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Nuclear Medicine Collimators for Radiology Board Review

Although there are at least 5 basic collimator designs, the good news is that I think you only need to know 3 of these for board examinations: parallel hole collimators, converging/diverging collimators, and pinhole collimators.

1. Parallel hole collimators—these have separate collimators for low, medium, and high energy imaging
    a. Low-energy all-purpose (LEAP)
        i. Have large holes allowing for high sensitivity (lots of counts can enter) but lower resolution
            1. There is a trade-off in nuclear imaging between sensitivity and resolution
            2. Sensitivity requires that you get as many counts as possible in the time allotted
            3. Maximizing sensitivity requires that you allow some scatter to enter the collimator which lowers resolution
    b. Low-energy high-resolution (LEHR)
        i. As in the name, this is the high-resolution collimator for use with low energies
            1. LEHR collimators obtain higher resolution than LEAP collimators by making the holes in the collimator smaller and elongating the holes in the collimator. This makes it harder for scattered gamma rays to reach the scintillation crystal. Many non-scattered gamma rays can still make it.
            2. By making the holes smaller, you have more of them within the same collimator field of view and therefore given better spatial resolution.
        ii. Use LEAP and LEHR collimators for Tc99 (140 keV), Thal201 (multiple energies, but over 90% are less than 81 keV).
    c. Medium energy
        i. These have thicker septa than a low-energy collimator which is necessary to reduce septal penetration when imaging more energetic radiopharmaceuticals
        ii. Septal penetration has a star pattern and is most commonly seen when imaging I131 with a low or medium energy collimator. Septal penetration is very commonly tested on board examinations.
        iii. Use a medium energy collimator for for Ga67, In111.

1. Gallium67 keV photopeaks are approximately 100, 200, 300, 400 keV
    a. About 65% of energy is around 200 keV or below, using the medium energy collimator is a compromise as Ga67 spans low to high energies
2. Indium111 keV photopeaks are approximately 175 and 250 keV

d. High energy
    i. Even thicker septae than a medium energy collimator
    ii. For board purposes you use this for I131 only, 364 keV
        1. Again, know what septal penetration looks like if you image I131 with a low or medium energy collimator

2. Converging/diverging collimators
    a. Converging collimator
        i. Key to answer board questions is to remember that the collimators converge toward the person/body part being imaged
        ii. This makes the imaged area appear larger because as gamma rays leave the body part being imaged they enter the holes that while converging towards the patient, by extension, diverge towards the crystal. So the rays diverge and are more spread out on the crystal face, therefore making the image on the crystal larger.
    b. Diverging collimator
        i. The collimators diverge toward the person/body part being imaged
        ii. This will allow a larger field of view to fit on a smaller crystal, so called "minification". The image on the crystal will be smaller as a result of passing through the collimator.
        iii. This decreases sensitivity but increases resolution.
    c. Key points:
        i. The reference point to which a collimator converges or diverges is the object being imaged NOT the crystal. A converging collimator converges toward the object being imaged. A diverging collimator diverges toward the object being imaged.
        ii. Converging collimators make an image larger
        iii. Diverging collimators increase the field of view beyond that of the crystal size

3. Pinhole collimator

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a. Magnifies images of small organs like thyroid, a joint, scrotal imaging
b. Image is inverted on crystal
c. Pinhole provides the most magnification but smallest field of view
d. Pinholes maximize resolution at expense of sensitivity because there is a very small opening for gamma rays to enter

Additional points:

Remember collimators have a lot to do with the resolution of an imaging study. The way you get positional data on an image through collimators is that a collimator only accepts counts from a small region of the object being imaged that is located directly in front of the collimator hole. The smaller the collimator holes, the higher the resolution, but also the lower the sensitivity because you will capture fewer counts in a given amount of time.

For illustration (I don't think you don't have to memorize these values):

-LEAP accepts about 500k counts per minute whereas LEHR accepts about 175k counts per minute. So you have lower sensitivity with a LEHR than a LEAP when imaging for the same amount of time with the same injected activity. But because the collimator holes are smaller and deeper on a LEHR, the LEHR has better resolution than a LEAP because it accepts fewer scattered gamma rays.

-LEAP has resolution of about 10 mm at 10 cm from the collimator, whereas a LEHR has a resolution of about 6 mm at 10 cm from the collimator.

What about Iodine 123? Several studies have shown improvement in image quality when using a medium rather than low energy collimator. I don't think they will ask this on the ABR core exam though because some sites may vary in what collimator is used.

Basically, on a multiple-choice exam, if the majority of energy is 140 keV or lower I would choose to use a low energy collimator (remember I123 has 159 keV), if you are using I131 choose high energy, and otherwise go with medium-energy.

What collimator do you use for the weekly bar phantom spatial resolution QC test? A low energy high-resolution collimator.

Collimators are made of lead or tungsten—you need really dense metals so the septa can be made as thin as possible.

For nucs QC testing an "extrinsic" test has the collimator in place. An "intrinsic" test is done without a collimator. I remember this by thinking that an "extrinsic" test has the radioactive source "external" to a collimator. An "intrinsic" source tests the intrinsic performance of a gamma camera without an external collimator.

How do we get rid of scatter in nuclear medicine? A few methods to be aware of:

1. Collimators
    a. Counts that come in off-axis will get blocked by the septae of the collimator and not reach the crystal face
        i. Remember the increasing the effectiveness by which the collimator blocks scatter will result in a lower sensitivity
        ii. 2D PET had collimators (tungsten, not lead), 3D PET does not have collimators. Hence 3D PET is more sensitive and uses other methods such as time-of-flight to reduce scatter.
    b. Pulse-height analyzers
        i. Selecting a narrow energy range on the pulse-height analyzer will make it so the system only uses gamma rays with the desired energy for an image
        ii. Scattered gamma rays that have given off portions of their energy from the Compton scatter event/collision will not be accepted in the final image
        iii. If you select the wrong energy you get low-resolution images with poor anatomic localization
            1. This is called "off peak" imaging
            2. This may happen if a technologist forgets to switch from a peak of 140 keV for Tc99 when imaging with something that has a different energy like Ga67.
            3. Also commonly may forget on first patient of day to switch from Co57 peak (122 keV) (used for cobolt flood QC testing) when imaging with Tc99m (140 keV) or another radiopharmaceutical.
    c. Time-of-flight and coincidence detection on PET scanners
        i. Will cover in more detail on discussion of PET physics
        ii. Uses a PET detector ring that has such high temporal resolution that it can detect within nanoseconds if a photon pair strikes one detector slightly before the other 180 degree opposed detector
        iii. Can use this difference in photon pairs hitting detectors to figure out the event must have occurred closer to the detector that detected the event a few nanoseconds earlier

iv. By using this method, you can reduce the length of the line of response and thereby get rid of scatter and improve resolution of an image

v. Coincidence detection also reduces scatter on its own because you only accept counts that are spatially correlated. The system will only accept counts that are registered at the same time on detectors that are 180 degrees opposed—therefore assumed to represent the non-scattered annihilation photon pair.

Collimator	keV	Radiopharmaceuticals
LEHR/LEAP	140 and below	Tc99m, Thal201
Medium Energy	Between Tc and I131 (140-365 keV)	Ga67, In111, I123
High Energy	364 keV and above	I131