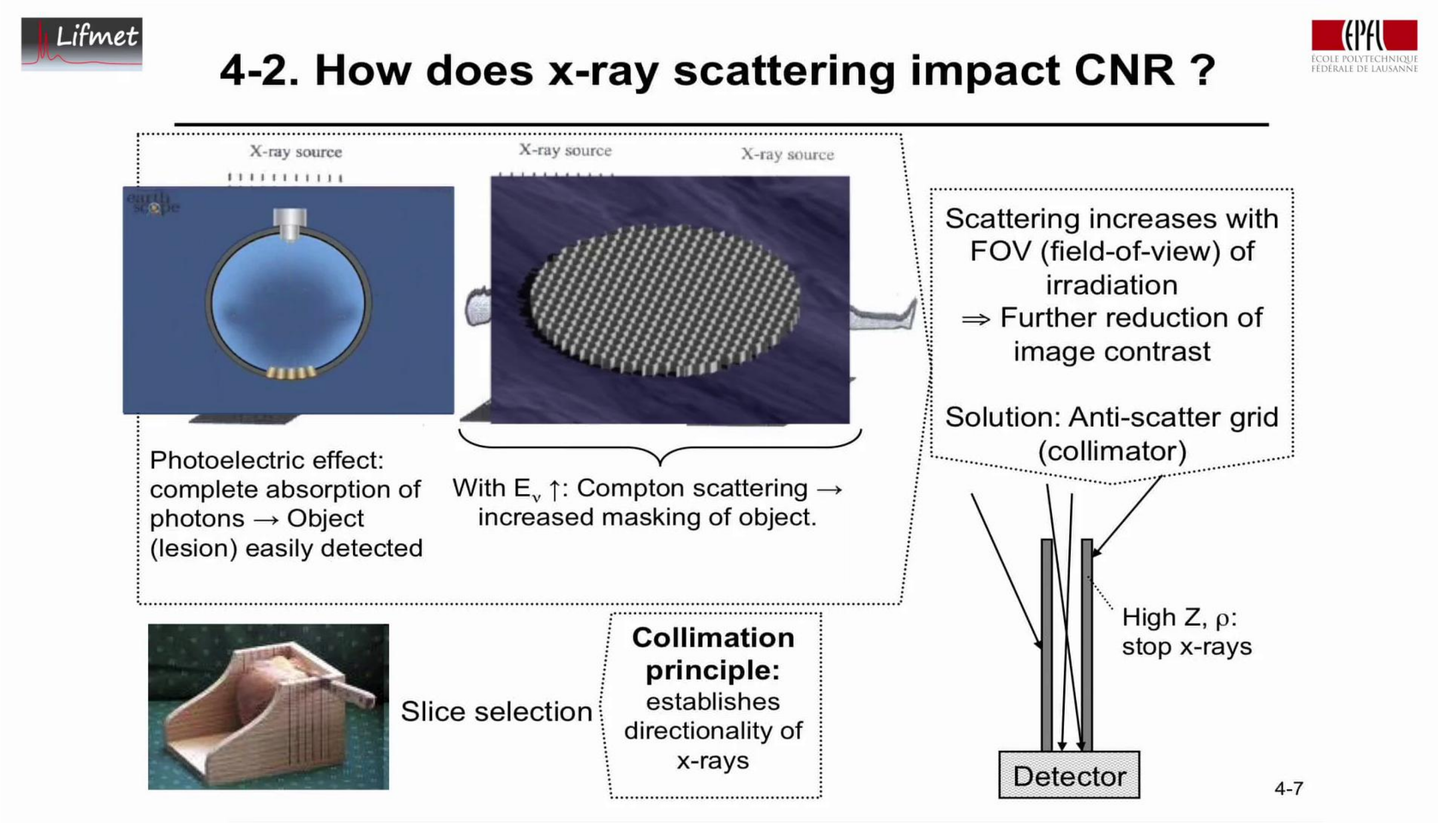


In the real world, the collimator grid looks like this image here. So, it's a hexagonal structure, has a certain thickness, and this does ensure a certain directionality of the x-rays. This collimation principle is brute force way of establishing directionality of the x-rays. If there's a way we could detect the x-rays--not only just the x-ray, but also say, well, it came in this direction, or that direction, this would be the perfect experiment to do--we wouldn't need it-- but this is not very easy to do, so this is a brute force way of establishing the directionality of x-rays, by elimination of those x-rays that do not fulfill the geometric requirements of the detection. And here, I want to illustrate this principle, so if we establish collimation, we can use this to select a slice. And this is the only time I'm going to talk for the x-ray techniques about slice selection. So we're basically--the collimation establishes that only x-rays that are coming in a certain direction, or nearly that direction, are passing through the detector. And the way we can see it is that we actually are taking this [spread], that's our body, and, virtually, with this instrument, we're cutting it into slices.

Notes

Summary

3m 50s



That's slice selection as it is being done. Obviously, we're not cutting the live subject-- that would not be very practical and admissible. It's done by the instrument. So, it's a virtual slice selection-- here, this is real, by cutting the slices with a knife, but we're doing it with collimation-- we're ensuring that only what is between these two cutting holes is being passed through the detector. And, so, here in this short video, we are seeing the detection of a CT scan. We're seeing the detector rotate with the source. This is what we'll discuss later this week, on how the images are being produced. And as you can see, as the video moves on, you are seeing, now, how the subject is being moved through the scanner. So, actually, here, the slice selection is being done through the collimation. We're selecting a slice. But instead of having multiple slices that we can select, we are physically moving the patient bed through the scanner, and this generates all these images that are then appearing in the video one by one. So this is a way to generate a slice selective information.

Notes

Summary

5m 07s

How is CNR quantified ?

Signal:

$\propto$ I(d) (no. photons detected)

$\propto$ I_0 (no. photons irradiated)

Contrast: ΔI(d) due to μ(d) differences

- i(E_v), μ_C produces reduced contrast
- Compton scattering: Antiscatter grid

CT intensity can be measured in absolute terms (CT-number)

4-8

Now, we will talk about the quantification of contrast to noise ratio. How is this, now, quantified? The signal is proportional to the intensity as a function of a distance. So, it is proportional the number of photons detected. It is, therefore, also proportional to the number of photons with which we irradiate the subject. And so, the contrast that we get is actually a contrast-- a change in the photon numbers, *Δ I*, as a function of distance due to differences in the linear attenuation coefficient. We have a distribution of the energies-- energy spectrum, *i(E_v)*. So, the Compton effect, *μ_ C*, produces reduced contrast. And we have Compton scattering. So, this is dealt with with the anti-scatter grid. So, let's assume we have all this solved. The scattering is eliminated, and we have a way to quantify. Now, the thing is, here, what I want to point out is we have the intensity, the *I_0*, we have-- the link here is the linear attenuation coefficient. And so, since we can measure the relative-- the *I(d)* as a function of *I_0*, we can have an absolute measure of the absorption of the CTs. And this is something where CT, for example, is different form MRI.

Notes

Summary

6m 30s

How is CNR quantified ?

Signal:

- ∝ I(d) (no. photons detected)
- ∝ I_0 (no. photons irradiated)

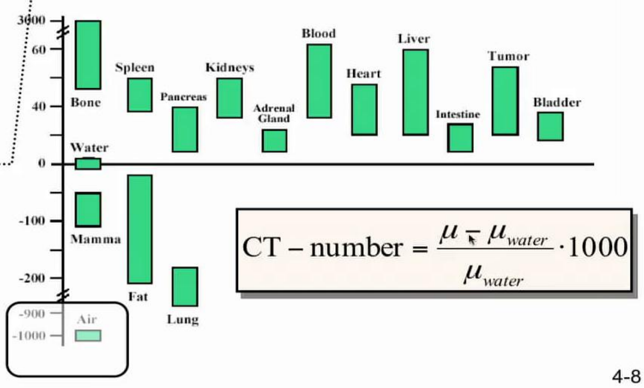
Contrast: ΔI(d) due to μ(d) differences

- i(E_v), μ_C produces reduced contrast
- Compton scattering: Antiscatter grid

CT intensity can be measured in absolute terms (CT-number)

Soft tissue: Typically has weak contrast (small **Hounsfield units**)

CT-numbers of tissue in Hounsfield units (HU)



$$\text{CT} - \text{number} = \frac{\mu - \mu_{water}}{\mu_{water}} \cdot 1000$$

HU : attenuation normalized to water (≡0)
range from -1000 (air) to +3000 (bone and contrast agents)

4-8

We have an absolute measure of the CT intensity, which gives rise to the term CT-number. In soft tissue, we typically have weak contrast, and so this is quantified in Hounsfield units, and they are small Hounsfield units. And so, we look here at the CT-numbers in terms of Hounsfield units. Now, a CT-number is the linear attenuation coefficient of the tissue in question, minus the linear attenuation coefficient of water divided by the linear attenuation coefficient of water, and then, the whole thing multiplied by a thousand. What does this mean? This means we're looking at the deviation of the linear attenuation coefficient from that of water. So, this would be a dimensionless unit, which gives us the relative deviation, and this is multiplied by a thousand. So, it is normalized to water by definition. If μ, here, is that of water, this is the CT-number is zero. And we have a range from minus 1,000 for air, to plus, 3,000 for bone and contrast agents. Air is at a minus 1,000-- well, air has, essentially, no linear attenuation coefficient-- there are no electrons in air, or very few; the density is very low. So, we are getting minus μ_water, divided by μ_water, that's minus 1, times a thousand, is minus 1,000.

Notes

Summary

8m 06s

How is CNR quantified ?

Signal:

- ∝ I(d) (no. photons detected)
- ∝ I_0 (no. photons irradiated)

Contrast: ΔI(d) due to μ(d) differences

- i(E_v), μ_C produces reduced contrast
- Compton scattering: Antiscatter grid

CT intensity can be measured in absolute terms (CT-number)

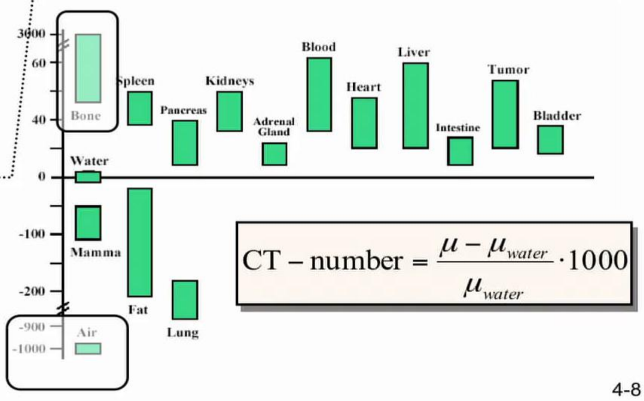
Soft tissue: Typically has weak contrast (small **Hounsfield units**)

HU : attenuation normalized to water (≡0)

range from -1000 (air) to +3000 (bone and contrast agents)

soft tissues: -300 to +100

CT-numbers of tissue in Hounsfield units (HU)



$$\text{CT} - \text{number} = \frac{\mu - \mu_{water}}{\mu_{water}} \cdot 1000$$

4-8

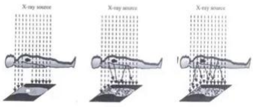
This is where we have the air, down here. And we have the bone, here-- this has a high electron density, so we have up to plus 3,000. So, what does 3,000 mean? 3,000 means that the linear attenuation coefficient of bone is 4 times that of water. 4 minus 1, divided by 1-- that gives us 3, times a thousand, gives us 3,000. Now, look at all the other tissues. And note here, the break in the vertical scale. We're looking at Hounsfield units, here, on the range of, essentially, from 20 to 60. So, these are very small deviations from the linear attenuation coefficient of water. They are, obviously, primarily water, so water does dominate our contrast. We have breasts, we have fat-- there's a lot of fat in breasts-- and we have the lung, here-- which is air, so it's getting close to air. So, we have weak Hounsfield units, that means we have not excellent soft tissue contrast. The main contrast mechanisms are air, tissue, and bone tissue-- those are the strong contrast that we see in CT images. So, we're looking at a range of minus 300 to plus 100 for soft tissue.

Notes

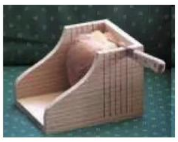
Summary

9m 36s

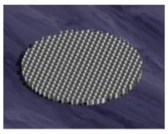
Credits



“Introduction to biomedical imaging”
Fig. 1-11, from Andrew Webb

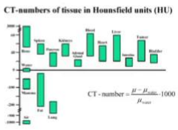


Bread Slicer
http://www.runnerduck.com/index.html



Varitech International
http://www.varitechinc.com/VariTech%20International/Varian/5006306093.jpg

Computed Axial Tomography (CAT) Scan
https://youtu.be/JrWfk6ih_nI



Data Acquisition, Representation and Reconstruction of medical images Application of Advanced Spectral Methods.
https://edurev.in/studytube/Data-Acquisition-Representation-and-Reconstruction-of-medical-images-/38083756-41cd-489d-b613-33456bedeefa_p

Notes

Summary

11m 05s