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Edited podcast transcription:

On this episode, I want to discuss radioisotopes other than Technetium. First, we can group three of these radioisotopes based on a shared approximately 3-day half-life. These radioisotopes are Gallium 67, Indium 111, and Thallium 201. Beyond having an approximate 3-day half-life, these radioisotopes also have multiple energy levels, unlike Technetium that has a single dominant energy of 140 keV. Each of these have multiple energy peaks. Each of these is also cyclotron produced.

Let us start with Gallium 67. Remember that Gallium 67 is used for general nuclear medicine studies. Gallium 68 is a PET agent used with Dotatate or other types of PET imaging. Remember, Gallium 67 is for general nuclear medicine and Gallium 68 is the PET agent.

What is the half-life of Gallium 67? It is 78 hours. Is that exactly 3 days? No. Is it close? Yes.

On the exam they might ask you a question on the half-life of Gallium 67. If they do, I'd be a little surprised if they grouped the half-life of Gallium 67 in with the half-lives of Indium and Thallium on a multiple-choice question stem because the half-lives are close requiring you to remember a very precise number, but you never know. In general, remembering that these all have an approximate three-day half-life will help you through most of the questions they are likely to ask. However, if you have the mental capacity to do so, remember 78 hours for Gallium 67.

I already told you that there are multiple energy peaks for each of these agents. Gallium 67 has four energy peaks. I'm not going to tell you exactly what the precise energy for each peak, but I want you to remember these are close to 100, 200, 300, and 400 keV. There are other memorization tricks where they do not go precisely on the hundreds, but from my experience remembering these exactly on the 100s is good enough for most exam questions.

Most of the energy coming out of Gallium 67 is in the lower range around 100 and 200 KEV. Therefore, if they ask you what type of collimator to use with Gallium 67, because most of the energy is in the 100 and 200 keV range, you should select a medium energy collimator because the medium energy will allow imaging in the lower energy ranges and allow a little bit of the 300 and 400 keV emissions as well. This is therefore the best compromise in terms of collimators.

What is the mechanism of action for Gallium 67? To help you remember this, think of Gallium 67 as an iron analogue. Why is that helpful? Things like bacteria and things like white blood cells both use iron and will increasingly take this up in the setting of inflammation, malignancy, or infection. We utilize that similarity to iron to our advantage when we image in these various states.

Gallium 67 is no longer frequently used, partly because the image quality is low, partially because the dose is high, and in large part because FDG PET replaced it for many indications. However, there is important testable trivia you should remember. For example, Gallium is one of the few agents that shows lacrimal gland uptake. If you see lacrimal gland uptake on an image you should be scrutinizing whether it could be a Gallium scan. Gallium also normally has more uptake in the liver than the spleen. That can help differentiate a Gallium 67 scan from something like a white blood cell scan where the spleen is hotter than the liver. Other key testable trivia is that Gallium 67 is preferred for spinal osteomyelitis evaluation and is better for suspected spinal osteomyelitis than a white blood cell scan.

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The thought is that the increased pressure from the infection within the vertebral body makes it too difficult for the white blood cells to get in, but for whatever reason, the iron mechanism, iron analogue pathway, allows Gallium to still work.

Gallium was commonly used and is still sometimes tested on board exams for pulmonary infections such as Pneumocystis pneumonia in HIV patients.

Finally, you need to know the critical organs for common radioisotopes as that is a very easy test question for people to write. For Gallium 67 the critical organ is the colon.

On to the next (approximately) three-day half-life radioisotope: Indium 111. Gallium 67's half-life is what? 78 hours. Indium 111's half-life is 67 hours, a little bit shorter but still close to three days.

Indium 111mhas two major energies. These are 173 and 247 keV. My brain remembers better if I round these to 175 and 250 keV.

So, Gallium is approximately 100, 200, 300 and 400 keV. Indium 111 is about 175 and 250 keV. Those values should be close enough to identify correct answers for multiple choice exams.

Which collimator would you want to use if Indium 111 has 173 and 247 keV? Like Gallium 67, the answer is a medium energy collimator.

One important thing to remember with Indium 111 is that it is very inert. It is very non-reactive so you can inject this many places without issue, including the cerebral spinal fluid via lumbar puncture. This is accordingly the FDA approved radioisotope for cisternography for normal pressure hydrocephalus.

Indium 111 is also used for tagged white blood cells scan, but not exclusively. There are two options with the tagged white blood cell scan. One is an Indium 111 white blood cell scan. The other is a Technetium 99m white blood cell scan. Board exam question writers often want you to know which patient population, meaning adults versus kids, is each of these better suited for imaging. Generally, the answer is that Indium might be best used for adults, whereas Technetium may be better used for kids. Indium also has less GI activity compared to a Technetium tagged white blood cell scan. Indium is therefore preferred for inflammatory bowel disease evaluation.

Why is a Technetium tagged white blood cell scan potentially better for kids?

This has a lot to do with radiation dose. Technetium has a much shorter half-life than Indium 111 and therefore allows a lower dose to patients. It is also better for small parts imaging because of favorable imaging characteristics.

The advantage with Indium?

You can delay imaging by a day and even potentially longer given the longer half-life of Indium 111. This allows more time for uptake to show up in an area of infection.

One other thing to remember is that Indium 111 is the radioisotope for an octreoscan that can be used for carcinoid tumors.

What is the critical organ for Indium?

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It depends on what the Indium 111 is tagged to and where it is injected. Indium tagged to DTPA is what we use for cisternography. The critical organ is the spinal cord. If you tag Indium 111 to white blood cells, the critical organ is the spleen.

Let's discuss the other approximate three-day half-life radioisotope, which is Thallium 201.

The half-life for Thallium is in between that of Gallium and Indium at 73 hours. To review, Gallium 67 half-life is 78 hours, Indium 111 half-life is 67 hours, and Thallium 201 half-life is 73 hours.

What are the principal energies to remember for Thallium 201? This is a little bit tricky. I'll explain. Technically the energies from Thallium 201 itself are 135 and 167 keV. But the highly testable trivia is that Thallium 201 decays to a daughter isotope of Mercury 201 and the emissions from Mercury 201 are the majority of what we image. You inject Thallium 201, it distributes through the body, and decays into the daughter Mercury 201. The Mercury 201 kicks out X-rays and those X-rays give you low-quality images compared to imaging gamma rays from things like Technetium 99m. The x-rays from Mercury 201 are also low energy at 69 to 81 keV.

The main energy I would remember for Thallium imaging is 81 keV because that is what is imaged, through x-rays from Mercury 201.

What is the mechanism of uptake for Thallium?

Think of Thallium 201 as a potassium analog. That is important to remember because potassium enters cells via sodium-potassium pumps. Those pumps are only functional if a cell is alive. Therefore, Thallium is a viability agent because it acts like potassium that needs to be actively transported into the cell which requires cell viability.

What can we use Thallium for? One use is cardiac viability imaging. Thallium can help answer whether the myocardium Is viable, though, poorly functioning, or dead and scarred? If the Thallium shows uptake on delayed imaging within the portion of myocardium of concern, it means it redistributed and some active transport happened. That means the myocardium that shows Thallium uptake is viable, even if poorly functioning.

A similar concept can help you answer other questions in terms of use of Thallium, such as uptake in Kaposi sarcoma that can confirm Kaposi sarcoma versus radiation necrosis which is often a differential consideration difficult to distinguish on imaging in the appropriate setting. Thallium will show uptake in Kaposi sarcoma because this disease state will have active sodium-potassium pumps. On the other hand, radiation necrosis will not have active sodium-potassium pumps. If Thallium shows no uptake in the areas of concern, that means the cells are dead and that supports radiation necrosis. If you see uptake in the area, it means there are some viable cells there, and more likely it will be Kaposi sarcoma.

What about Thallium imaging for toxoplasmosis? Thallium 201 will show uptake with *human* sodium-potassium transporters and parasites do not have the human variety, so things like toxoplasmosis would be predicted to show no uptake. Tumors do have human sodium-potassium pumps so Thallium will show uptake in human tumors that are viable. Therefore, one can use Thallium 201 to help distinguish between infections like toxoplasmosis (no uptake) and cancers like lymphoma (uptake).

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What collimator do we use for Thallium 201? Remember, this uses low energies for imaging, the principal energy being 81 keV from Mercury 201, so a low-energy collimator is used.

Remember, Gallium 67, Thallium 201, and Indium 111 all have an approximate three-day half-life, multiple energies, and are cyclotron produced. That concludes my review of the common three-day half-life radioisotopes.

Let us discuss Iodine. There are 2 main types of Iodine to know for board exams (123 and 131). There is also I124, which is used in radioactive seeds for breast cancer localization. We may talk about that later because I will get into breast imaging as well, but for now, let us focus on I131 and I123.

Let us start with Iodine 131. This has an 8-day half-life. I remember this by remembering it is just barely longer than a week. I131 has an energy of 365 keV. That is high for a general nuclear medicine radioisotope. I remember about one week is the number for the half-life of 8 days, and I remember one year is the number for energy, 365 keV. I131 is the only SPECT and general nuclear radioisotope that uses a high energy collimator. Be prepared to remember that on a board exam.

I131 uses a high energy collimator. I said Gallium does get up to 400 keV, but you still use a medium energy collimator for Gallium because most of the emissions are in the 100 and 200 keV range.

I131 is reactor produced, not cyclotron produced. I123 is cyclotron produced.

What is the mechanism of uptake? Not surprisingly, I131 acts like iodine. The body recognizes it as Iodine (because it is). What the body does with iodine is pack it into the thyroid. The I131 or I123 will selectively go to the thyroid, areas of thyroid cancer metastasis, or ectopic thyroid tissue.

There will be only minimal salivary and GI activity on a whole-body image.

The critical organ should be no surprise: the thyroid.

What is some testable trivia? I131 has beta particle emissions. I123 does not. We use that beta particle for therapy. Therefore, I131 works for both imaging and therapy. If you are using this for an imaging purpose only, you would typically use a much lower dose because you do not want to stun the thyroid with those beta particles (which would subsequently reduce uptake in the thyroid tissues for I131 therapy). So lower doses are used for I131 imaging and uptake evaluation. Higher doses are used for therapy.

Remember, however, that after you give the high dose for therapy, you can have the patient return later for imaging (given the 8-day half-life) which allows a post-therapy whole body iodine search. However, the high doses used for therapy are reserved for therapy and we use lower doses if you are only performing imaging.

Another key fact for I131 is the energy is so high that it can cause septal penetration. This is commonly tested because septal penetration has an Aunt Minnie imaging appearance. When the energy is high enough that the gamma rays penetrate through the septa of a collimator in a gamma camera, this results in a star-like pattern on the image. If you don't know what this looks like, look it up online or in a textbook. Make sure you know what septal penetration looks like because it is a highly testable imaging finding and a common imaging artifact question on board exams.

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Another point with I131 is if that for I131 therapy or I131 imaging you need to stop breastfeeding completely. I131 poses an unacceptable risk in terms of ablation of the baby's thyroid from breastfeeding because I131 gets into the breast milk.

Let us now discuss I123.

I123 has a 13-hour half-life. How do I remember that? I was taught in training to remove the “2” from the “123” and you are left with 13. That is your half-life for I123—13 hours.

The emission energy is 159 keV. How I personally remember this is that I123 gives good images because the energy is close to Technetium 99m’s 140 keV. I 23 is just a smidge higher at 159 keV. That is an optimal energy for our gamma cameras. With I123 we have a radioisotope that has an energy like Technetium, and a half life, not particularly unlike Technetium at just a little more than twice Technetium’s 6-hour half-life with I123 having a 13-hour half-life. This all means you can image with high quality at a lower dose when using I123 compared to I131.

Therefore, I123 is preferred for imaging compared to I131 other than the fact that it is historically a lot more expensive to acquire. Why is it more expensive? Unlike I131 that is nuclear generator produced (essentially a waste byproduct), I123 is cyclotron produced which historically has increased the cost.

Which collimator would you use for I123? The answer I would select on board exams is a medium energy collimator. Why, you may ask, would you need a medium energy collimator if the energy is close to Technetium? The reason is because the energy emission is not purely all 159 keV. There is a small fraction of energy from I123 that is over the 400 keV range. The down scatter from those rare high-energy emission are enough that you will get better quality images using the medium energy collimator compared to the low energy collimator.

Remember there is no beta particle emission with I123 so you cannot do any therapies with I123.

What is additional testable trivia for I131 or I123?

I would remember for both I123 and I131 that you can use Lugol’s solution, which is potassium iodide, to block the thyroid when you are imaging with radioactive Iodine for purposes other than thyroid or thyroid cancer imaging. What that means is you give the Lugol's solution before radioactive Iodine administration to saturate the thyroid with potassium iodide. Then when you give the I-131 or I123 most of the radioiodine will not go to the thyroid because it is already saturated. Why would you want to do this? If you are using a radiopharmaceutical tagged to Iodine and the thyroid is not an organ you are interested in imaging. When would you do that? The number one example is an MIBG scan in kids that is evaluating for neuroblastoma or pheochromocytoma.

MIBG can be tagged to either I123 or I131. In either case, you are not interested in imaging the thyroid. When using I131 with MIBG, you do not want to ablate or stun the thyroid. So, you give Lugol’s first and that blocks subsequent thyroid uptake.

Unlike I131 that requires cessation of breastfeeding, with I123 you can resume breastfeeding in two to three days.

Finally, let us discuss Xenon 133.

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The physical half-life is 125 hours. The biological half-life is 30 seconds. That is a substantial difference. The key is that the short biological half-life is the driver of the effective half-life. The actual amount of time the Xenon 133 spends in the body is short, despite the long physical half-life, because you breathe it quickly in and you quickly exhale it out.

What is the energy of Xenon 133? It is 81 keV. This is a very low energy. Because of that, you would use a low energy collimator. Remember that both Xenon and Thallium (via the daughter radioisotope of Mercury) both have extremely low energies in the range of 81 keV or less. This low energy means you do get lower image quality.

What is the critical organ for Xenon 133? It is the trachea and airways.

What is some highly testable trivia for Xenon 133?

You should know the energy for Xenon 133 is so low that you must perform the Xenon ventilation scan before you perform the Technetium MAA perfusion scan. Remember that MAA is a perfusion agent for VQ scans. Xenon is one option for ventilation. It is not the only option. The other most common option in the U.S. is Technetium DTPA. When you are using xenon, you need to perform the ventilation scan first, or else you will image too much down scatter from the 140 keV remaining from the Technetium MAA scan. That will interfere with your ventilation imaging. (But imaging with Xenon 133 ventilation first, and then imaging with Technetium MAA afterwards poses no problem as the lower energy Xenon will not downscatter onto the higher energy Technetium image).

The short effect of half-life of xenon means that you only have enough time to obtain ventilation imaging from a single projection, which is commonly the posterior view. One quick way to tell the difference between a Xenon ventilation scan and a Technetium DTPA ventilation scan is that with Xenon you only will see a single projection, whereas with Technetium you will get additional projections such as anterior, posterior oblique, and lateral views.

Additionally, with Xenon, unlike Technetium, because you are only imaging from a single view you can image early after inhalation, image in the middle, and image shortly thereafter while expiring, and that gives you wash in, equilibrium, and wash out images. Therefore, if you see multiple phases of wash in, equilibrium, and wash out on a ventilation scan that tells you this use Xenon.

What if you see air trapping on the delayed wash out images, which will look like persistent uptake in a portion of the lung? This should make you consider the possibility of emphysema or COPD.

What if you see activity in the right upper quadrant of the abdomen on a Xenon scan?

This is an extremely common question on board exams. This should cause you to immediately think of fatty liver, also termed hepatic steatosis. You need to know that Xenon is lipophilic, so if your liver is filled with fat particles the Xenon will diffuse into the fatty liver and show hepatic uptake. This is so commonly tested that whenever I see a question asking about Xenon and they show imaging, I always look for any right upper quadrant uptake first, just to check if that is what they are testing.

If using Xenon, you should know that you use a Xenon trap on the administration system for the Xenon because this is an aerosolized particle that could otherwise diffuse throughout the nuclear medicine

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suite. You also commonly use a negative pressure room to further reduce the risk of Xenon entering the general airflow.

If they ask you a half-life question in terms of how long you must hold the trap, the answer to remember is you must store it for 10 physical half-lives. For Xenon, the physical half five is 5.5 days. Therefore, you must store the Xenon trap for 55 days to allow it to completely decay to background, before you throw it away.

Some final points to discuss:

This is a good time to review the concept of effective half-life, biological half-life, and physical half-life. Physical half-life is the time required for a given number of radioactive nuclei to decay to half of the original value. Biological half-life is the time required for the body to eliminate 50% of any substance by normal routes of elimination, whether metabolism or excretion. Effective half-life is the time required for radioactivity to decrease to half of the original value due to radioactive decay and biological clearance. For the core exam I would remember the equation to calculate effective half-life, which is 1/Teffective = 1/Tphysical + 1/Tbiological (T=half-life).

One trick that has helped me on multiple choice examinations is that the effective half-life will never be longer than the physical half-life or the biological half-life. Therefore, if you are shown values on a multiple-choice question for the effective half-life that is higher than what they told you for either the biological or the physical half-life, you can immediately eliminate those as correct answers because the effective half-life cannot be longer than either the physical or biologic half-life.