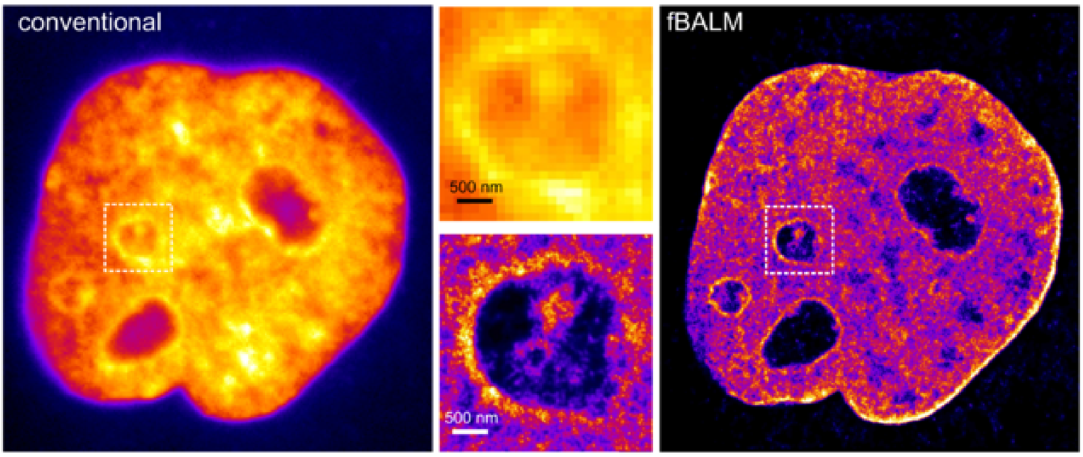
Nuclear Medicine: Introduction to Nuclear Imaging

See online here

While "positron emission computed tomography" scanning is becoming more commonly seen in the clinical practice of molecular imaging, other forms of nuclear imaging also exist that should be discussed. Magnetic resonance imaging, computed tomography, ultrasound, and X-rays are the main diagnostic imaging modalities for structural abnormalities. Nuclear imaging is more concerned with the functional and molecular aspect of the problem. For instance, nuclear imaging can answer questions related to myocardial perfusion and ischemia, differentiate between malignant and benign thyroid nodules or confirm the diagnosis of acute cholecystitis.



Nuclear Imaging and Myocardial Ischemia

SPECT

Patients with a history of atypical angina pectoris, or those who have established a history of ischemic heart disease, might benefit from a myocardial perfusion **single-photon emission computed tomography (SPECT)** scan. Similar to SPECT studies of the brain in epileptic patients, SPECT studies of the heart show whether perfusion is abnormal in certain regions during a physical or pharmacological challenge.

The images obtained from SPECT can be later superimposed on a magnetic resonance image. After co-registration of the two imaging modalities, one can tell with excellent certainty if regional myocardial wall ischemia is present or not during the physiologic challenge.

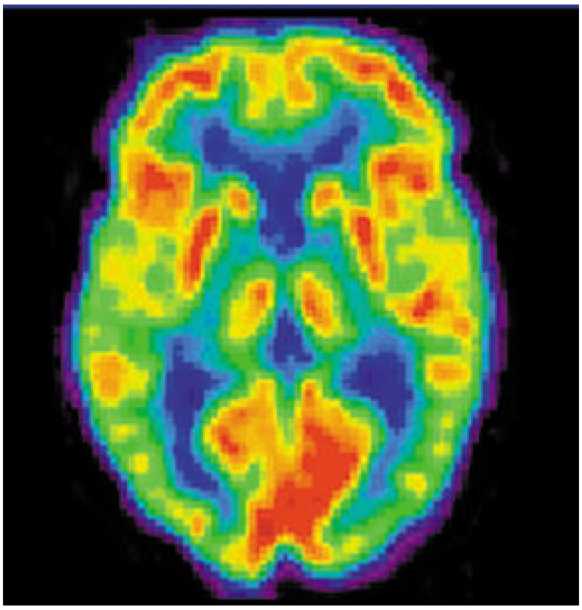


Image: “NIH PET” by the United States Department of Health and Human Services. License: Public Domain

SPECT imaging is largely based on the statistical comparison between rest and exercise images. The principle behind the interpretation of the SPECT result is that patients with ischemic heart disease will have impaired myocardial perfusion during exercise or pharmacologic stress. Ischemic myocardial regions will show hypoperfusion on SPECT.

SPECT is based on the detection of a radioactive tracer that is injected into the blood stream via an intravenous injection in small amounts. The injected tracer is specifically taken by the cardiomyocytes. The amount taken by the heart muscle is proportional to the number of viable cardiomyocytes.

From our understanding of the pathophysiology of ischemic heart disease, we know that the number of viable myocardial cells is expected to decrease in the ischemic region of the heart. Therefore, the concentration of the radioactive tracer in that region will be lower compared to the adjacent tissues and it will show as a defect of hypoperfusion on SPECT.

SPECT is very cost-effective compared to any other imaging modality in the evaluation of acute and chronic ischemic heart disease patients. Additionally, **SPECT has the strongest predictive power in predicting adverse cardiac events** in patients with coronary artery disease. Because of this, myocardial perfusion SPECT is now recommended in all patients with acute or stable chest pain suspected to have an acute coronary syndrome or ischemic heart disease.

Nuclear Imaging and Thyroid Nodules

Image: “Thyroid Ultrasound” by Nevit Dilmen. License: CC BY-SA 3.0

Thyroid nodules are quite common. The main goal of nuclear imaging in the past with a thyroid nodule was to differentiate between malignant and benign lesions. Unfortunately, the technique was neither specific nor sensitive for thyroid cancers.

The isotopes used for nuclear imaging of thyroid nodules include technetium-99m, iodine-123, gallium-67, thallium-201 and iodine fluorescence imaging. Each isotope has its advantages, disadvantages, and indications.

Note: Technetium-99m studies are very cheap and safe to make, but they tend to have low sensitivity, especially for evaluating the mediastinal region. Additionally, technetium-99m does not show organification of the tracer within the thyroid gland.
The most commonly used isotope nowadays in the diagnostic workup of thyroid nodules is iodine-123. **Radioactive iodine has good stability, can produce a 159-keV photon that can be readily taken by the available cameras**, and does not emit any particulates that can put the patient at significant radioactive harm. **Iodine-123 has a half-life of 13.3 hours;** therefore, frequent supply to the imaging facility is needed. Thyroid nodules can appear as hot or cold depending on whether they take more or less of the tracer compared to the surrounding tissue.

The terminology of hot and cold nodules should be abandoned in current practice. Instead, the terms **functioning or non-functioning** are more accurate in describing the nodule:

Functional nodules are usually benign and resemble adenomas. Malignant disease was found only in 1 % of the functioning nodules. Unfortunately, up to 90 % of thyroid nodules are non-functioning. The risk of malignant disease in non-functioning nodules is quite high. Thyroid carcinomas, lymphoma, a significant proportion of thyroid adenomas, nodular goiter, and thyroid cysts all appear as non-functioning nodules on iodine-123 scintigraphy.
The risk of malignancy in a single non-functioning nodule on an iodine-123 study is around 10 to 25 %.

When the patient has multiple **non-functioning nodules**, the risk of malignancy drops to only 1 %. Hot nodules on a technetium-99 m study can be malignant in up to 29 % of the cases, whereas functioning nodules on iodine-123 carry a 1—4 % risk of being malignant. Because of this, iodine-123 is said to have a much higher sensitivity and specificity compared to technetium-99 m.

Iodine-123 studies

Iodine-123 studies are also helpful in the evaluation of the possibility of metastatic papillary or follicular thyroid carcinoma. **Gallium-67 studies cannot differentiate between benign and malignant thyroid nodules** but are useful in the evaluation of thyroid lymphoma. Thallium-201 studies add more to our certainty that a nodule is indeed malignant as it tends to be of a much higher intensity in malignant thyroid nodules.

Iodine fluorescence imaging

Iodine fluorescence imaging is not available in most centers, and is used for the functional assessment of the thyroid gland. Iodine fluorescence imaging **is based on the principle that irradiating the thyroid gland can make the iodine inside the gland radioactive**. The concentration of intrinsic stores of stable iodine can then be studied.

In summary, nuclear imaging in thyroid nodules is more useful for the exclusion of thyroid metastatic cancers, rather than for the differentiation between malignant or benign thyroid nodules.

Ventilation-Perfusion Scanning and Pulmonary Embolism

Note: V/Q scanning of the lungs is indicated for the evaluation of a patient suspected to have a pulmonary embolism when a computed tomography scanner is not available or when computed tomography scanning is contraindicated.

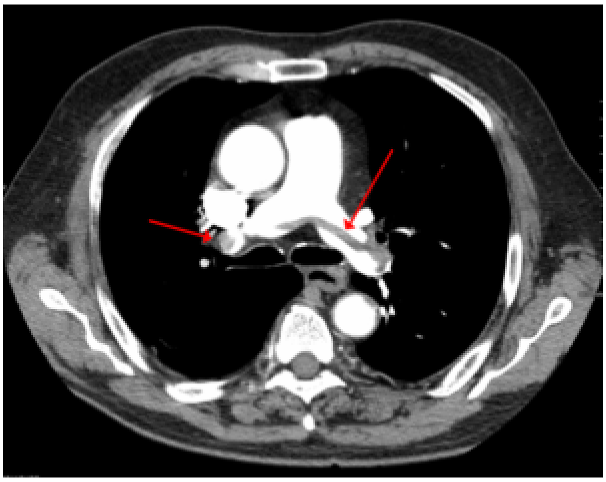


Image: “Pulmonary Embolism” by James Heilman, MD. License: CC BY-SA 3.0

V/Q scanning in children is believed to have the best accuracy in the identification of a significant pulmonary embolism. The images obtained with a V/Q scan can be of high, intermediate or low-probability for pulmonary embolism. **High-probability perfusion scans show segmental or sub-segmental perfusion defects in the lungs**.

When the ventilation scan is performed, a mismatch will be observed between the two images and then a high-probability ventilation-perfusion scan is diagnosed. Intermediate perfusion scans show moderate or small segmental perfusion defects that also show mismatch with the ventilation scan.

When the perfusion and ventilation scans match for the site of the defect, a radiograph is obtained. If the radiograph is normal, then intermediate probability V/Q scan is diagnosed. If an opacity is found on the radiograph and it is in the lower lung zone, then again, the V/Q scan is considered as an intermediate probability for pulmonary embolism.

When the V/Q scan shows multiple matched defects on both the perfusion and the ventilation scans, the probability of pulmonary embolism is low. Patients with a matched defect on a V/Q scan with middle or upper lung opacity on the radiograph are also considered to have a low-probability V/Q scan for pulmonary embolism. Patients with matched V/Q defects who have large pleural effusions are also unlikely to have a pulmonary embolism.

Finally, the V/Q scan can be considered as normal if no perfusion defects were observed and the radiograph was normal. A patient with a low-probability V/Q scan and a low pretest pulmonary embolism Wells score can be reliably considered as not having a pulmonary embolism.

Technetium-99m Iminodiacetic Acid (HIDA) scan and Acute Cholecystitis

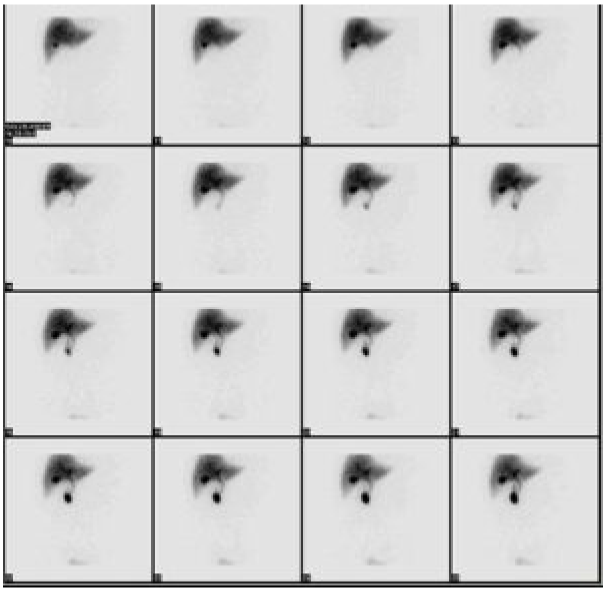
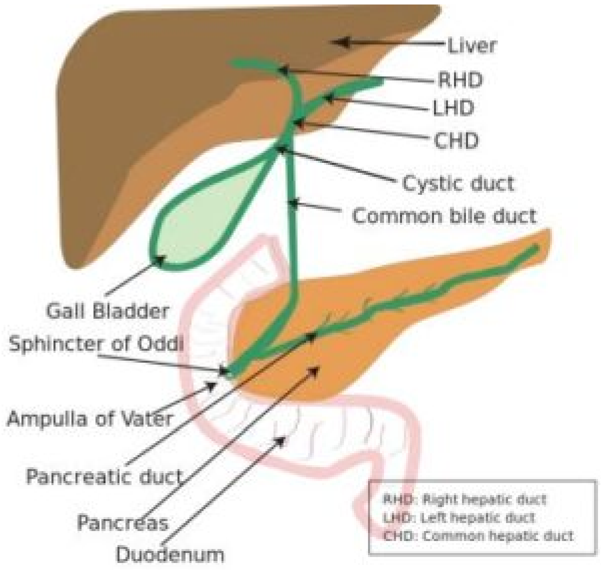


Image: “HIDA” by Myohan. License: CC BY-SA 3.0

HIDA scans **are used to confirm the diagnosis of acute cholecystitis** in a patient with symptoms and signs suggestive of acute cholecystitis and an equivocal ultrasound scan.

The main principle behind a HIDA scan is that, after the injection of the radioactive tracer technetium-99 m, it is expected that most of the tracer will go unchanged to the gallbladder and biliary tract; therefore, a normal and non-obstructed gallbladder is expected to undergo complete visualization one hour after the injection of the tracer.



"HIDA Scan Mechanism of Action" Image created by Lecturio

The iminodiacetic acid binds to protein and is taken up by the liver and then excreted, similar to bile.

On the other hand, **an obstructed gallbladder will not take the tracer as expected**. Instead, the gallbladder will not be visualized at the cut-off 60 minutes. In some cases, it might be unreasonable to wait for 60 minutes to consider the gallbladder as non-visualized and to confirm the diagnosis of acute cholecystitis.

In that case, morphine can be injected with the tracer. **Morphine is known to lower the tone of the sphincter of Oddi** and complete visualization of the gallbladder is now expected after 30 minutes. If the gallbladder is not visualized 30 minutes after the injection of the tracer and morphine, then the diagnosis of acute cholecystitis can be confirmed.

Normal Imaging Finding

Time after IV injection of radiotracer	Normal Imaging Finding	What it means
10 min	Bile ducts visible	Normal hepatic function
30-60 min	Filling of the gallbladder	Patent cystic duct
60 min	Radiotracer seen in the duodenum	Patent common bile duct

References

Myocardial Perfusion SPECT via emedicine.medscape.com

Thyroid Nodule Imaging via emedicine.medscape.com

Pulmonary Embolism via emedicine.medscape.com

Acute Cholecystitis Imaging via emedicine.medscape.com

Notes