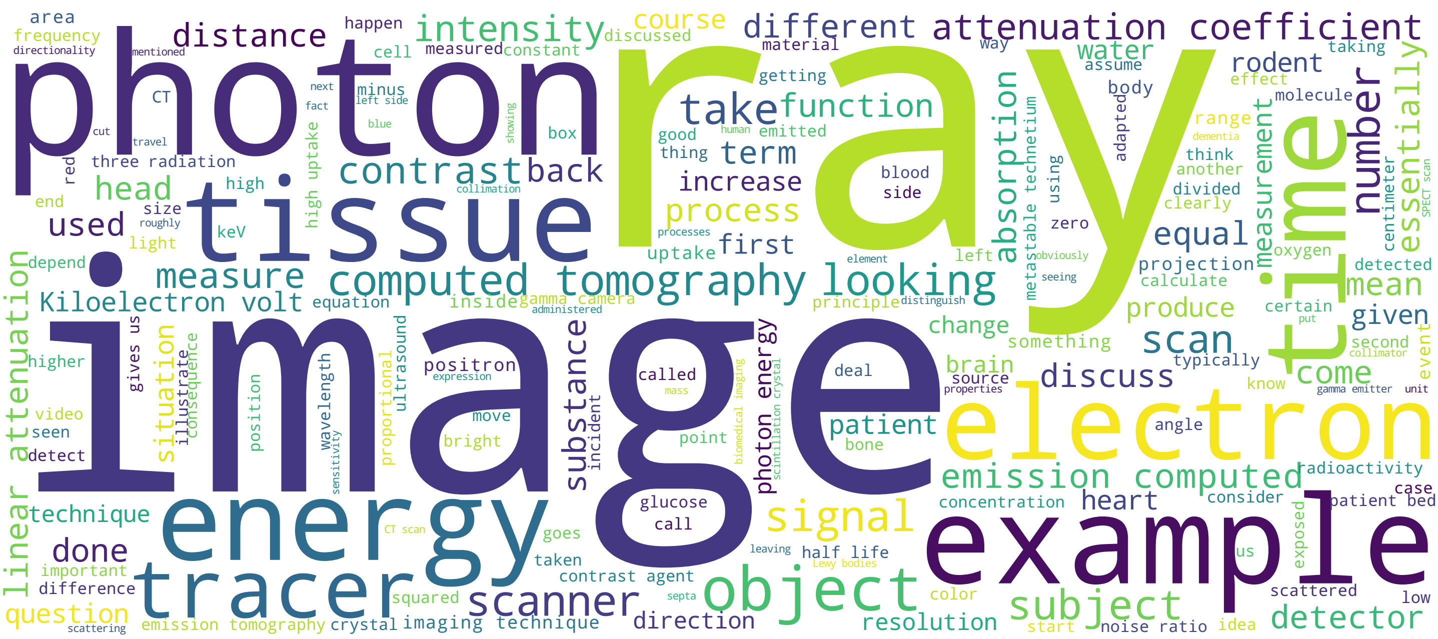
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

5.1 Introduction to Emission Tomography

Fundamentals of Biomedical Imaging

Prof. Rolf Gruetter



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Video

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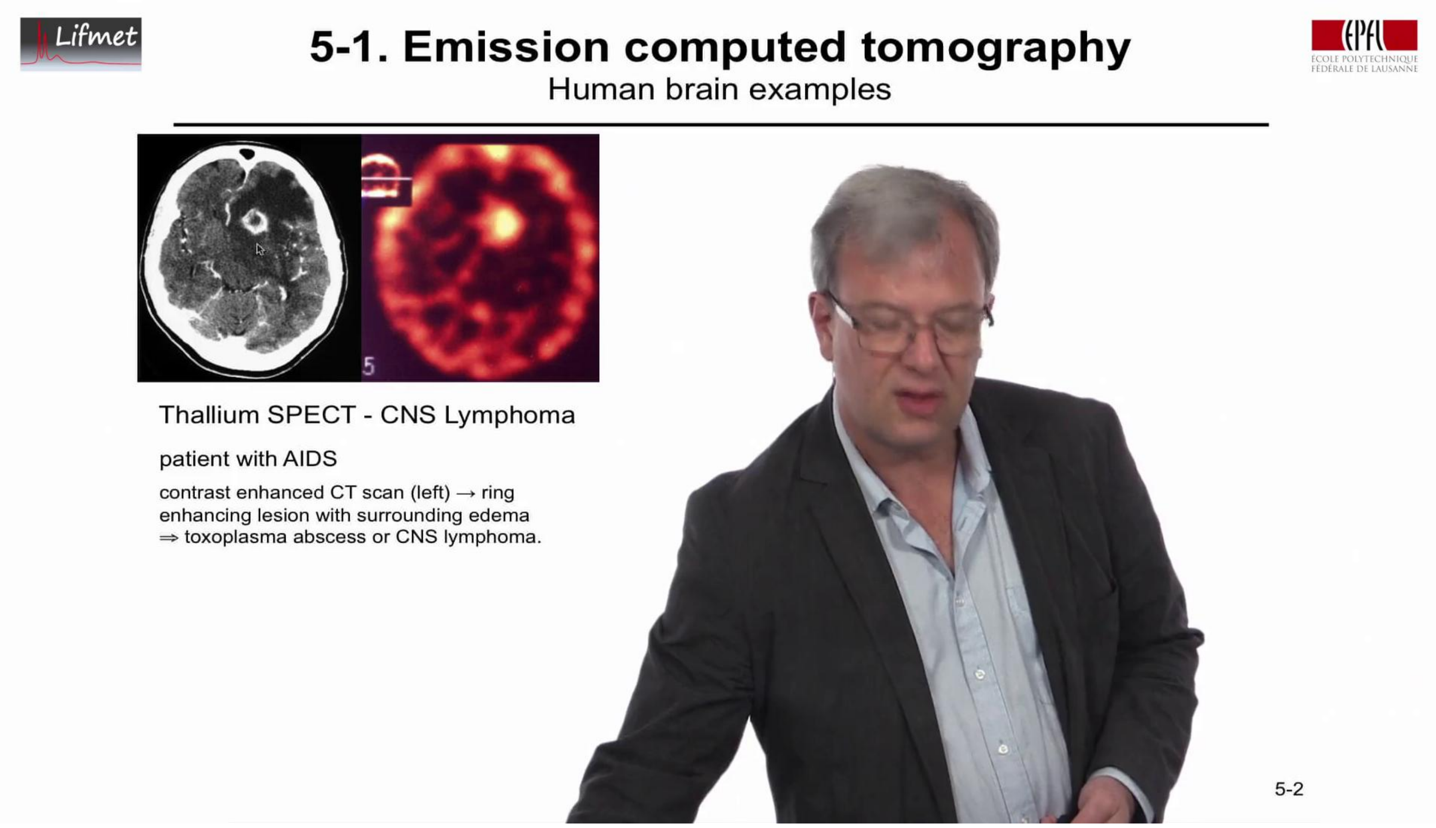
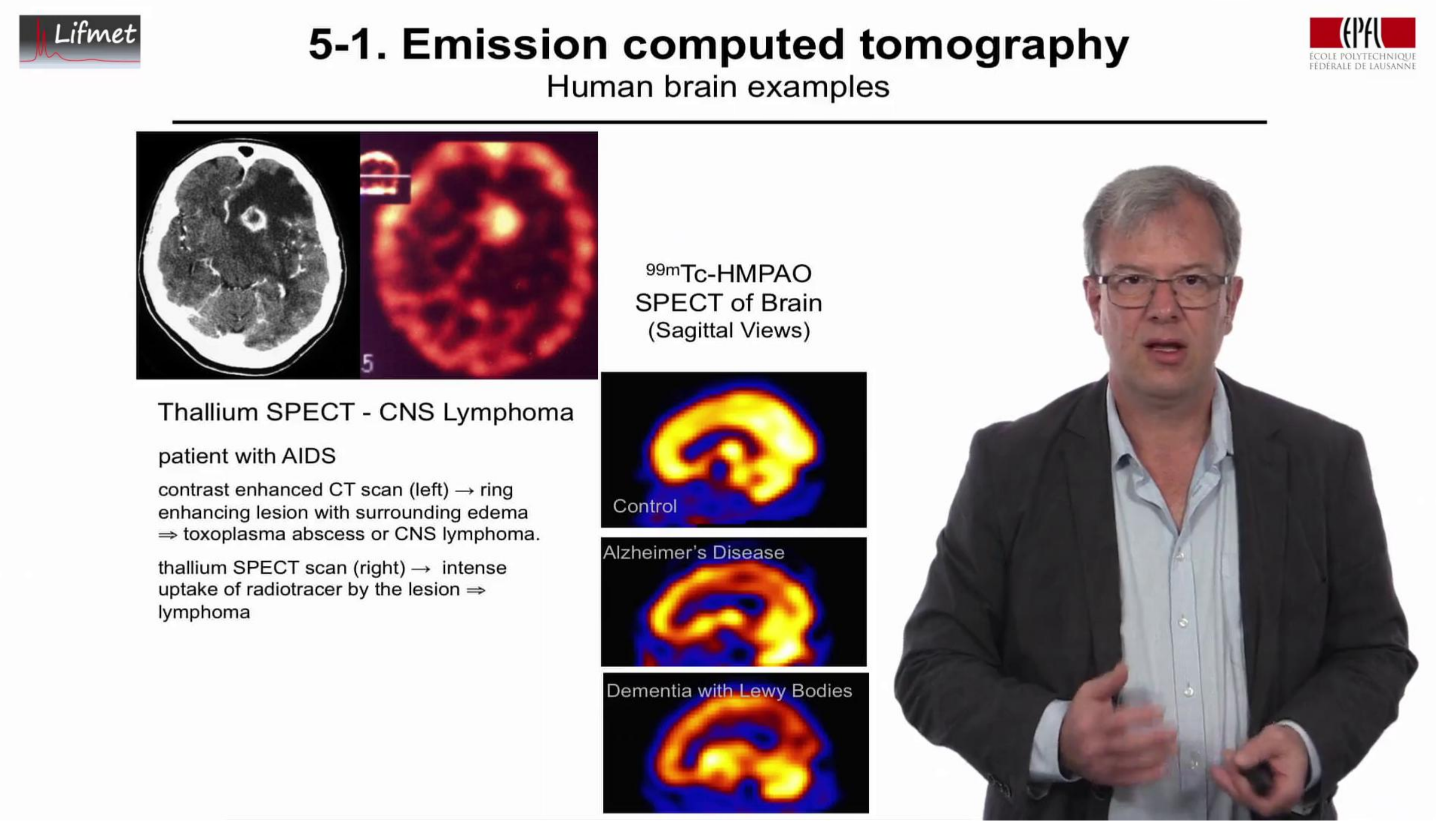


So, in this week's lecture we are going to discuss the next x-ray-based imaging technique, and that is emission computed tomography, or, as it is more known, single photon emission computed tomography. But we'll stick here with the term emission computed tomography because it is emphasizing the difference to computed tomography, which we dealt with last week, that is, we're looking at emission of x-rays. But first, I want to give you some examples of what this technique does. This is an example of two images. Can you guess what the image on the left side is? Look at it a little bit. Well, we notice here, on the outer rim, the image is bright, so there's a lot of contrast. Here it is bright, and on the inside there is a grayish kind of color. This is a cut through the head, and what we're seeing here on the outside, this is the skull bone. So we're looking at a computed tomography scan on the left side. On the right side, we're looking at a thallium PET scan. So, this is a patient with AIDS. The patient received a contrast agent. This is what we discussed two weeks ago in Segment Three. And so, the contrast enhancement here, this could be a toxoplasmosis abscess. It could be an abscess or a lymphoma.

Notes

Summary

0m 04s

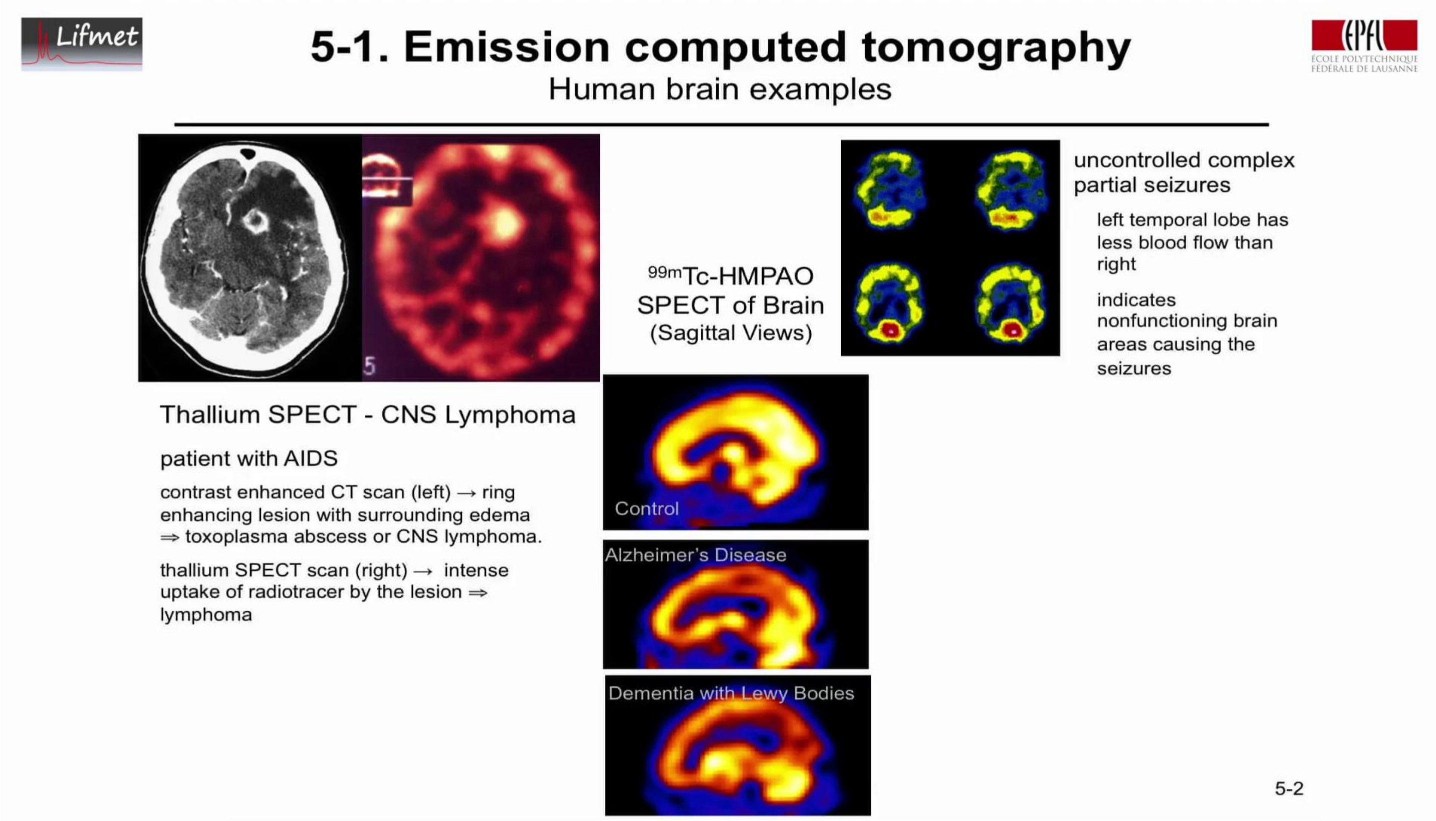


It's a breakage of the blood-brain barrier because the contrast agent is here in this lesion. What the thallium scan here tell us, there's thallium uptake, that this is, indeed, a intense uptake of the tracer and therefore, of the substance, and therefore, it is a lymphoma. So here, the use of two imaging techniques allows one to distinguish what the lesion exactly is that is present in the brain. Here is HMPAO SPECT scan now using the *metastable technetium*, a ubiquitously-available isotope. This is from the control, a *sagittal cut*, so it's cutting through the head like this. We have here, at the front, the nose. This would be the nose here, and the *occipital lobe*, the visual processing that we have back here, is on the back of the head. Here's the same scan, now applied to a patient with Alzheimer's. You can see clearly, a different uptake of the substance, a different map. This is showing the degeneration of the brain tissue. And we have now, the scan from a dementia with Lewy bodies, also showing, clearly, a reduced uptake. The color code here goes from yellow to blue, high to low, and this is dementia with Lewy bodies. Do you know what *dementia with Lewy bodies* [is]?

Notes

Summary

1m 40s



Well, one example is Parkinson's disease, is a Lewy body disease. Here we have an example of a patient with uncontrolled epileptic seizures, and this is a measurement of metabolism in the brain. On the bottom, we have the normal subject, so we have high uptake here in the visual cortex, in the back of the head. And here on the sides, on the surface in the cortex, we have high uptake. So, we have in the area here, we have low blood flow in this area which indicates reduced functionality of the brain tissue.

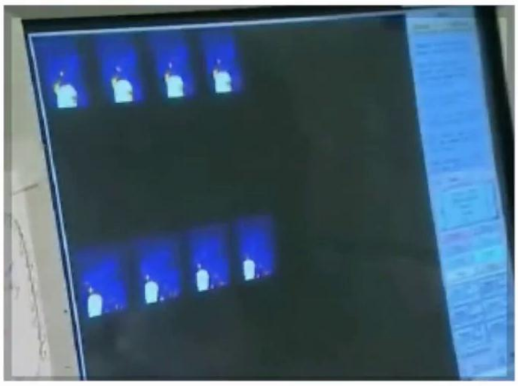
Notes

Summary

3m 00s

Emission computed tomography

Heart and rodent examples



5-3

Now, we'll come to examples of human heart scan and then some rodent examples. First, I want to show you this video. This is showing you a typical SPECT scan. Now, it's for the heart, so what would be the stress test. So, the subject is doing a hand grip exercise as you can see on the screen. This hand grip exercise is meant to stimulate the heart rate so the heart is working harder, and he does that for a certain while. And then, as you can see, the nurse administers the tracer, that's the substance that's used for emission computed tomography. This is done with a syringe as you can see, fairly heavy, so it's shielded, that the nurse is not exposed to radioactivity. It is being infused into the patient. Then, one waits a certain amount of time. He's being put onto the scanner-- there you can see the patient bed-- and as he is on the scanner, you will see that there's a big box here that starts to move. That is actually the instrument that is now being moved, physically, around the subject. As we keep scanning on the screen, the different projections are being recorded, and as they are being recorded, later, the computer puts them together, reconstructs them into an image, and we can see the typical characteristic v-shape of heart uptake of the substance in the heart.

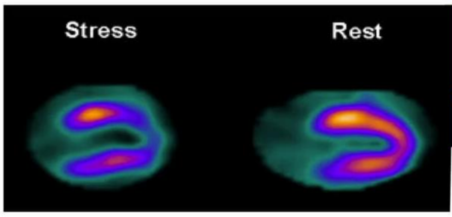
Notes

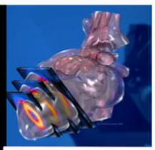
Summary

3m 40s

Emission computed tomography

Heart and rodent examples





perfusion of heart muscle

- orange, yellow: good perfusion
- blue, purple: poor perfusion

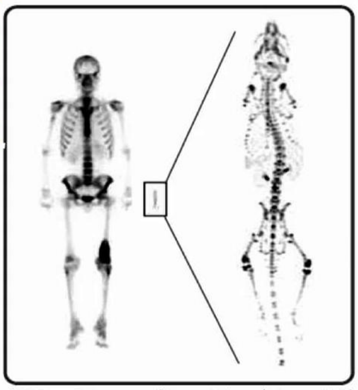


FIGURE 1. Bone scans (Tc-99m-HDP and Tc-99m-MDP) obtained in patient and mouse (right), the latter using NanoSPECT (Bioscan, Washington, DC, USA).

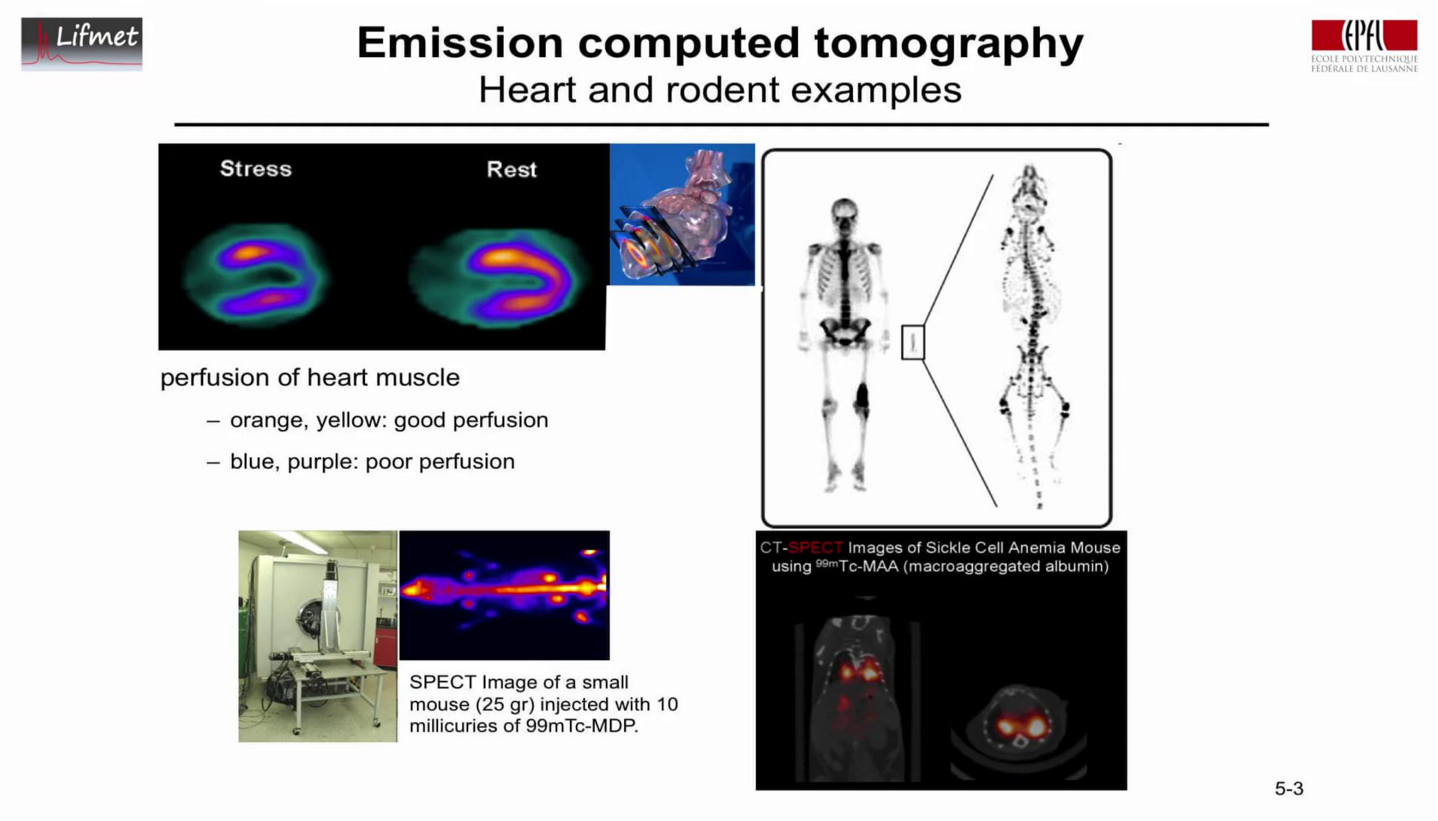
5-3

In the end, when the scan is done, the subject comes out. We can see the head moving still. So, this are some examples of such a heart scan. We have under stress and under rest, and it is pseudo-colored with colors so if it's orange and yellow, it means good perfusion. If it is blue or purple cold colors, then it means poor perfusion in this scan, so we can very easily depict heart function. Now, what we're looking at here are *slice images*, so these are slices cut through the heart, and this is illustrated here in this 3D model. We have the heart here, this is a model of the heart, and this illustrates how, with the imaging technique one virtually cuts slices. One does not, of course, physically cut the slices, but with the imaging technique there are slices selected, and that's what we're looking at here on the left. Now, if we go to rodents, we have here a scan from a human on the left side, it's a bone scan. We see the entire skeleton. And here, on the side to the subject, you see the size of a rodent. It's a mouse or a rat. So, you can see how much smaller that is, and then we see the scan of the rodent here, in greater detail.

Notes

Summary

5m 21s

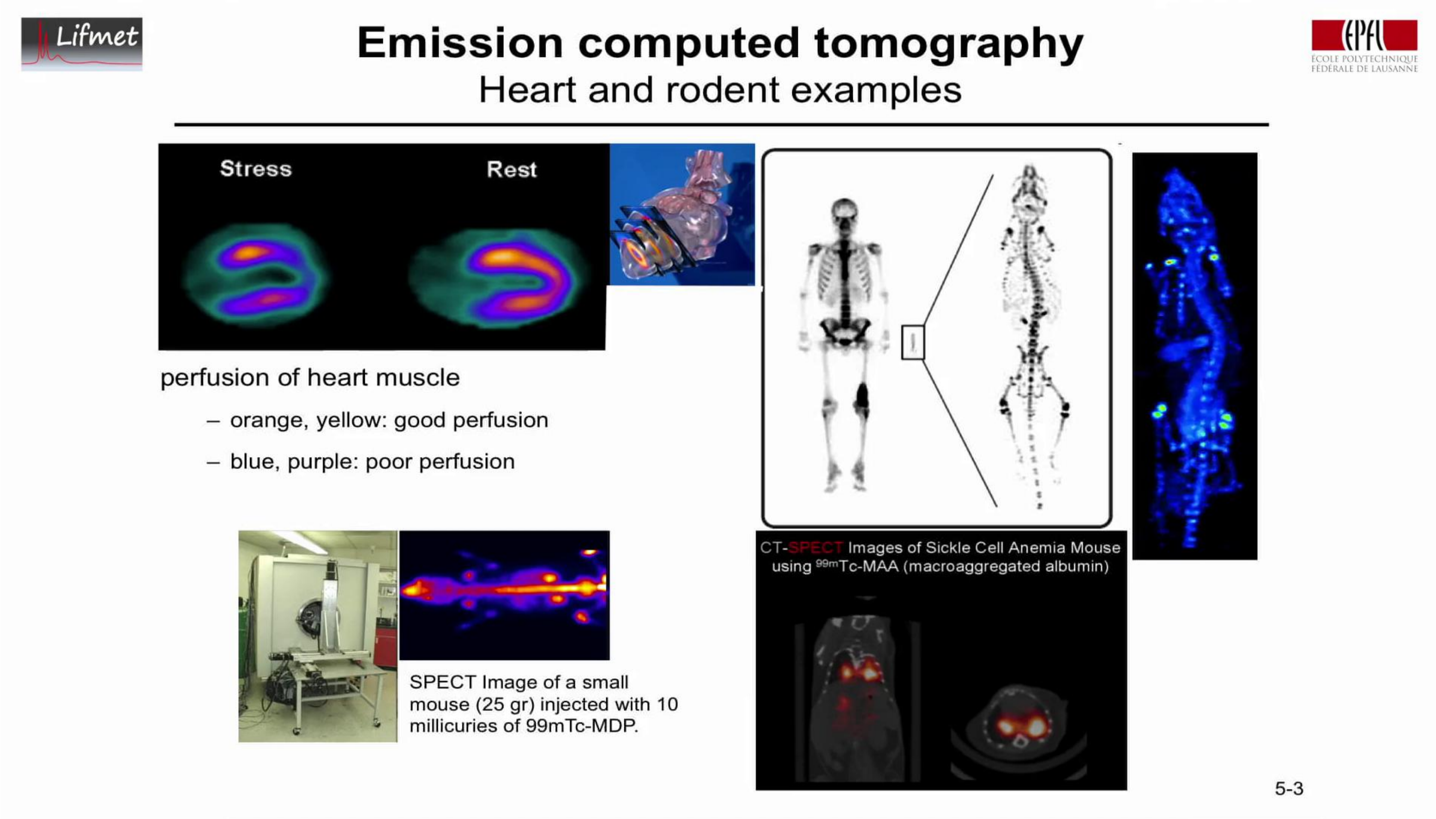


So clearly, as a scanner that's adapted to the size of a human subject is not adapted to the size of a rodent or vice versa, so the technology has to adapt to the subject in question. And so, if you look at a SPECT scanner for rodents, here we're looking at it, it's behind this box here, and we have here the opening. This is the patient bed now pulled up vertically. This would move the subject into the scanner here. So clearly, this is a scanner where a human doesn't fit in there, but the rodents, it is adapted to the size of the rodents, made smaller. Everything scales down. Here's a SPECT scan of a, again, 99 technetium, metastable technetium MDP scan. It's a small mouse. We can see, there's the head, the tail would be here, and we have uptake in the legs, we have the glands here. And, of course, also, the kidneys, which have uptake. Here's a scan of a sickle cell anemia mouse, using macroaggregated albumin, again, with 99 technetium, metastable technetium. And we look here, we're having here the bright uptake in color. Now, what we also see is this grayscale image here, and this grayscale image is a CT scan that's done in parallel to the examination. We see the bone is bright.

Notes

Summary

6m 44s

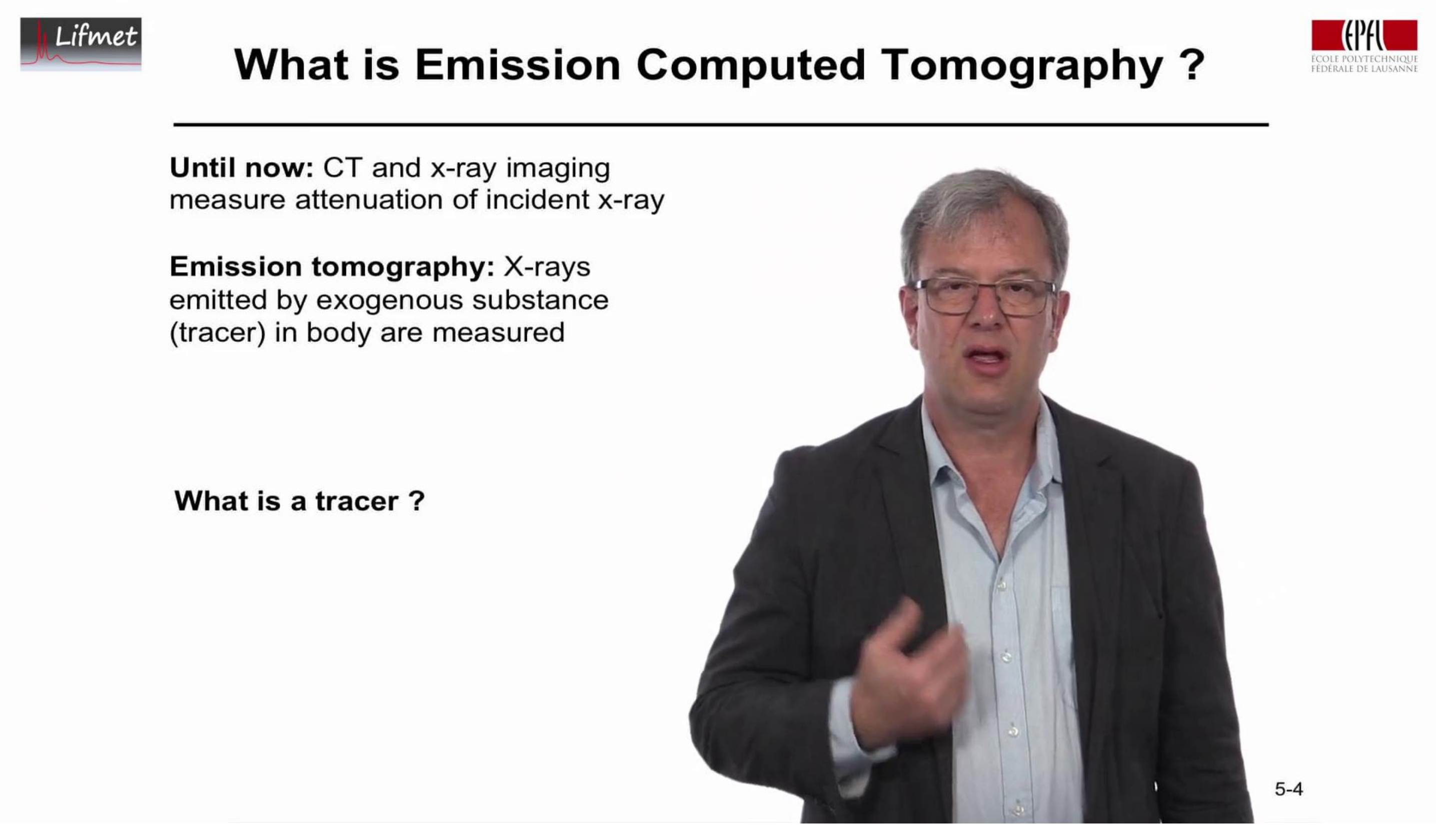


We see here the rib cage. We see here other bone structures. Here's a cut through the torso, again, the rib cage, and the spine back here. This serves to give a background anatomical image which serves to identify exactly the areas of high uptake, here in this case of metastable technetium. And here is a cut, an image of a bone scan. This is the same technique that we have here. This is rotating. We can see, again, the glands here, taking up a lot of the tracer. And otherwise, it's a good tracer of the skeleton of this animal.

Notes

Summary

8m 08s



So, what is *emission computed tomography*? We have, until now, for computed tomography and x-ray imaging, we have dealt with the fact that they measure the attenuation of the incident x-ray. So we have an x-ray that moves towards the object. At the end, once it's passed through the object, we measure its intensity. The absorption of the x-ray is linked to the linear attenuation coefficient, and so we are using the attenuation of the incident x-ray that is giving us the contrast, i.e., that's the distribution of the linear attenuation coefficient. Now, emission computed tomography, or emission tomography, what we're actually looking here at as the name implies is, emission. So, x-rays are being emitted by a substance, an exogenous substance, that is a foreign substance that is being administered, and those x-rays that this substance emits are being measured. Hence, the name emission tomography. So what is a *tracer*? And I'll go here with a much more general definition because the properties of a tracer-- how it is being analyzed, as we will discuss in a few weeks-- are fairly ubiquitous. And I'll use it in a very loose term here.

Notes

Summary

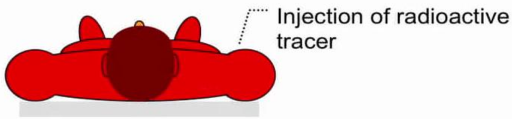
8m 57s

Lifmet

What is Emission Computed Tomography ?

Until now: CT and x-ray imaging measure attenuation of incident x-ray

Emission tomography: X-rays emitted by exogenous substance (tracer) in body are measured



What is a tracer ?

Exogenously administered substance (infused into blood vessel) that

(a) alters image contrast (CT, MRI)

(b) has a unique signal (γ **emitting**)

-> **Emission** computed tomography

5-4

It is, essentially, and this is what is common here, it's a substance that is exogenous, so it's not naturally occurring. It is administered into the body, typically infused into the blood vessels, sometimes, also, ingested. And now I'll go with a more generalized definition. It is: The tracer can be something that alters the image contrast, as in CT and MRI. There, we call it contrast agent, but it essentially has the same properties as a tracer. And, the second definition is, that it has a unique signal. And for this week's and next week's purpose, it is a *gamma emitter*, and it traces, therefore, the processes. It's administered in trace amounts, therefore, it's called a tracer. And since it is gamma emitting, that explains the term "emission" in emission computed tomography. It's emission of x-rays and not transmission or absorption of x-rays that we're looking at. So, let's look at this situation here. We inject the radioactive tracer and watch this subject as the tracer's being taken up. The color changes, with red implying that this tracer, that the gamma emitter has now been distributed, and now we have emission of x-rays from the body. So, the body is now radioactive.

Notes

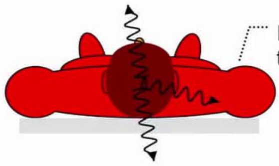
Summary

10m 19s

What is Emission Computed Tomography ?

Until now: CT and x-ray imaging measure attenuation of incident x-ray

Emission tomography: X-rays emitted by exogenous substance (tracer) in body are measured



Injection of radioactive tracer

What is a tracer ?

Exogenously administered substance (infused into blood vessel) that

(a) alters image contrast (CT, MRI)

(b) has a unique signal (γ **emitting**)

-> Emission computed tomography

Typical tracers for emission tomography

half-life and photon energies

	[h]	[keV]
^{99m}Tc	6	140
^{201}Tl	73	70
^{123}I	13	159
^{133}Xe	0.08	81

5-4

The x-rays are leaving the body, and that is the signal that we would like to measure. So, let's look at some typical tracers for emission tomography. This is giving you an idea of what their half-life is, and also the photon energies. We have, as mentioned, the metastable technetium 99. It has a half-life of six hours, and the photon energy is 140 Kiloelectron-volts. We have thallium that we have also, I mentioned, has a half-life of 73 hours. The photon energy is 70 Kiloelectron-volts. We have iodine, 13 hours half-life, 160 Kiloelectron-volts. And Xenon. Which, Xenon interestingly has only five minutes of half-life here. That's a twelfth of an hour. So, the photon energies, as we can see in these examples, they range between 70 and 160 Kiloelectron-volts, so they are pretty much in the range of what we've discussed for computed tomography. Now, imagine you have this tracer in your body. It is the result of a nuclear decay process. So, this process: A) does not know anything about chemistry, and B) doesn't know anything about directionality. So the x-rays that we see here, they are leaving in all sorts of directions, and that is not very useful for generating an image, and we'll have to deal with that fact.

Notes

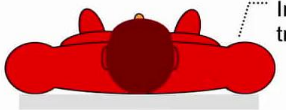
Summary

11m 42s

What is Emission Computed Tomography ?

Until now: CT and x-ray imaging measure attenuation of incident x-ray

Emission tomography: X-rays emitted by exogenous substance (tracer) in body are measured



Two issues:

1. How to determine directionality of x-rays ?
2. Absorption is undesirable

What is a tracer ?

Exogenously administered substance (infused into blood vessel) that

(a) alters image contrast (CT, MRI)

(b) has a unique signal (γ **emitting**)

-> Emission computed tomography

Typical tracers for emission tomography

half-life and photon energies

	[h]	[keV]
^{99m}Tc	6	140
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^{133}Xe	0.08	81

5-4

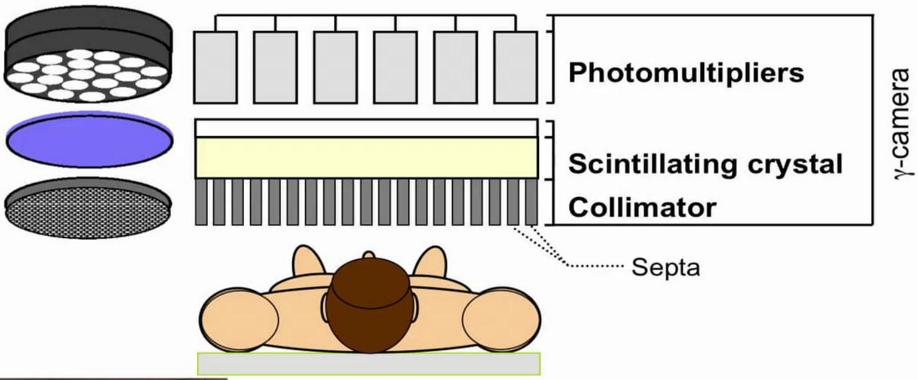
So, essentially, we have this emission computed tomography to get to an image. We have two major issues to deal with. Number one is: How do we determine the *directionality* of the x-rays? There is no good method that allows us to directly measure a photon that comes in, and its direction of flight. So, this is something that we have to deal with. And the second element that is important here is, *absorption* for emission computed tomography is undesirable. It's not the measured variable. It is a nuisance effect. Ideally, we would want to have a situation where we have no absorption and, as you can guess, this does not exist, so it is a unwanted and not-measured effect, but it does impact our images as we generate them.

Notes

Summary

13m 06s

What are the basic elements needed for γ-emitter imaging ?



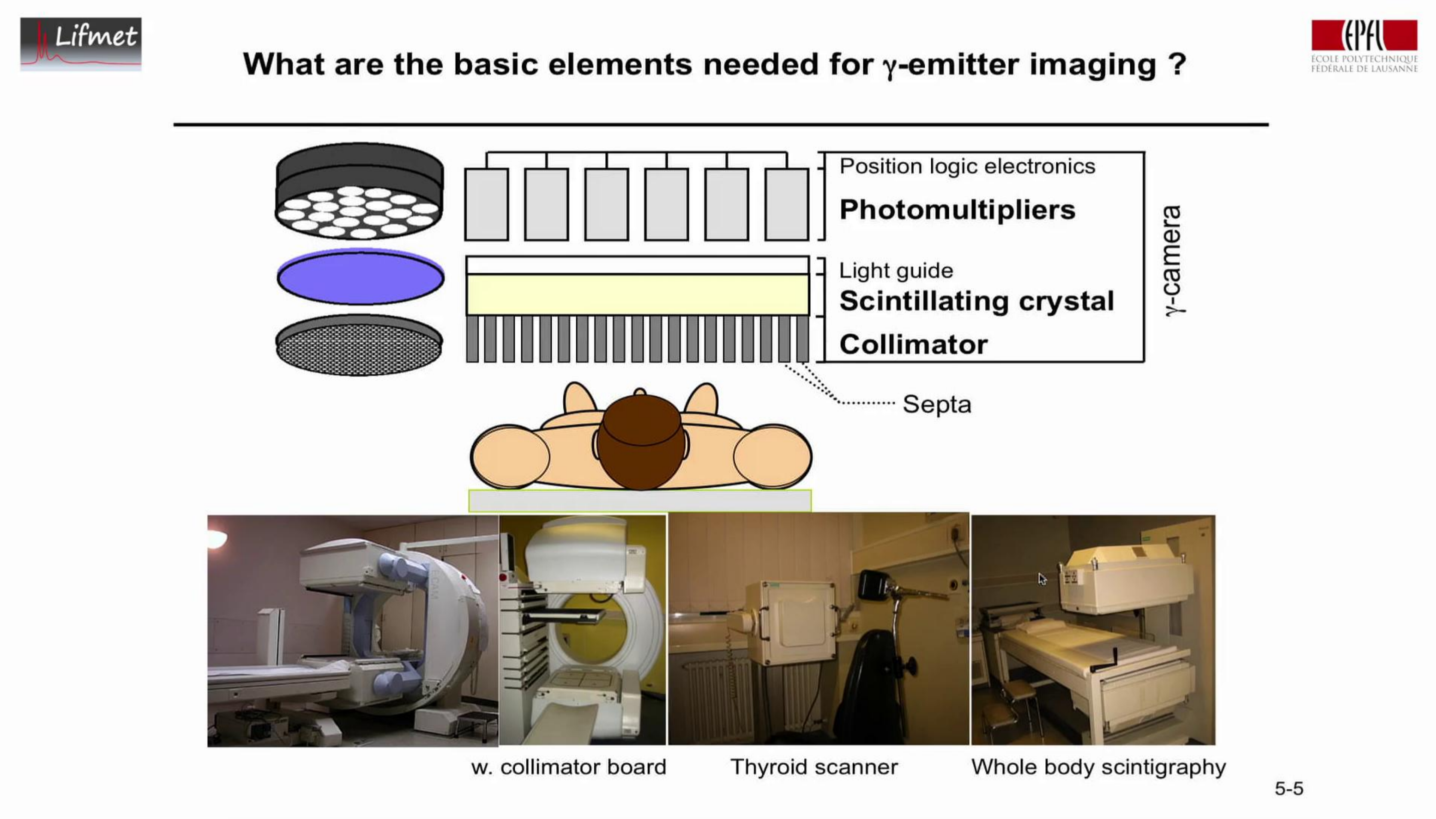
5-5

So now, the question is: What are the basic elements that are needed for gamma-emitter imaging? Here, on the bottom left, you can see an image of such a *gamma camera*. We have the patient bed here on the left. This is the scanner here, the holder. And here is the box that contains the scanner, which is what we've seen on that video at the very beginning, that moves around the patient. This is what contains the gamma camera. So what is inside this box? So, I'll try to illustrate this. Here's the subject below the box, here's the subject. And this, what we're looking at, is inside the box. And there are a number of elements that we can observe in the gamma camera. We have number one, we have a *collimator*. The collimator is made out of septa, and we will discuss shortly some consequences of this and why this is needed. Then we have a *scintillating crystal*, that's the next element here. And, we have the *photomultipliers*. These are the three major elements I want to discuss that have the major impact on scanner performance that we are discussing in this course. We have here schematically: collimator, scintillation crystal, and photomultipliers.

Notes

Summary

13m 59s



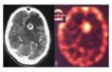
These are the three elements we're going to discuss. We have, of course, additional elements. That is, the light guide, I will not discuss this, and position logic electronics that are used. We'll briefly touch on that as well, but only briefly. So here is the same camera. Here's the gamma camera, top and bottom, and we have the collimator board here that's pulled out, so they have different collimator boards for this scanner. This is a thyroid scanner for the thyroid gland. And, finally, we have here, a scanner for the whole-body scintigraphy, so here's the patient bed, here's the gamma camera, and this is moved up and down to do whole-body scintigraphy.

Notes

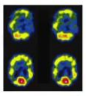
Summary

15m 16s

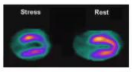
Credits



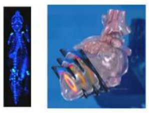
Imaging of Neuroaids K. E. Sakaie and R. G. Gonzalez
http://aidscience.org/neuroaids/zones/articles/1999/08/Imaging/



MayField Clinic SPECT Scan
http://www.mayfieldclinic.com/HT_medtests.htm



Patient Education - Myocardial Perfusion SPECT
http://www.brighamandwomens.org/Departments_and_Services/radiology/services/nuclearmedicine/Patient/myocardial.aspx



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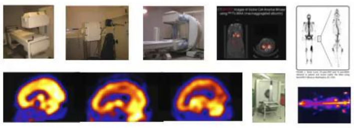
SPECT imaging technique - Imaging in medicine (11/13)
https://youtu.be/l6V6VLxQlkY



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Notes

Summary

15m 59s