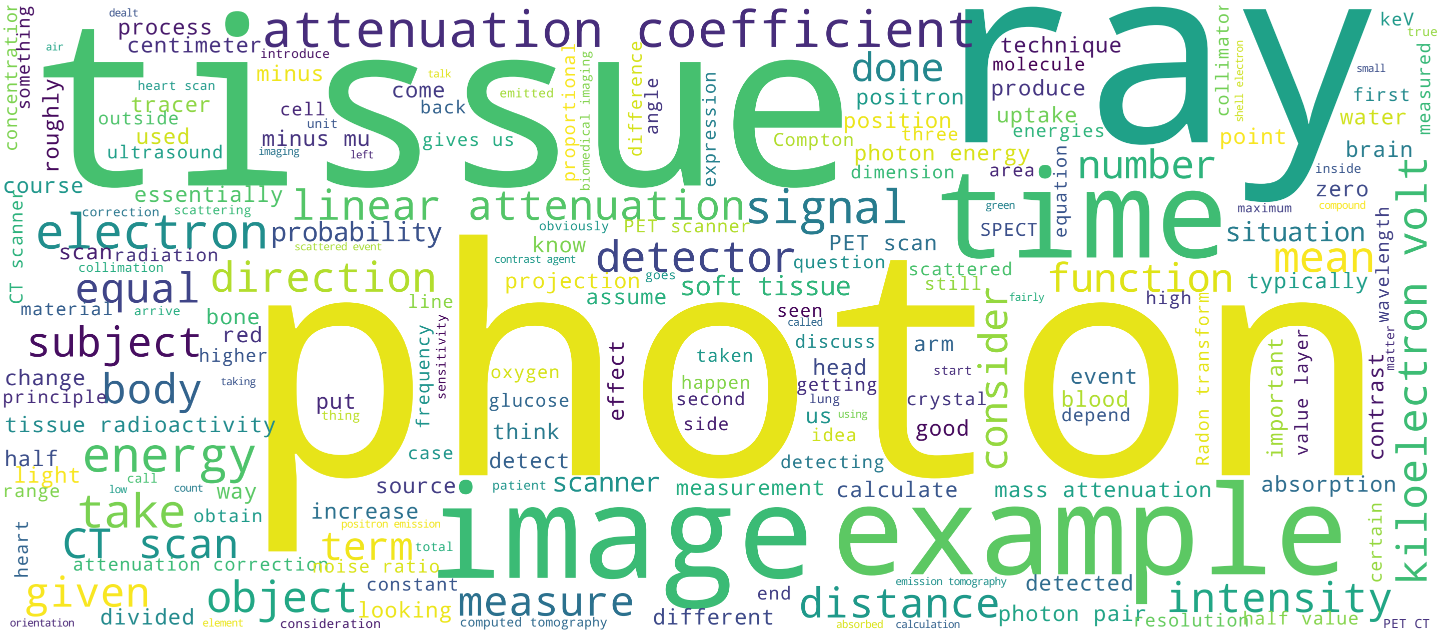
6.3 Attenuation correction in PET & PET/CT

Fundamentals of Biomedical Imaging

Prof. Rolf Gruetter



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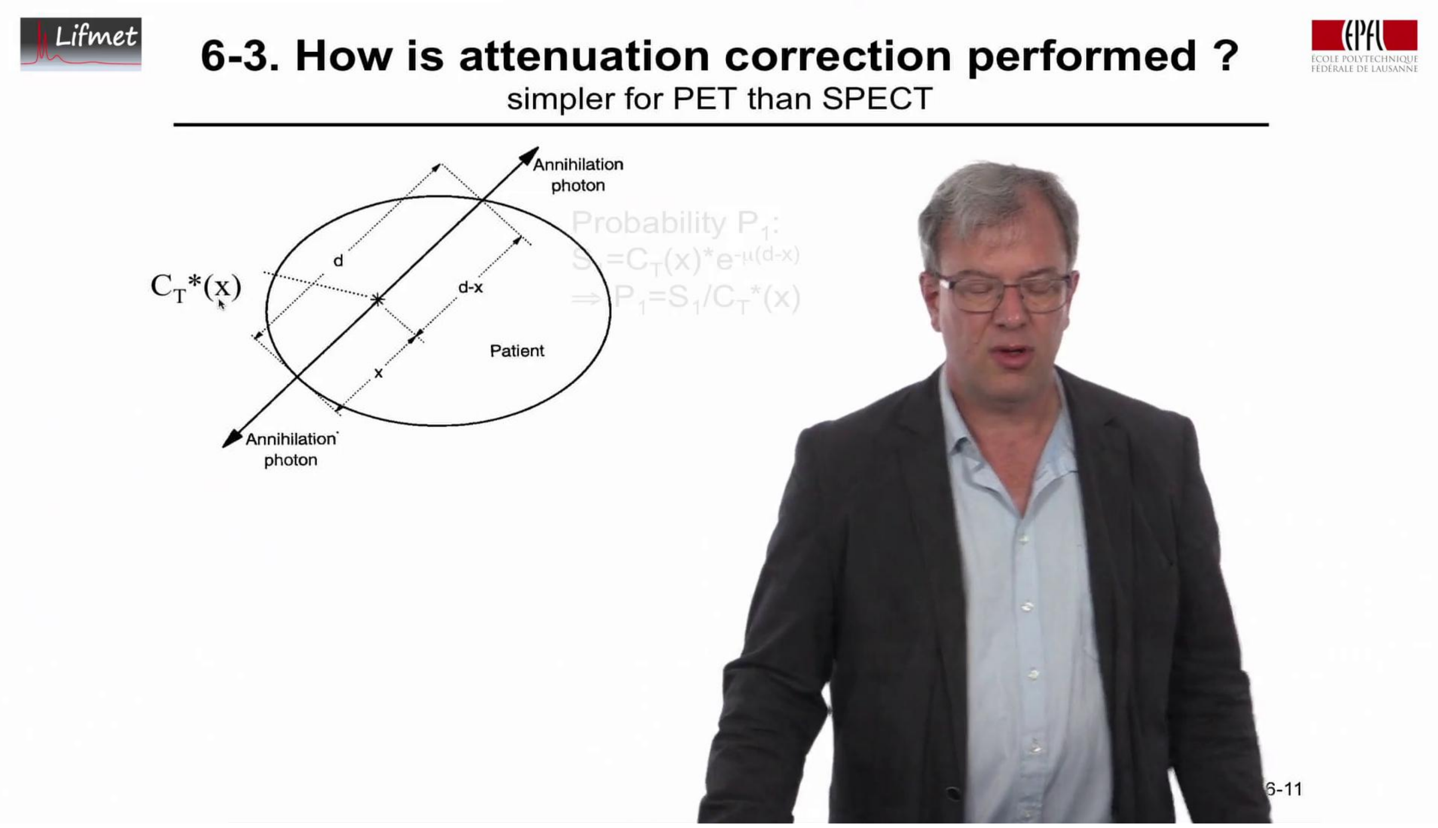
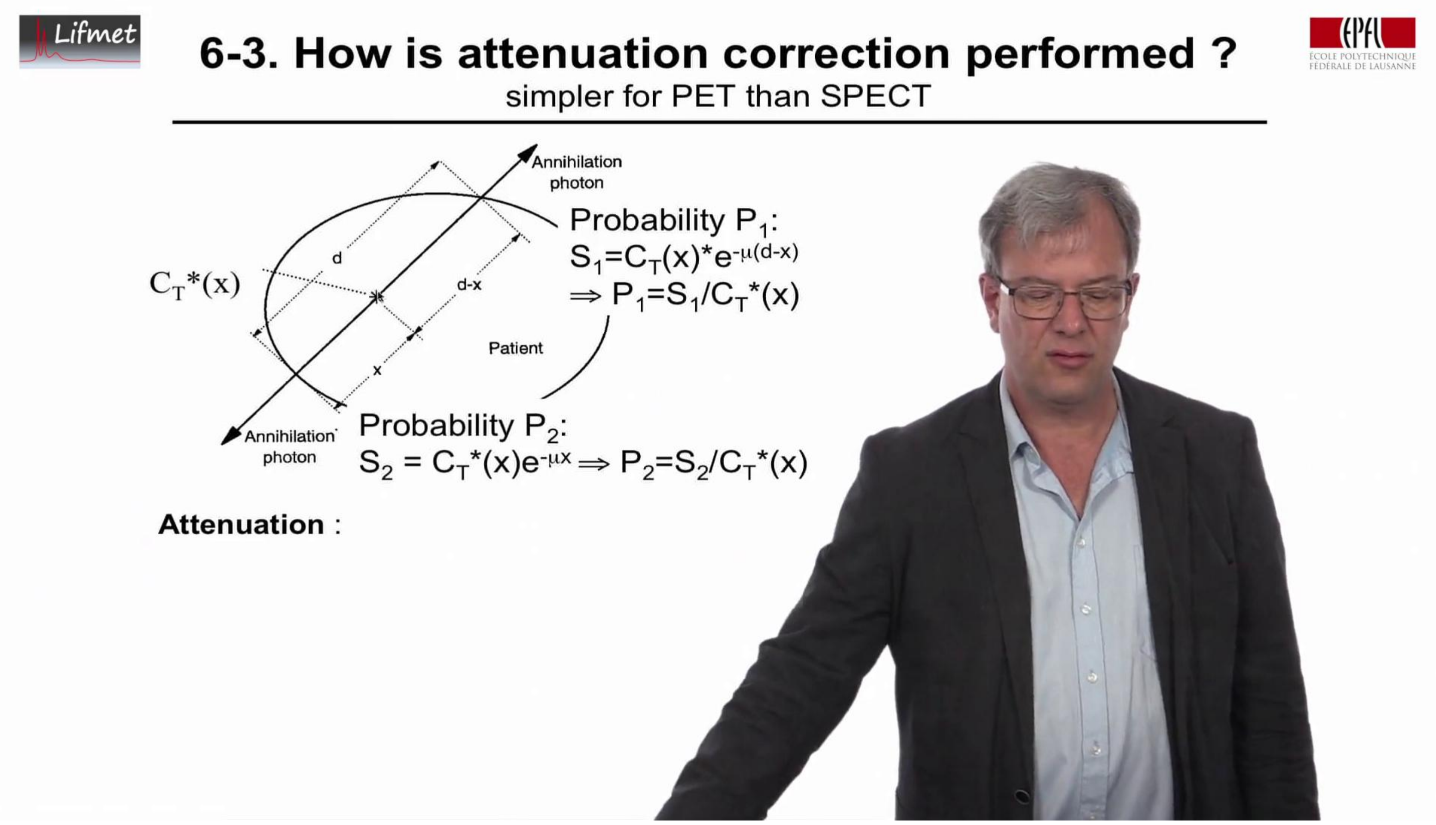


We have, in a previous section, mentioned that the events that we are detecting are trues, randoms, and scattered events. And for trues, we have to apply attenuation correction. So, let's assume we have a situation where we've dealt with the scattered events, we've dealt with the random events-- but still, for the two coincidences, we have to consider the fact that they are not detected at 100% because some of them are being absorbed in the body. So, let's look at the situation, here, schematically. We have our subject, here, the patient, as an oval. We have a generation of an annihilation photon pair, here, at this point. We'll consider the direction of the photons. One photon travels a distance *x* through the body, and the other photon travels a distance d minus x. So, the total path that the photon pair travels through the body is the length is given by *d*. We'll now say, at this point, we have a tissue radioactivity of *C* for tissue radioactivity, *T* for tissue, star to indicate x-ray activity, as a function of position *x*, here. So *x* is our variable. Now, what is the probability that the signal arises in detector-- arise in detector 1?

Notes

Summary

0m 04s

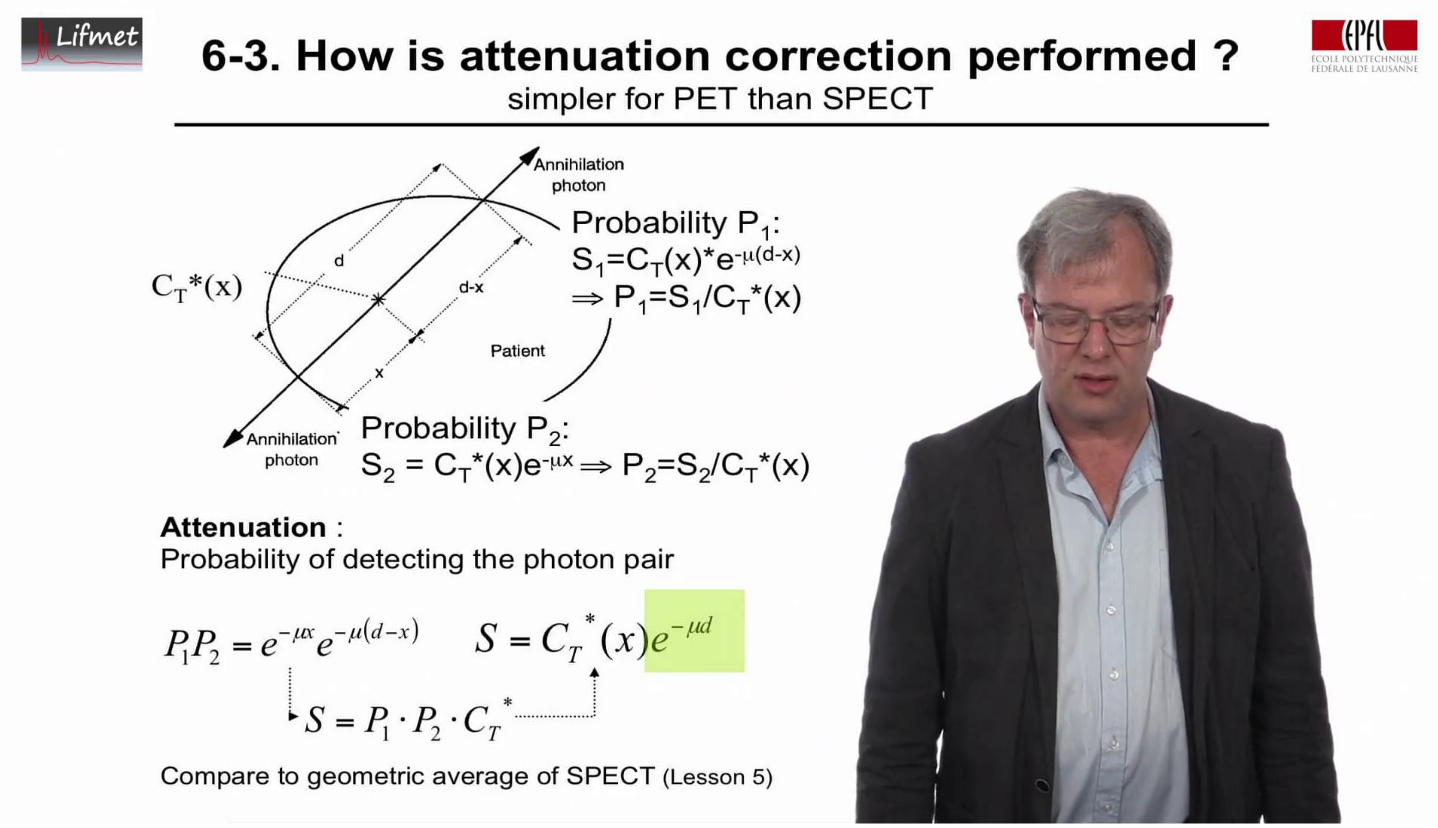


The probability is given by the signal that we detect, divided by the tissue radioactivity, plus a few corrections, but for all the photons that go in this direction, we're only considering those, only those that go in this direction-- the photons that we detect is given by the tissue radioactivity times the attenuation. That's the signal that we get, so, the probability of detecting the signal is equals to *e* to the minus mu times distance traveled. The same thing applies here for this position-- for this detector, the probability is given by *e* to the minus [mu x]-- *x* being the distance from this place to the edge of the tissue. Same consideration. So, if we now look at the attenuation, how do we calculate the attenuation? The attenuation is essentially the probability that we see the photon pair. So, let's assume that half of the photons that go in to the direction of detector 1 are being eliminated. So, we only see half of the annihilation photon pairs of the coincidence events. Now, let's assume in the other direction, we also only see half of the photons. So, for those photons that arrive here at detector 1, those half out of 150, the other photon, half of them are being eliminated.

Notes

Summary

1m 26s



So, in the result-- in the end result, we have only 25 photons that we count, if the total is a hundred. So, only 50 arrive in detector 1, so, we can only have 50 simultaneous events. And of the 50, half of them are being absorbed here. So, we end up with 25. Or, in other words, the probability of detecting the photon pair is given by the multiplication of the two probablities of detecting each of the photons. So, this is the probability is equals to *e* to the minus [mu x], times *e* to the minus mu *d* minus *x*. And so, we can simplify that-- we have the signal now-- is the probability of the photon pair times the tissue radioactivity. And so, this gives rise to an attenuation. We have the signal is equals to the tissue radioactivity at this position, times *e* to the minus [mu d]. If you take this term here, you'll see, rapidly, that this is equals to minus [mu d]. And this is quite similar to this correction-- to the geometric average that I introduced last week for SPECT scanning in lesson 5. So, what this means is essentially, for doing the attenuation, estimating the attenuation, we just need to know the dimension of the object along our Radon transform, along our orientation, and from that, we can calculate the attenuation.

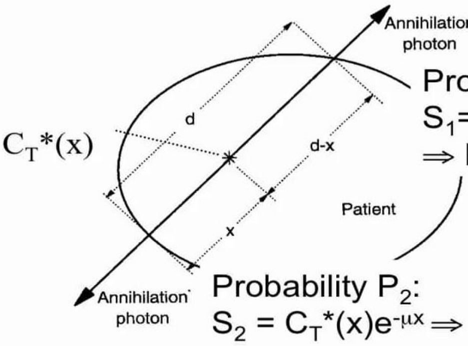
Notes

Summary

2m 48s

6-3. How is attenuation correction performed ?

simpler for PET than SPECT



Probability P_1:
$S_1=C_T(x)*e^{-\mu(d-x)}$
$\Rightarrow P_1=S_1/C_T*(x)$

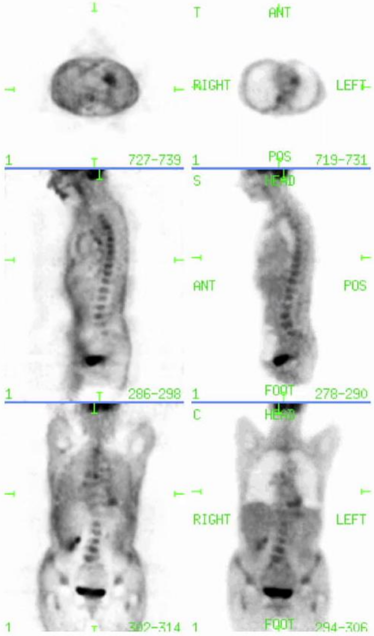
Probability P_2:
$S_2 = C_T*(x)e^{-\mu x} \Rightarrow P_2=S_2/C_T*(x)$

Attenuation :
Probability of detecting the photon pair

$$P_1P_2 = e^{-\mu x}e^{-\mu(d-x)} \qquad S = C_T^*(x)e^{-\mu d}$$

$$S = P_1 \cdot P_2 \cdot C_T^*$$

Compare to geometric average of SPECT (Lesson 5)



uncorrected corrected

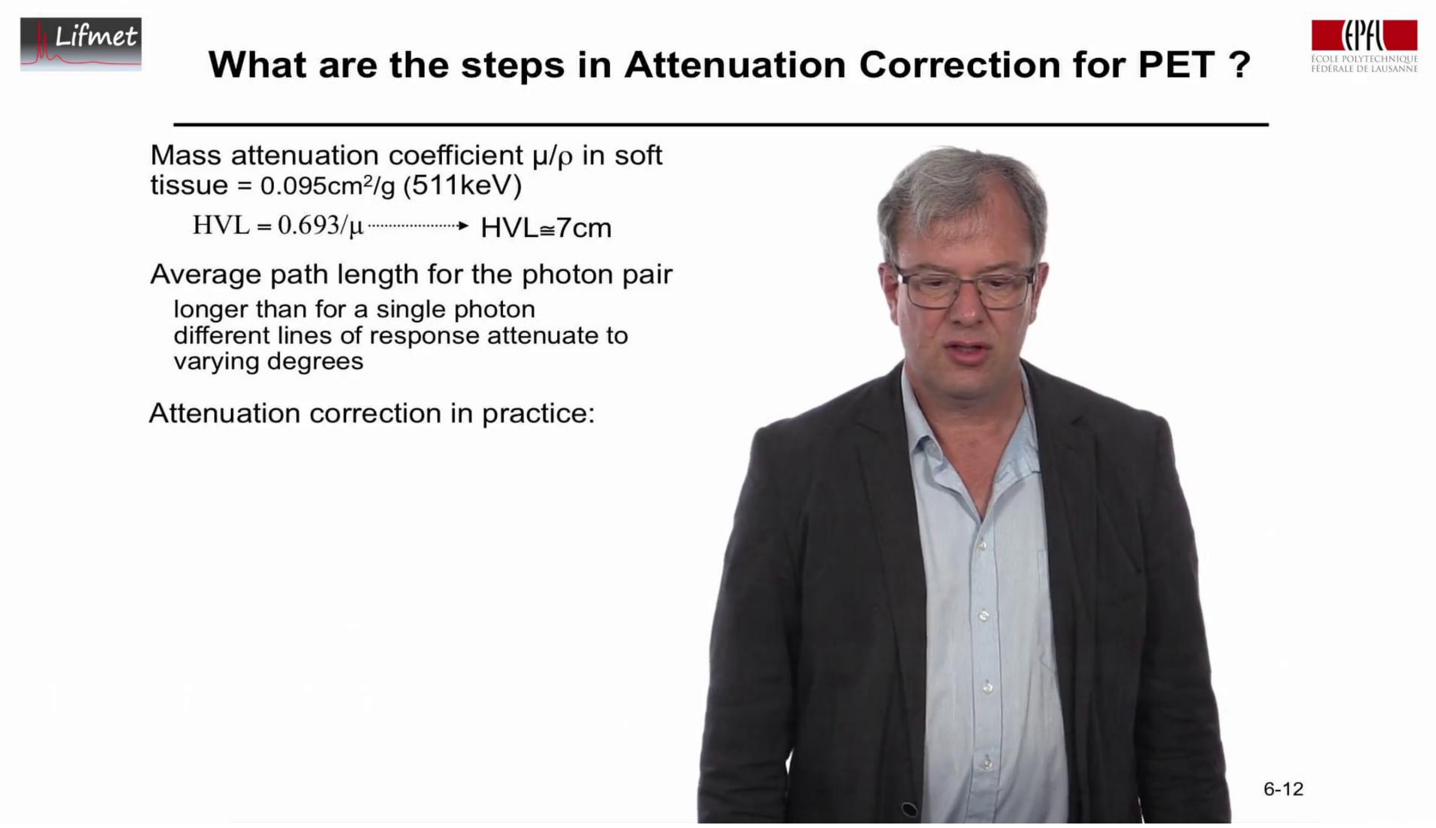
6-11

Be aware that here, in this situation, we have assumed uniform attenuation-- in reality, situation is slightly more complicated. Here is an uncorrected PET scan of a subject. Here is the cut through the torso. We can see the nose here, the spine-- and here's the coronal, here we have the bladder, here we have the brain, the arms are up here. This is the uncorrected scan, and here is the scan corrected. And you can see, certainly, if we correct for the attenuation-- if you take the sinogram and correct it for attenuation, the image is much more crisper and clear in allowing us to discern the uptake of the radio tracer. So, attenuation correction is important in producing a faithful representation of tissue radioactivity in the body.

Notes

Summary

4m 18s



So, what are the steps in attenuation correction that we need to do for PET? Let's look at the mass attenuation coefficient in soft tissue-- this is roughly 0.1 centimeters squared per gram, for the 510 kiloelectron volt photons. Now, does this give us an intuitive feel for what this means? It's quantitatively important-- we'd have to do some calculation. So, the more easier way to assess this is to look at the half value layer of these photons in soft tissue. The half value layer, as you might remember, is 0.7 divided by mu-- the linear attenuation coefficient-- and so, it turns out that for photons in soft tissue, the half value layer is roughly 7 centimeters. So, that is not a very long distance. We have to consider that the entire path of the photon pair through the tissue is taken into consideration-- it's the distance *d* that we had on the previous slide. So, it is longer than for a single photon. But, we also have to consider that the lines of response, lines of incidence, have different attenuations, depending on how big we are. If we were perfectly cylindrical objects-- if we were imaging perfectly cylindrical objects, it wouldn't matter as much. So, what are we doing in practice?

Notes

Summary

5m 09s

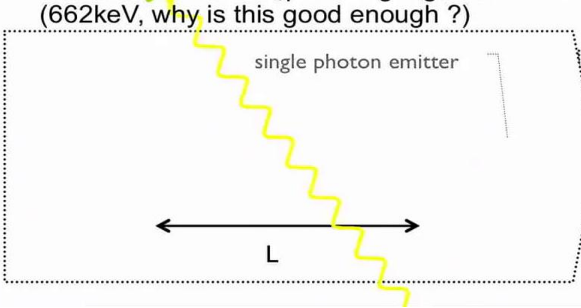
What are the steps in Attenuation Correction for PET ?

Mass attenuation coefficient μ/ρ in soft tissue = 0.095cm^2/g (511keV)

$HVL = 0.693/\mu$ → HVL≅7cm

Average path length for the photon pair
- longer than for a single photon
- different lines of response attenuate to varying degrees

Attenuation correction in practice:
- Spatially uniform attenuation coefficient assumed
- Transmission technique using e.g. Cs source (662keV, why is this good enough ?)



Comparison with blank scan

i.e. subject removed

$$e^{-\mu d(\varphi)}$$

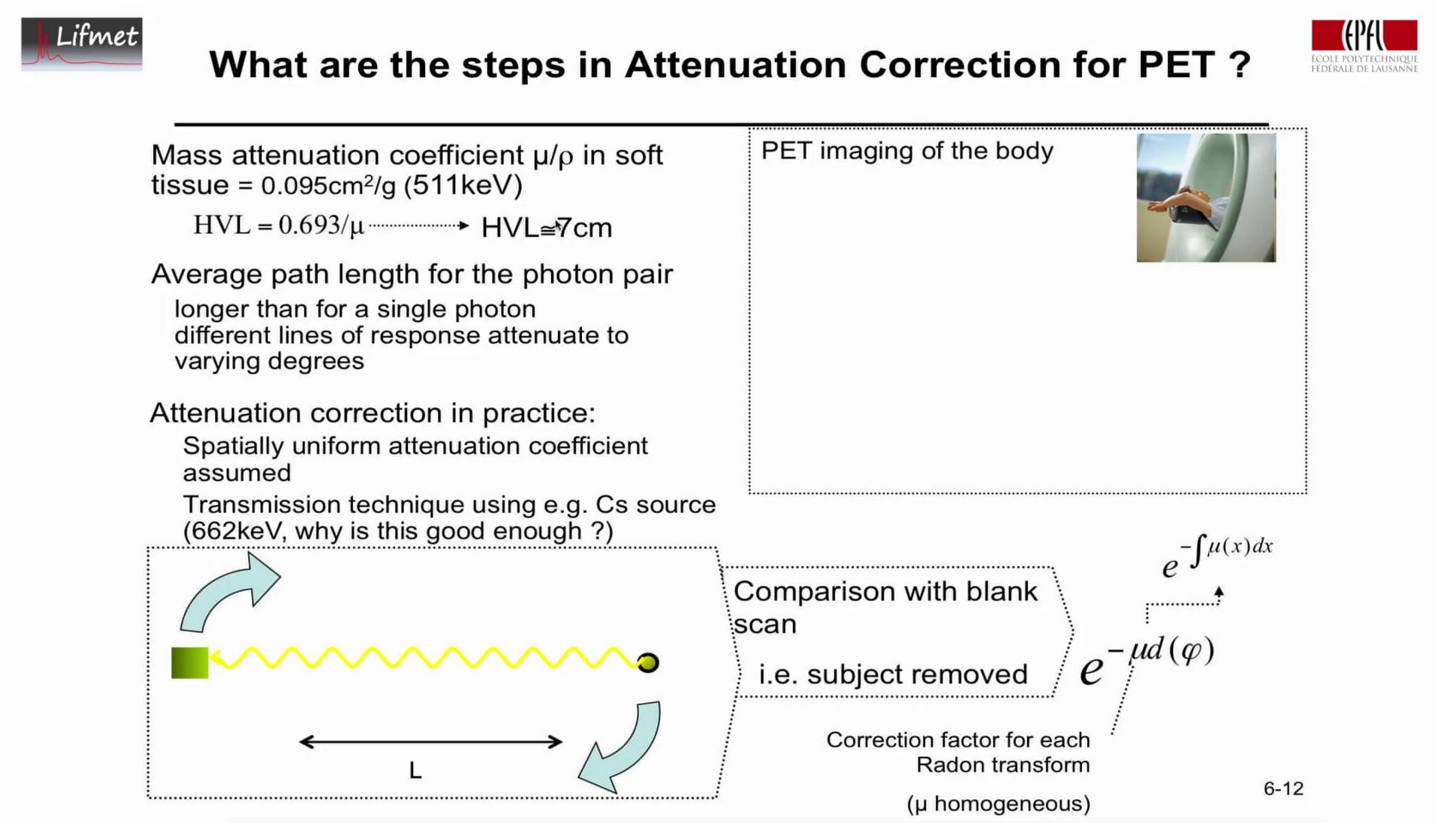
6-12

For this example, I'll assume my spatial uniform attenuation coefficient and my subject here, that is oval, and one uses, for example, can use a cesium source in this illustration-- the cesium source has a photon energy of 660 kiloelectron volts. Now, why is this good enough for estimating the attenuation in 510 kiloelectron volts? Remember this: we have, at these energies, we have the Compton effect that dominates, and linear attenuation coefficient for Compton is essentially proportional to the electron density, and varies very slowly with the photon energy at these high energies. So, it is a good approximation of what is going on. So, we just take the source, we rotate it, and we have the detector on the opposite side, and we will measure the intensity as a function of the angle phi-- we have seen the thing rotate. Now this is not good enough. We have to compare that to the blank scan. And the blank scan means we will remove the subject. So, here's the subject removed. We will repeat the same scan, so we measure the intensity of the source as it is being detected.

Notes

Summary

6m 43s

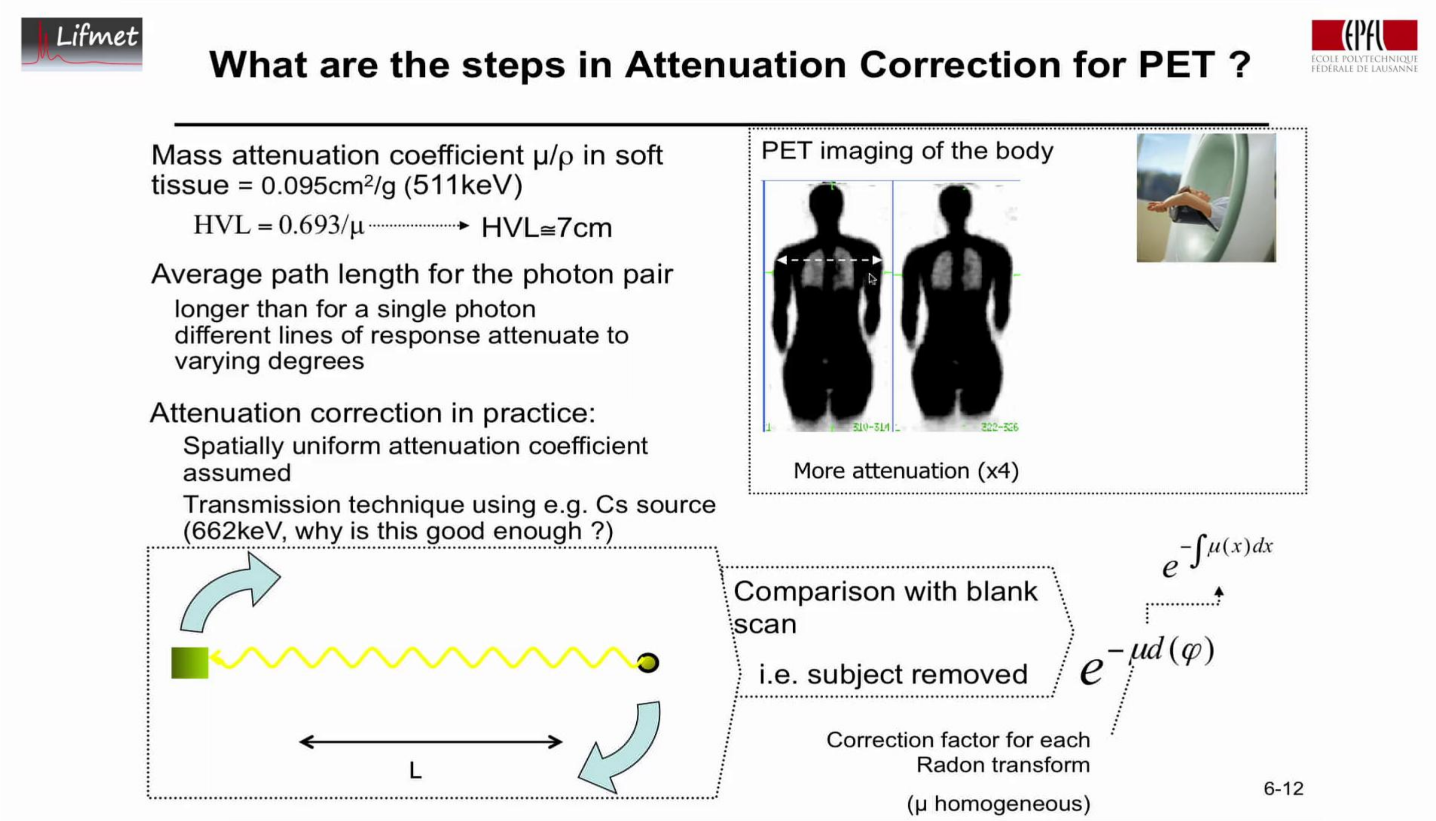


And then we divide the two intensities, and what we are obtaining is *e* to the minus [mu d], and *d* here, this is important, is a function of the projection angle that we have-- so as we rotate around the foreign object, that is, for example, elliptical, we have different attenuations to consider. So, this basically means, we will produce a correction for each Radon transform, for each orientation. This example that you have here on the screen, is for a homogeneous linear attenuation coefficient, here-- mu doesn't vary. For situations that are more complex, as in real life, we would, actually, have to integrate the linear attenuation coefficient along the perpendicular to the projection-- and this is nothing but the measurement of a-- the expression that we have for a CT scan. So, if you look at the PET imaging of the body-- let's look here at this subject that's in a PET scanner. And I want you to think a little bit, here, what is being scanned here. What organ? Well, it's not the head. The head is outside the scanner. We are outside-- the detector ring is here, so, it's not the head. It's not the prostate, or the lower abdomen. It is actually at the level of the heart. It's a heart scan. So, second question: why is the subject putting his arms behind the head? Because they like to be relaxed, or because they were being told so? Well, look on the left.

Notes

Summary

8m 04s

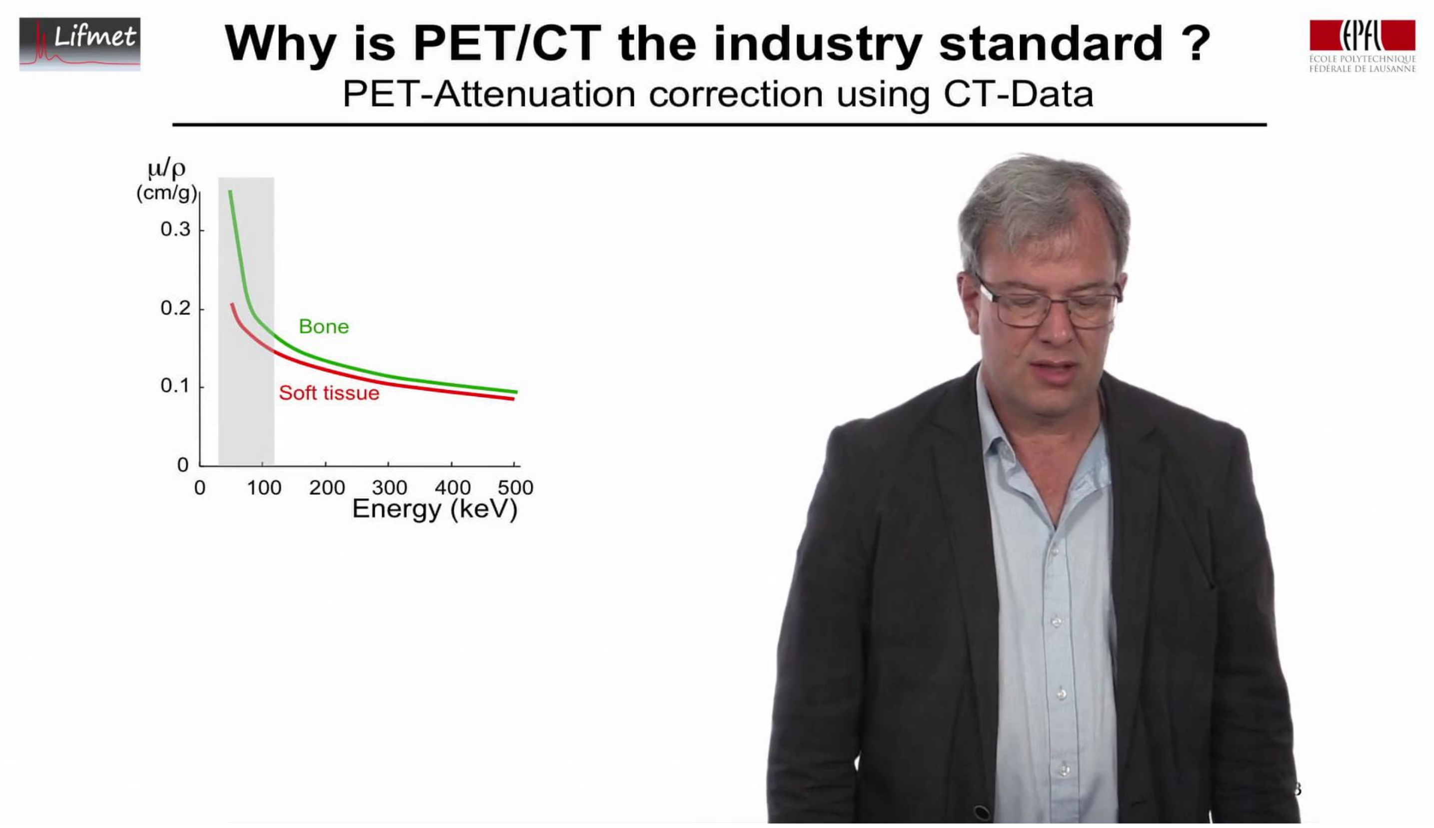


The half value layer for positron photons is 7 centimeters. This means, if you take an average thick arm, like mine here, Roughly, let's say, it's 7 centimeters. And I put it on the side. And I measure the Radon transform in this direction the projection. Putting my arms down means that I increase the average path length by 14 centimeters. That is, I only detect 25% of the photons. So, for a heart scan, I will measure, in this direction, a substantially reduced intensity. So, if we have the arms along the side for a cardiac scan, we have a lot of attenuation, because we have the additional attenuation of the arms to consider.

Notes

Summary

9m 42s

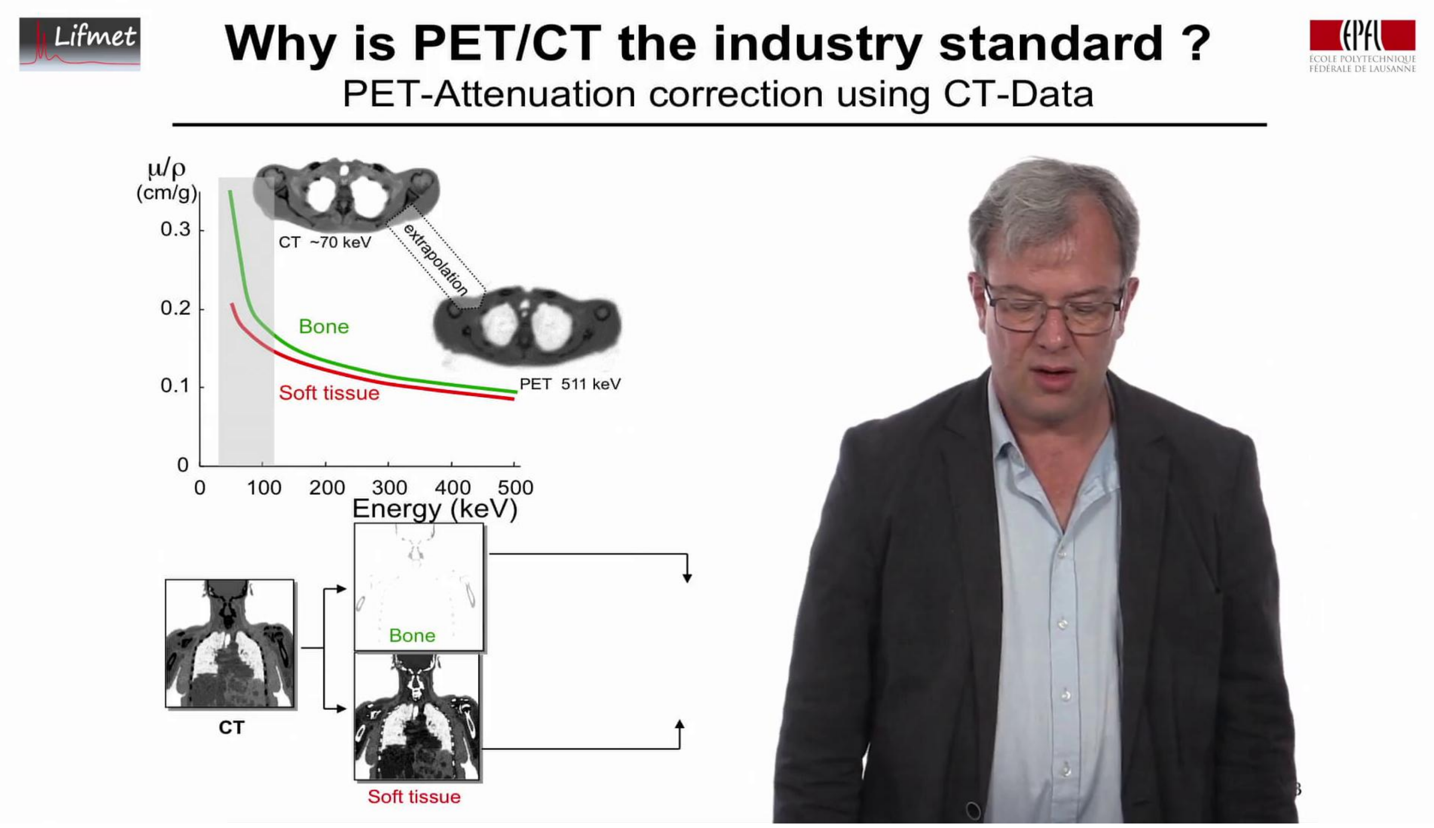


And so, for a heart scan, we put the arms up, and we scan around here, and so the arms don't enter into play. Conversely, if we do a brain scan, we're not going to put the arms here, because that-- we will introduce, again, for a substantial fraction of the projections that we measure, we will lose substantial intensity, and that is not good. We want to have the best intensity, so, we do not expose our subject to a higher radiation dose than necessary. I mentioned early on that the PET/CT scanner is the industry standard. You can no longer buy a PET scanner that is standalone. You buy them together with a CT scanner. We have, on the previous slides, seen that the attenuation correction uses expressions, or measurements, that are akin to what is being done in a CT scanner. And so, I want to explain here how this can be done. We have plotted here the mass attenuation coefficient on the vertical axis, here, versus the photon energy on the horizontal axis. And this is roughly the change in linear attenuation, or mass attenuation coefficient for soft tissue. And in red and in green, we have the same for bone. The photon energies that are used for CT scanning are typically between 30 to 40 kiloelectron volts, to 120 kiloelectron volts.

Notes

Summary

10m 26s

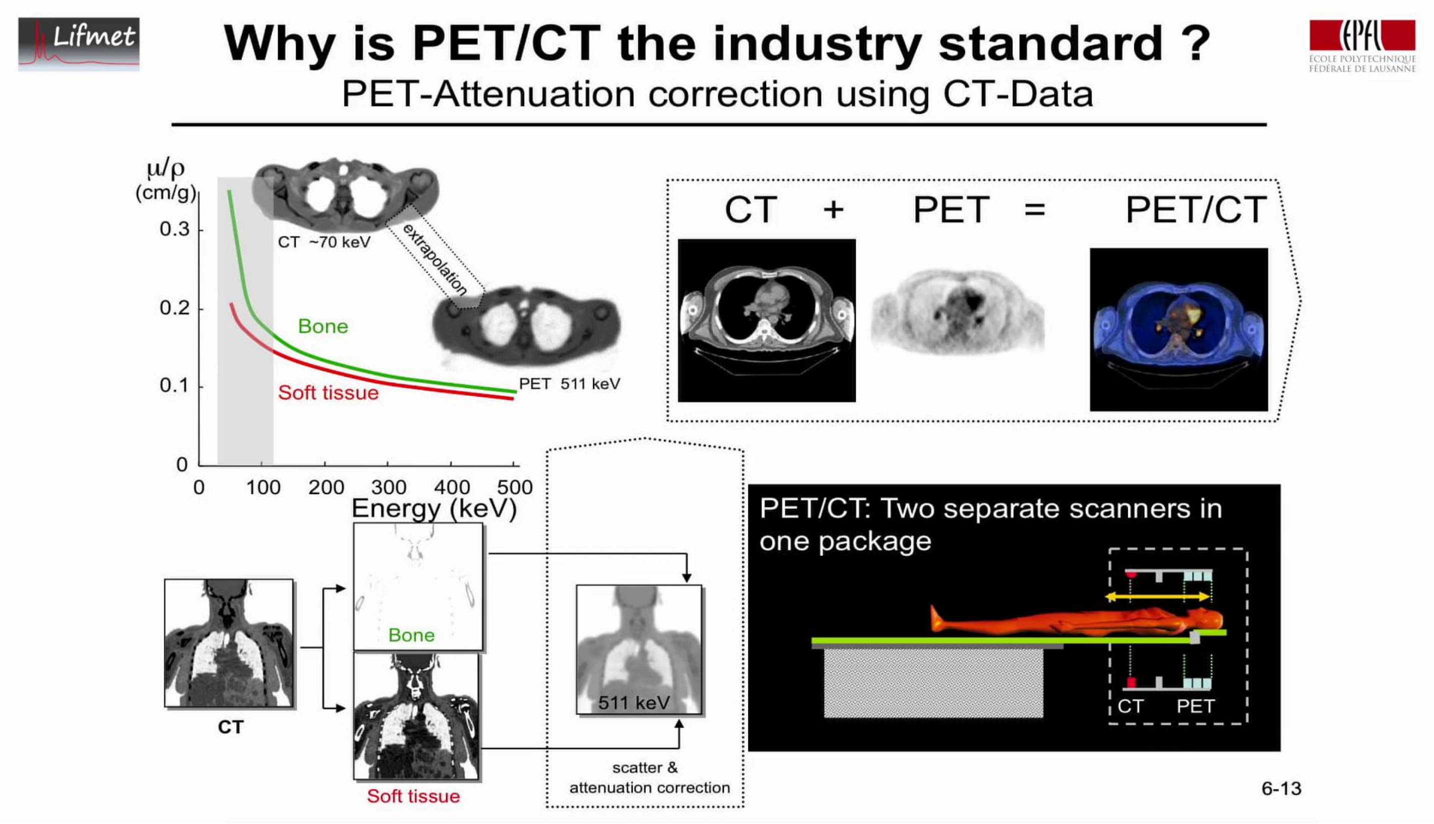


And so we obtain-- at these energies-- we obtain a CT scan of the body, which is depicted here. So, this is roughly a scan at roughly 70 kiloelectron volts that's been done here. Now, what one can do is, given that we can easily identify bone in a CT scan and soft tissue, we can extrapolate what the image would look like, and we get, then, the CT scan at a supposed photon energy for 510 kiloelectron volts. So, this is done by extrapolation. A bit more sophisticated-- here's a CT scan-- you can see the lungs, in white, no attenuation-- You see the head, here, you see the rib cage, a lot of attenuation. And, now, based on the absorption, since the bones have a lot of electrons, they have a lot of calcium-- we can actually identify the areas-- calcium rich areas. This is the-- such segmented image for bone, and for soft tissue. And since we have, in green, the extrapolation of the mass attenuation coefficient, and in red, the mass attenuation coefficient for soft tissue-- we have these two images. One can calculate a synthetic image, taking into account the effect of-- the slightly differential effect of bone, and this gives us, now, the distribution of the linear attenuation coefficient at 510 kiloelectron volts.

Notes

Summary

11m 50s



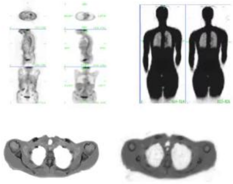
So, this measured at low energy, based on-- segmented into bone and soft tissue we composed with a-- the measured mass attenuation coefficient for 510 kiloelectron volts. And this, in the end, will give us the justification for combining, here, a CT scan with a PET scan-- so this is a CT scan of the abdomen, here's the heart, black is the lungs. We have the PET scan of the same area in grayscale, and now for the fusion of the two images, the PET scan is color coded, it's lower resolution than a CT scan, super imposed on the high resolution CT scan, and now we can easily see with the warm colors delineating high activity in the tissue where the high activity of the PET tracer uptake is. So, PET/CT is actually not one modality, although, in theory, one can think of doing it this way-- it is actually, in reality, two scanners. We have up front, the patient first sees the CT scanner, and behind it, the PET scanner, and they're put into a single package with a nice little cover. So, we have the patient bed, we'll put the subject on here, and the subject first undergoes, for a few seconds, a CT scan. Once that is done, the patient table is moved forward, and then we take another ten minutes for the PET scan to measure the uptake of the positron emitter in the body of this subject. So, it is PET/CT-- two scanners in one package that puts the two techniques together.

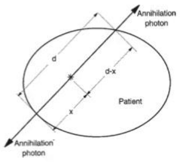
Notes

Summary

13m 20s

Credits





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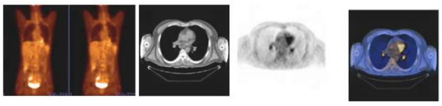

General Electric Medical Systems

PET/CT Scan
http://www.pius-hospital.de/03_01_07_07.php

Attenuation correction for a combined 3D PET/CT scanner
Kinahan PE et al: *Med Phys*, 1998, 25:2046

Notes

Summary

15m 02s