Introduction to Nuclear Medicine

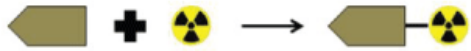
Objectives

- What is nuclear medicine?
- Pros and cons
- Safety
- Indications
- A few sample types of studies

Radiolabeling Labeled Compound

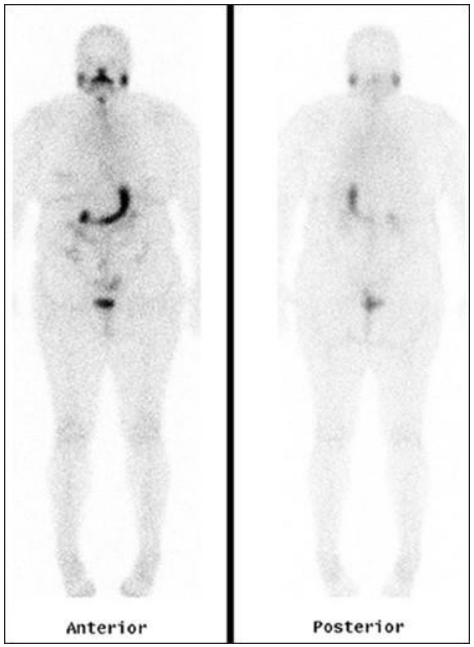
What is nuclear medicine?

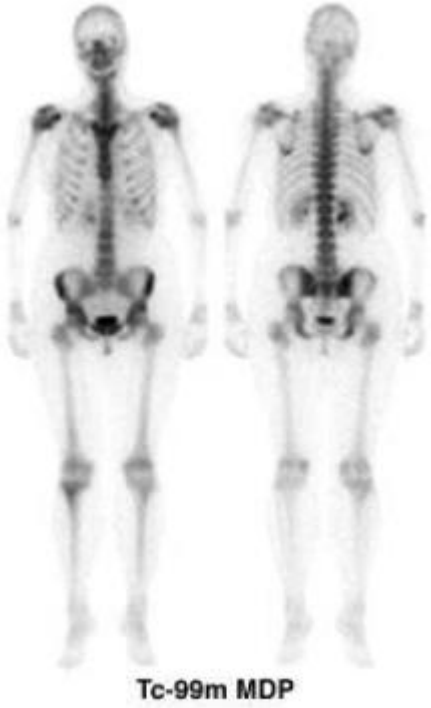
- Nuclear medicine uses **radionuclides** (unstable forms of elements whose atomic nuclei decay and emit gamma radiation that we can detect with gamma cameras) for diagnosis and treatment of disease
- We can use the radionuclides in certain drugs to create **radiopharmaceuticals**
- When radiopharmaceuticals are administered to patients, they accumulate in different organs or tissues
  - Thus, HIDA (a lidocaine analog) stuck to technetium will accumulate in the bile like lidocaine would and take a picture of the bile.
  - Radioactive iodine will go to the thyroid like normal iodine and show us what parts of the body are taking up iodine.
  - FDG (a glucose analog) will be taken up like normal glucose and show us what parts of the body have heavy anaerobic metabolism

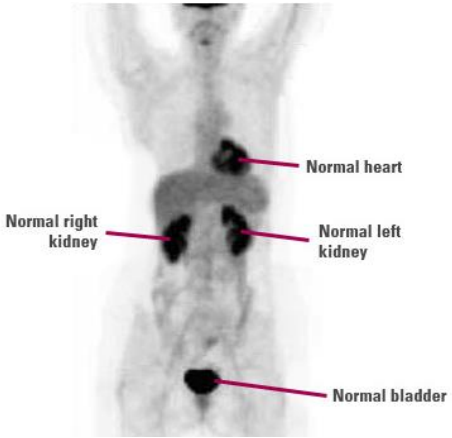


Some radionuclide scans

In-111 labeled WBCs





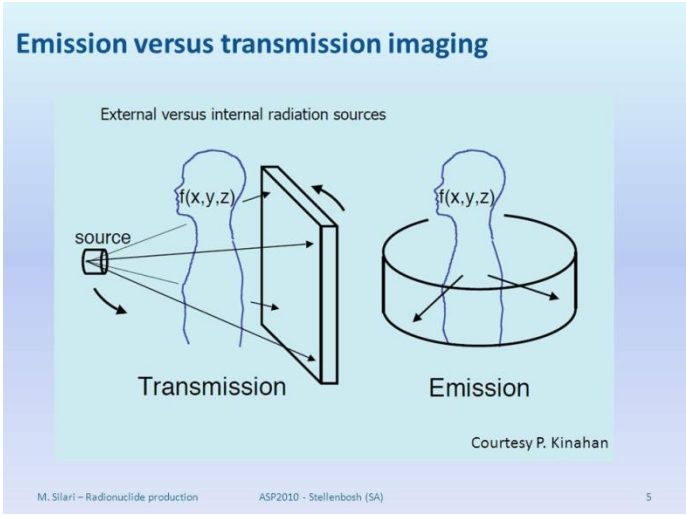


FDG-PET

Whole body iodine scan (post-thyroidectomy)

What is nuclear medicine?

- In radiographs and CT, X-rays are transmitted *through* the patient's body.
- In nuclear medicine, gamma rays (from the radiopharmaceutical, presumably localized by physiology) are emitted *from* the patient's body
  - They are then detected by a gamma camera or PET scanner



Nuclear medicine basics: pros

- Examine physiology
  - Sometimes allows us to answer questions not answered by other imaging modalities
  - Possibility of molecular targeting/precision medicine (we can see if a tumor has somatostatin receptors, for instance)
- Take as many images as we want after injection
  - Since the dose is administered at the time of injection, we can get as many extra pictures as we want without additional radiation.

Nuclear medicine basics: pros

- Concentrations are low, so safe for patients in renal or hepatic failure
- Less affected by obesity (gamma rays are very penetrating)

Nuclear medicine basics: cons

- Relatively high radiation dose—CT or more
  - The patient keeps getting radiated by the radiopharmaceutical until it gets excreted, so we have to give relatively little to start with
- Low spatial resolution (‘unclear medicine’)
- Variations in biodistribution for reasons other than disease
  - As a result, often extensive preparation (some exams may require the patient to be NPO, others to be off certain medications)

Nuclear medicine basics: safety

- Radiopharmaceuticals are at nanomolar (subpharmacologic) concentrations, so we can give pharmacologically active drugs
  - Ioflupane (DaT Scan) is a cocaine analog on Schedule II
  - HIDA is a lidocaine analog
  - Thallium is poisonous at higher concentrations
- Reasonably high radiation dosage (similar to CTs)

Nuclear medicine basics: terminology

- Much of the confusion from a new field can arise from the unfamiliar terminology
- Terms:
  - Increased uptake
  - Normal uptake
  - Decreased/absent uptake or photopenic (there is no antonym)
- Compare: increased or decreased opacity (radiograph), attenuation (CT), intensity (MR), echogenicity (US)

Nuclear medicine basics: indications

- Note that the nuclear exam typically answers one question
- A V/Q scan will rule out pulmonary embolism, but will not distinguish among pneumonia, pleural effusion, and malignancy.
- A HIDA scan will rule out cholecystitis, but will not distinguish kidney stones, appendicitis, and diverticulitis.

Nuclear medicine basics: indications

- By far most common nuclear scan is **PET scan with FDG**
  - This is mostly used for cancer staging
  - Exploits dedifferentiated tumors' heavy anaerobic metabolism and consequent glucose utilization
  - Also has applications in cardiology (viability), neurology (finding seizure foci), and infectious diseases (finding sites of occult infection)

Nuclear medicine scan: indications (by organ system)

- CNS—dementia, tumors, epilepsy
- Endocrine—thyroid, parathyroid, neuroendocrine tumors
- Cardiovascular—coronary artery disease
- Pulmonary—pulmonary emboli
- GI—delayed emptying, GI bleed, cholecystitis, others
- MSK—bone metastases, osteomyelitis, prosthetic joint infections
- Oncology—various (FDG—generic, MIBG, DOTATATE—neuroendocrine tumors, FACBC–prostate, NaF/bone scan—bone mets)

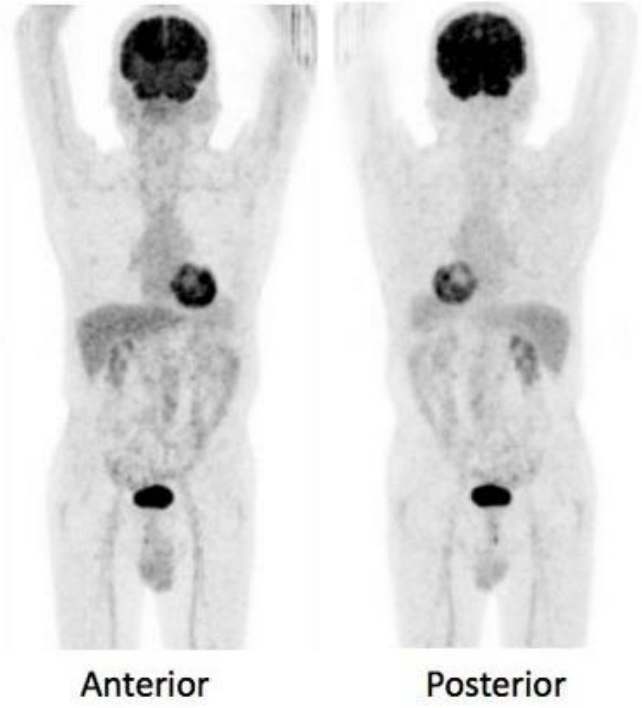
Nuclear medicine basics: indications (most common at UNC)

- Oncologic staging and restaging (FDG-PET)
- Coronary artery disease (myocardial perfusion imaging)
- Skeletal metastases, prostate and breast cancer (bone scan)
- Gastric dysfunction (gastric emptying study)
- Urinary tract obstruction (Lasix/MAG3 study)
- Pulmonary embolism (V/Q study)
- Sentinel node staging (Lymphoscintigraphy)
- Cholecystitis (HIDA scan)
- Hyperthyroidism and thyroid nodules (thyroid scan)
- Parathyroid adenoma (parathyroid scan)
- Calculation of GFR (DTPA)
- Therapy of hyperthyroidism or thyroid cancer (radioiodine treatment)
- Staging of thyroid cancer (whole-body iodine scintigraphy)
- Assessment of renal scarring (DMSA)

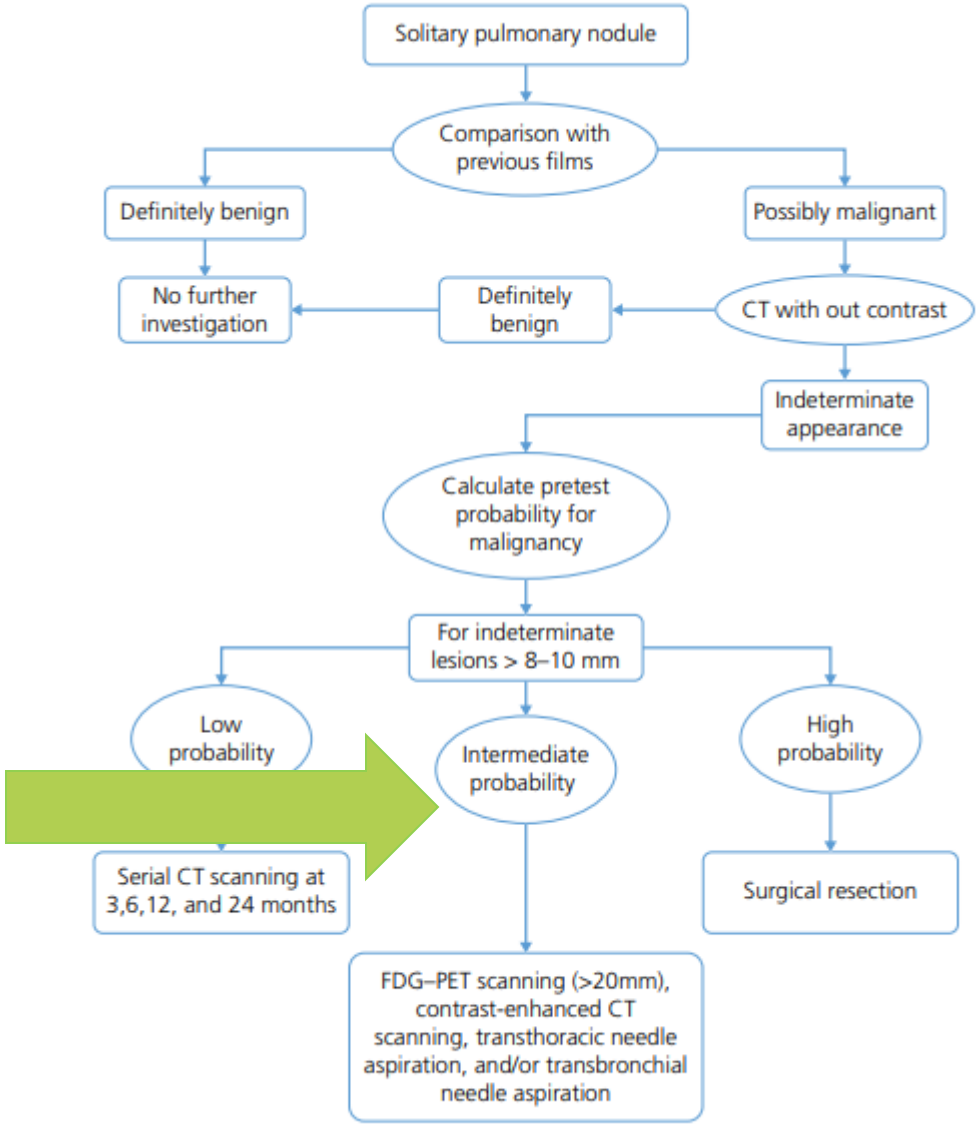
Oncology: FDG-PET

- When do we order the study?
  - Initial staging of a malignancy
  - Response to chemotherapy and/or radiation
  - Detection of recurrence
- What is the clinical question?
  - Is there cancer somewhere? If so, where is it?
- What are we studying? Anaerobic metabolism (and consequent glucose upake)

Normal FDG PET scan



FDG PET for widespread lymphoma

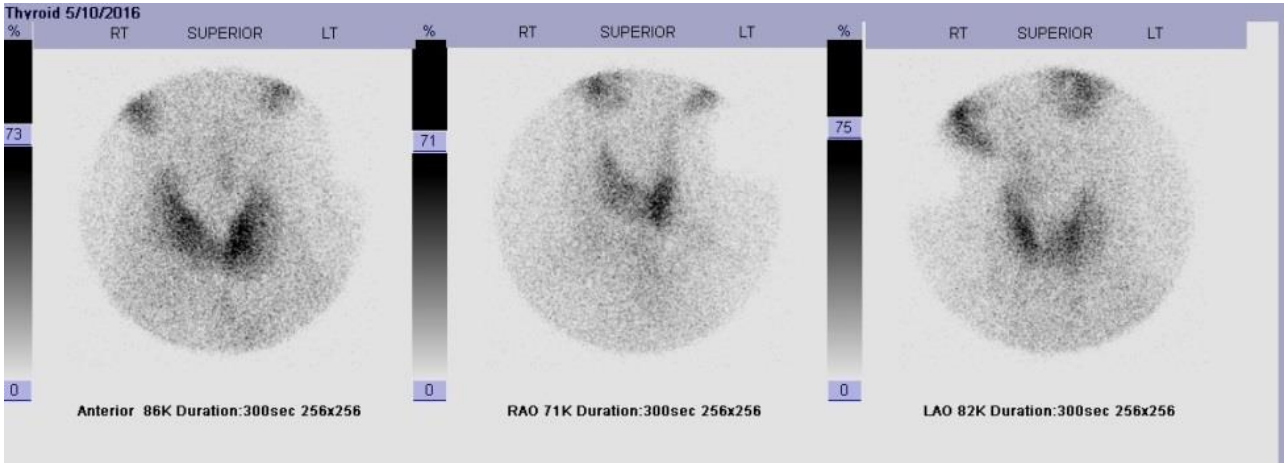


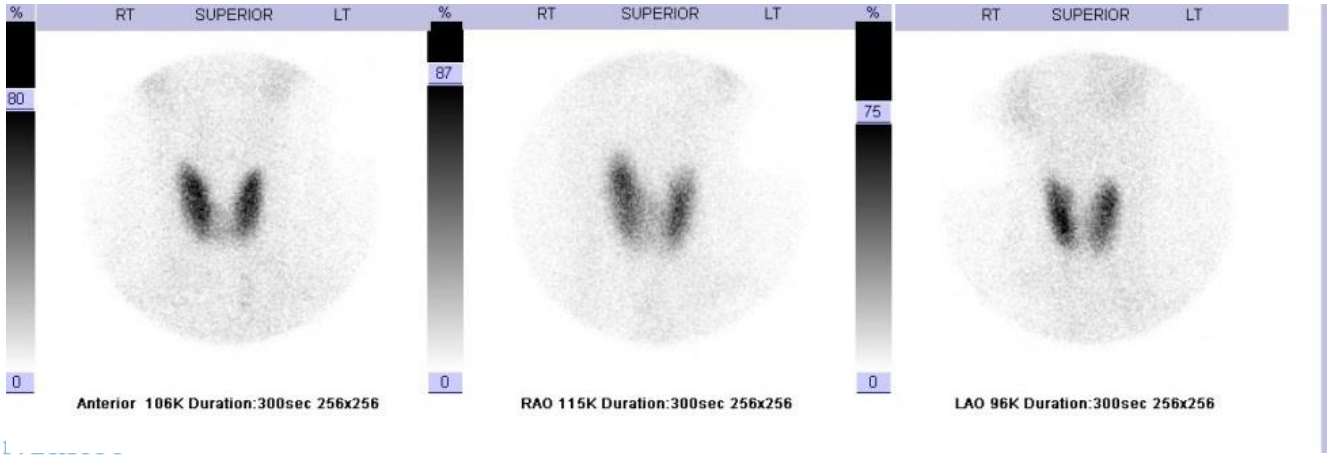
CT, computed tomography; FDG–PET-fludeoxyglucose–positron emission tomography

Endocrine: thyroid

- When do we order the study?
  - When the patient's hyperthyroid, especially if we're worried about a nodule
  - After thyroidectomy for cancer and we want to know if there's thyroid tissue left
- What is the clinical question?
  - Either: what is thyroid function (hyperthyroidism)?
    - If low, the patient likely has subacute thyroiditis (which resolves on its own); if high, it is likely Graves' disease or multinodular goiter (which can be treated with medications, surgery, or radioactive iodine)
  - Or: is there thyroid tissue, benign or malignant, left (thyroid cancer)?
    - If you start seeing thyroid tissue in the lymph nodes, lungs, or bones, you have a metastasis.
- What are we studying? Iodine uptake

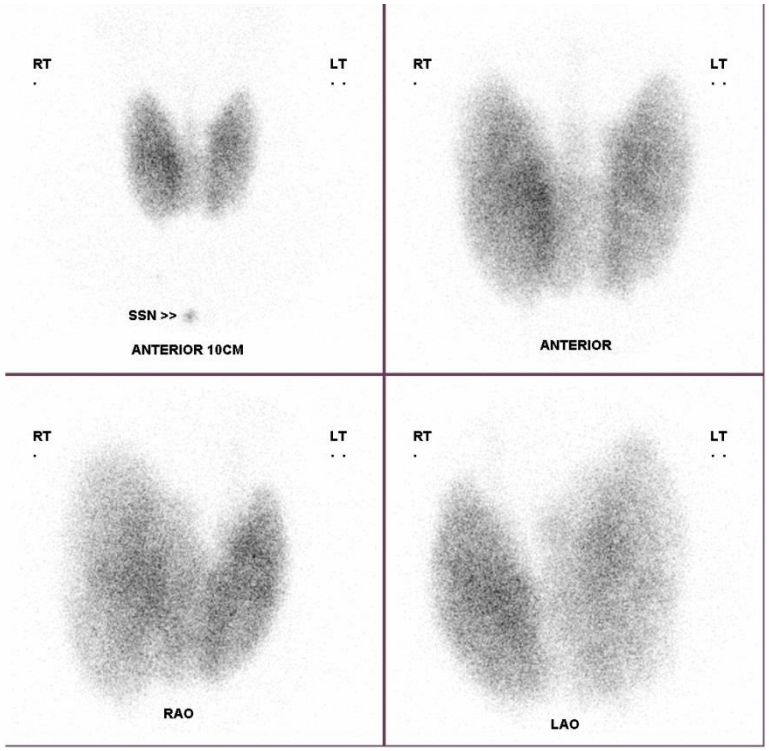
Normal thyroid studies (18%, 27% uptake)



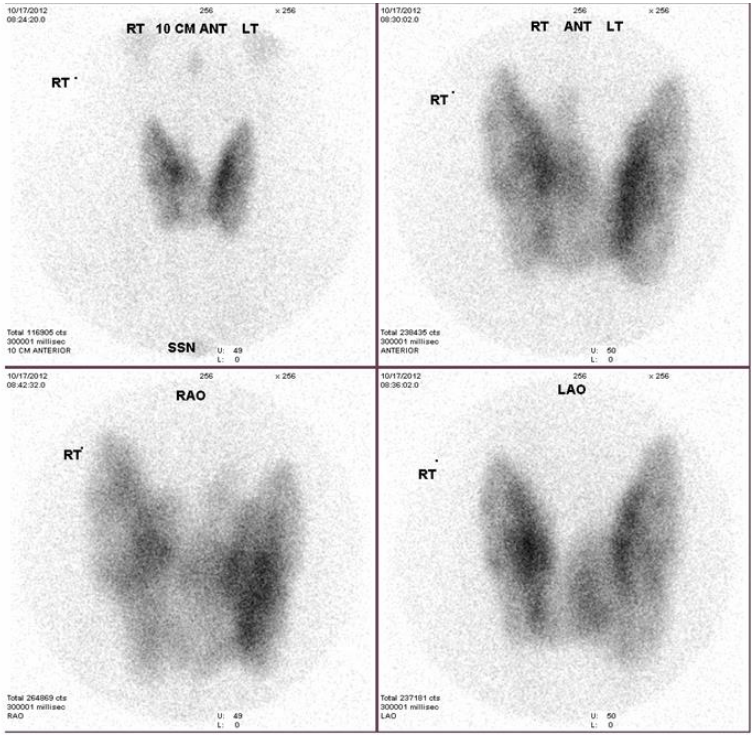


Hyperthyroidism

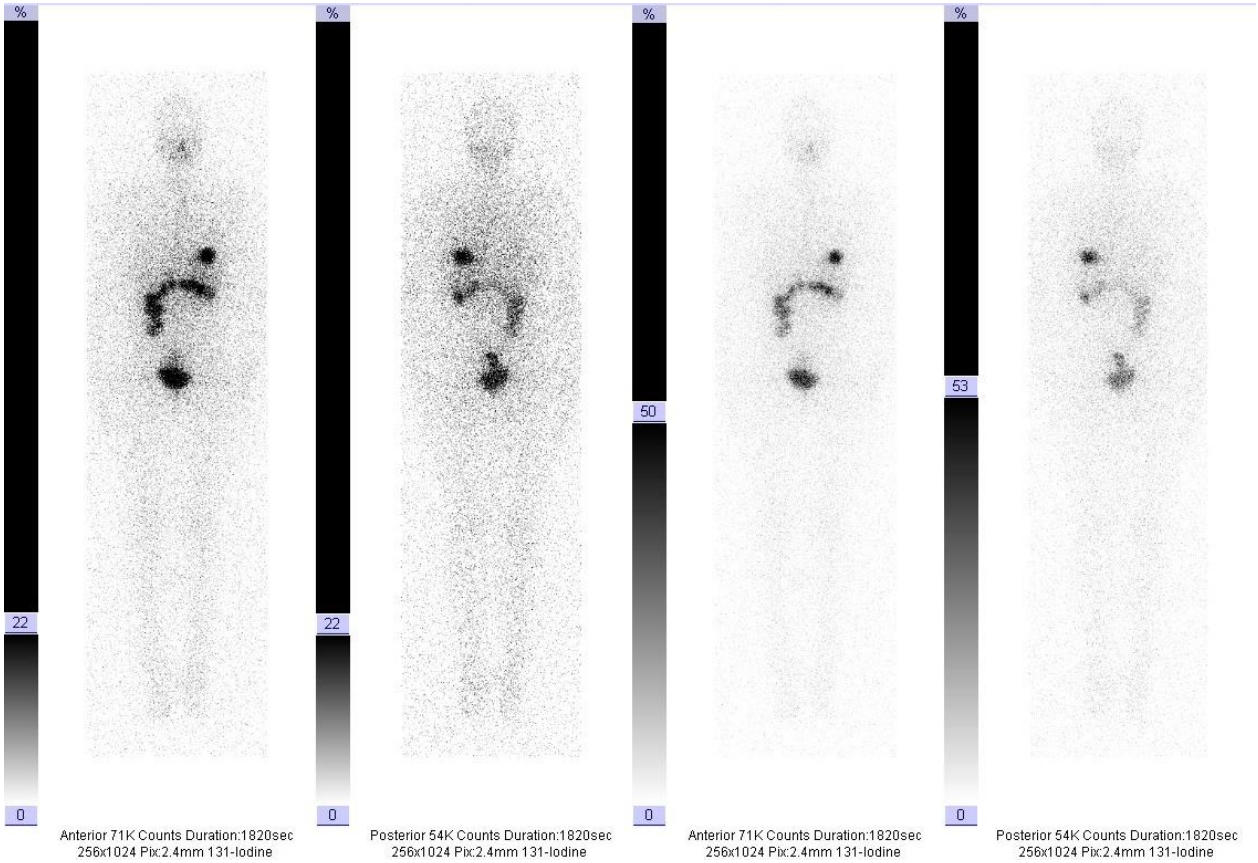
Graves



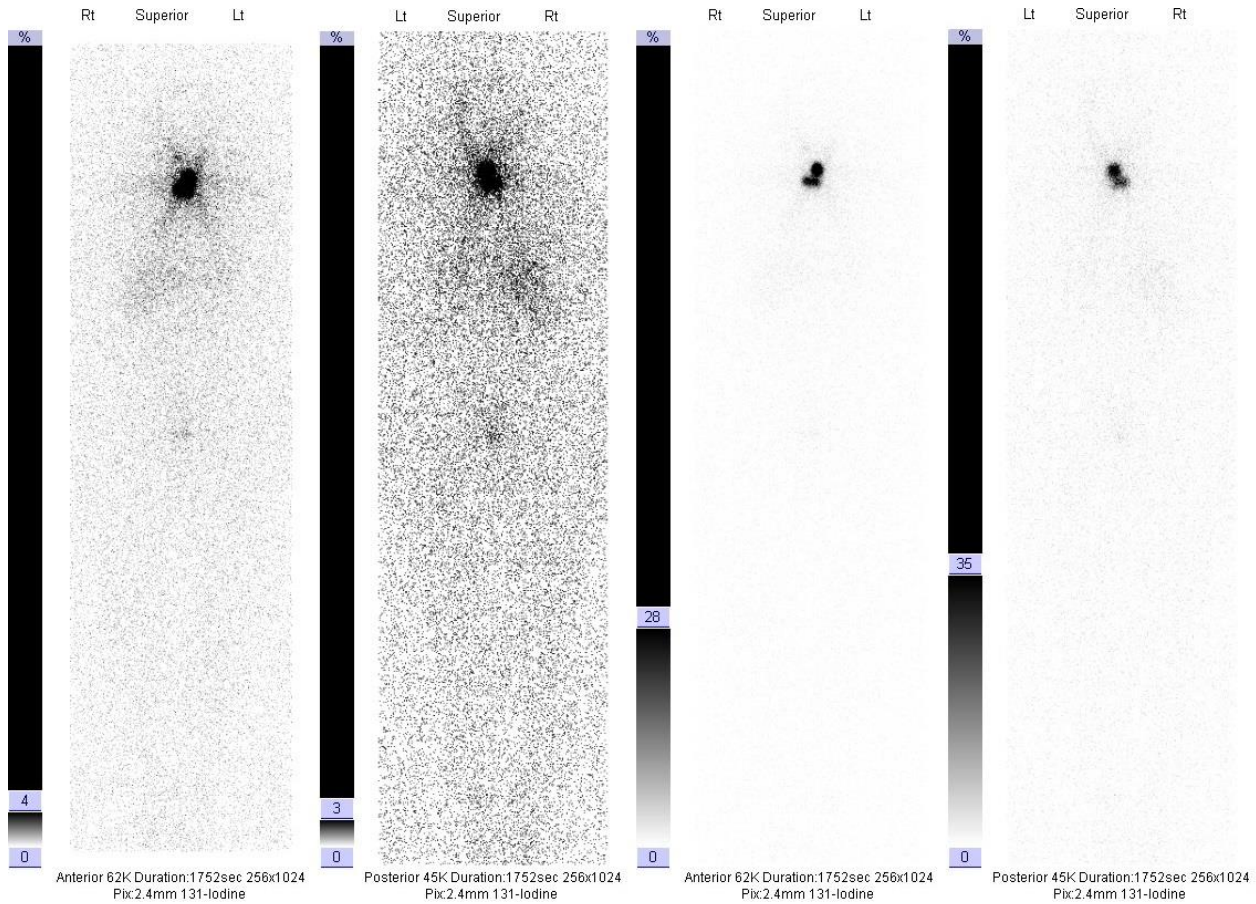
MNG



Whole-body iodine scan, negative

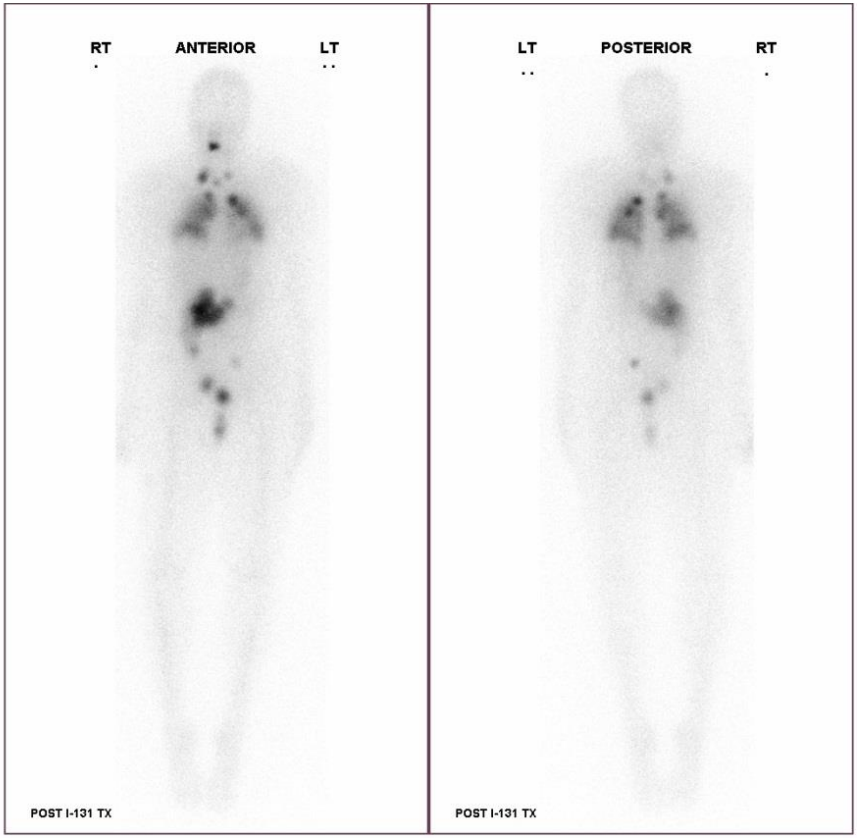


Whole-body iodine scan, residual tissue



Thyroid cancer

Pulmonary and nodal mets



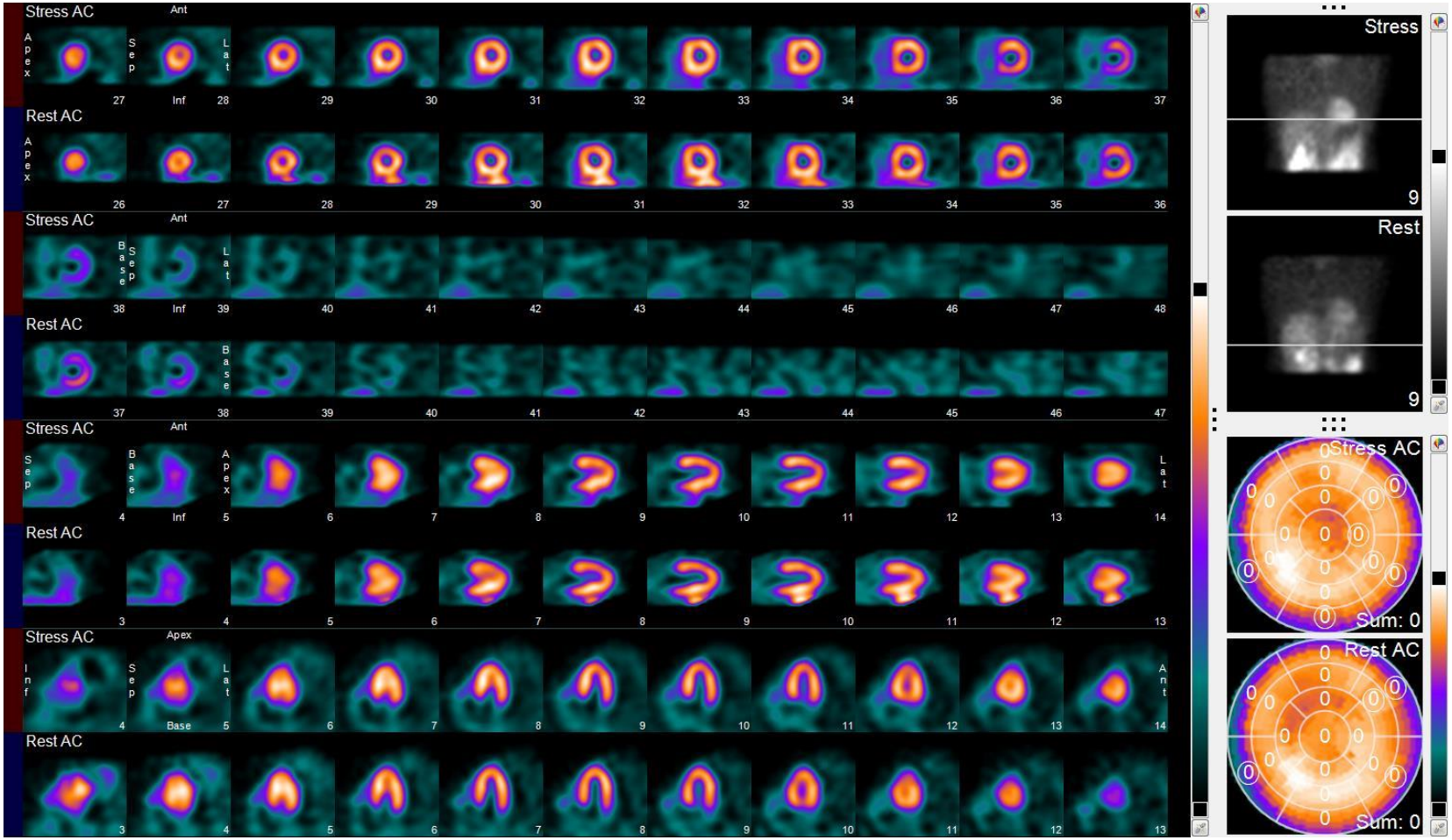
Cardiac imaging

- **When do we order the study?** When we're worried about CAD
- **What is the clinical question?** Is there clinically significant coronary artery disease and, if so, is the affected tissue still alive?
- **What are we studying?** Perfusion (mostly) *at time of injection*
- **What's the name of the tracer?** Tetrafosmin/sestamibi (SPECT), ammonia or rubidium (PET)

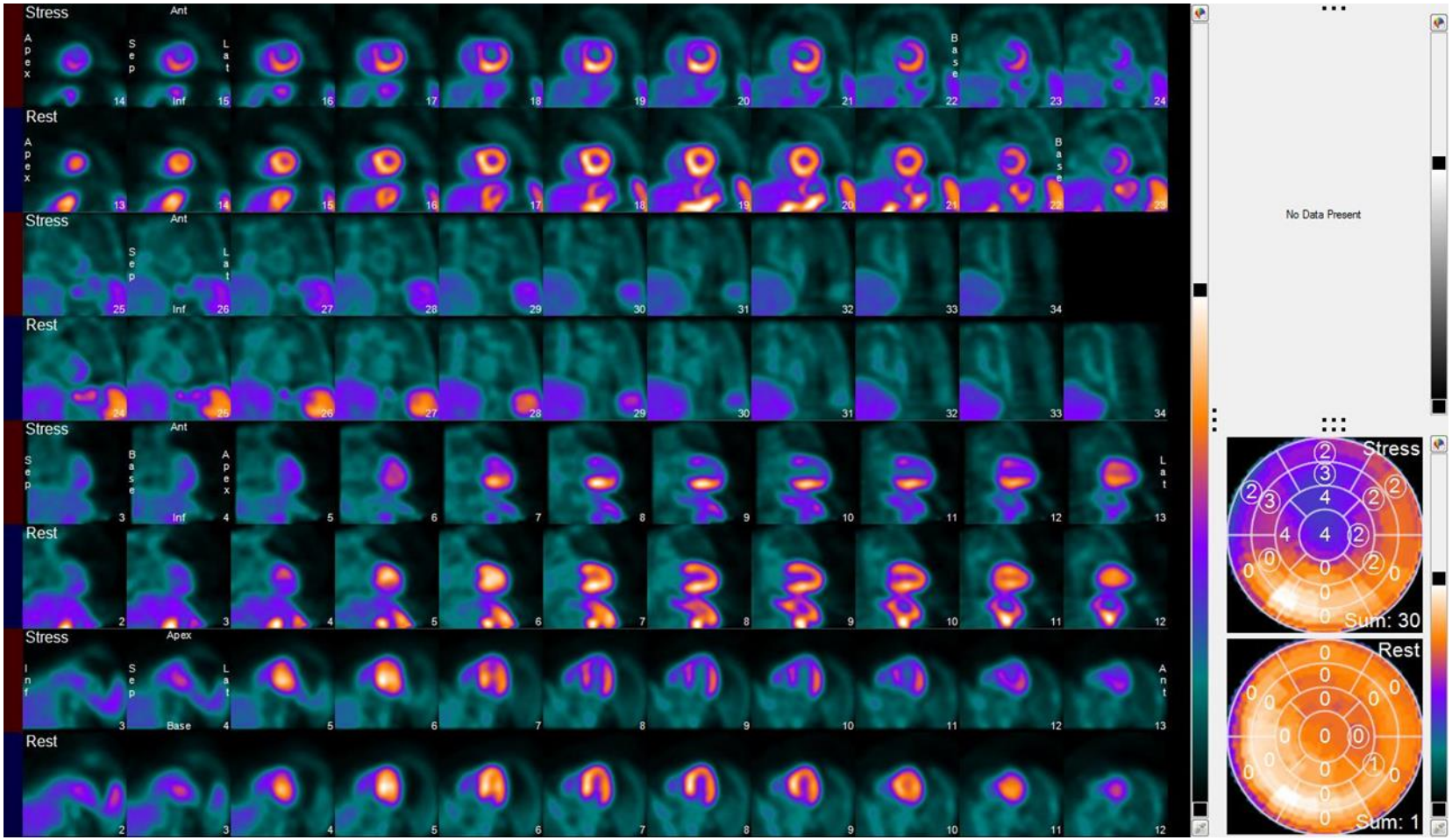
Stress and rest imaging

- To compare the two, we get stress and rest images
- There are a few ways to stress patients
  - We can use exercise or drugs
    - Drugs can be vasodilators or inotropes

Normal



Ischemia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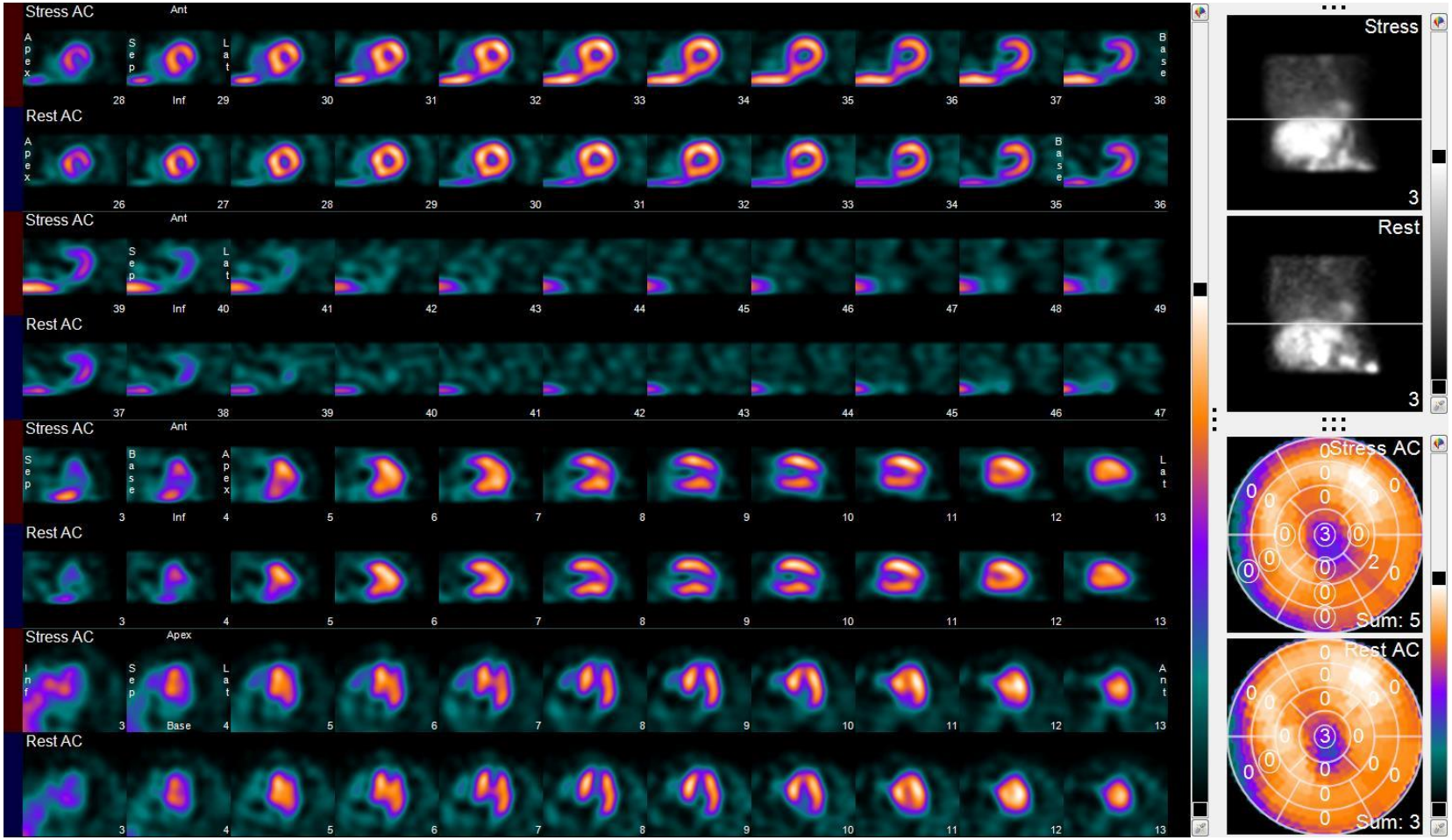
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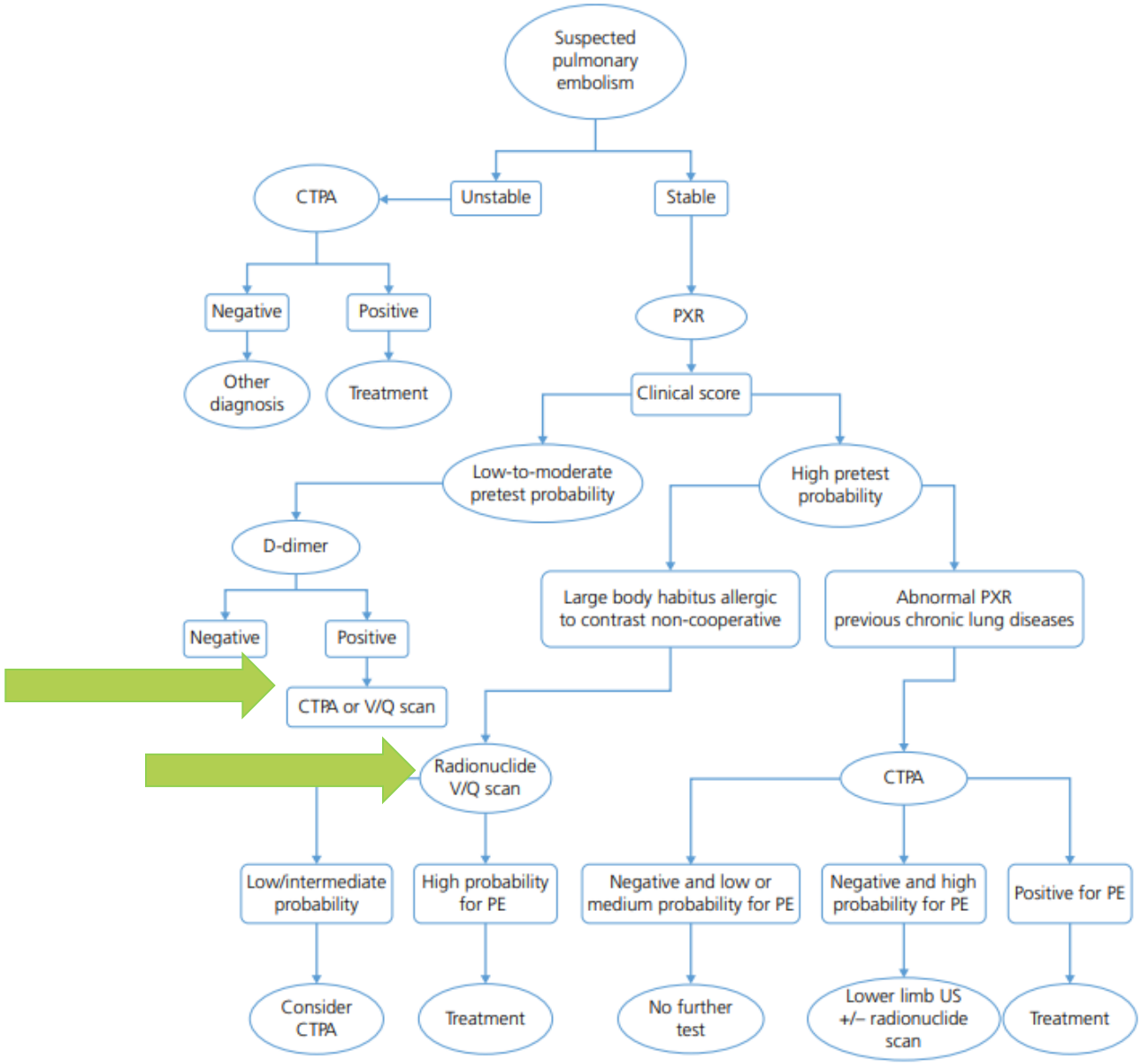
V/Q scan

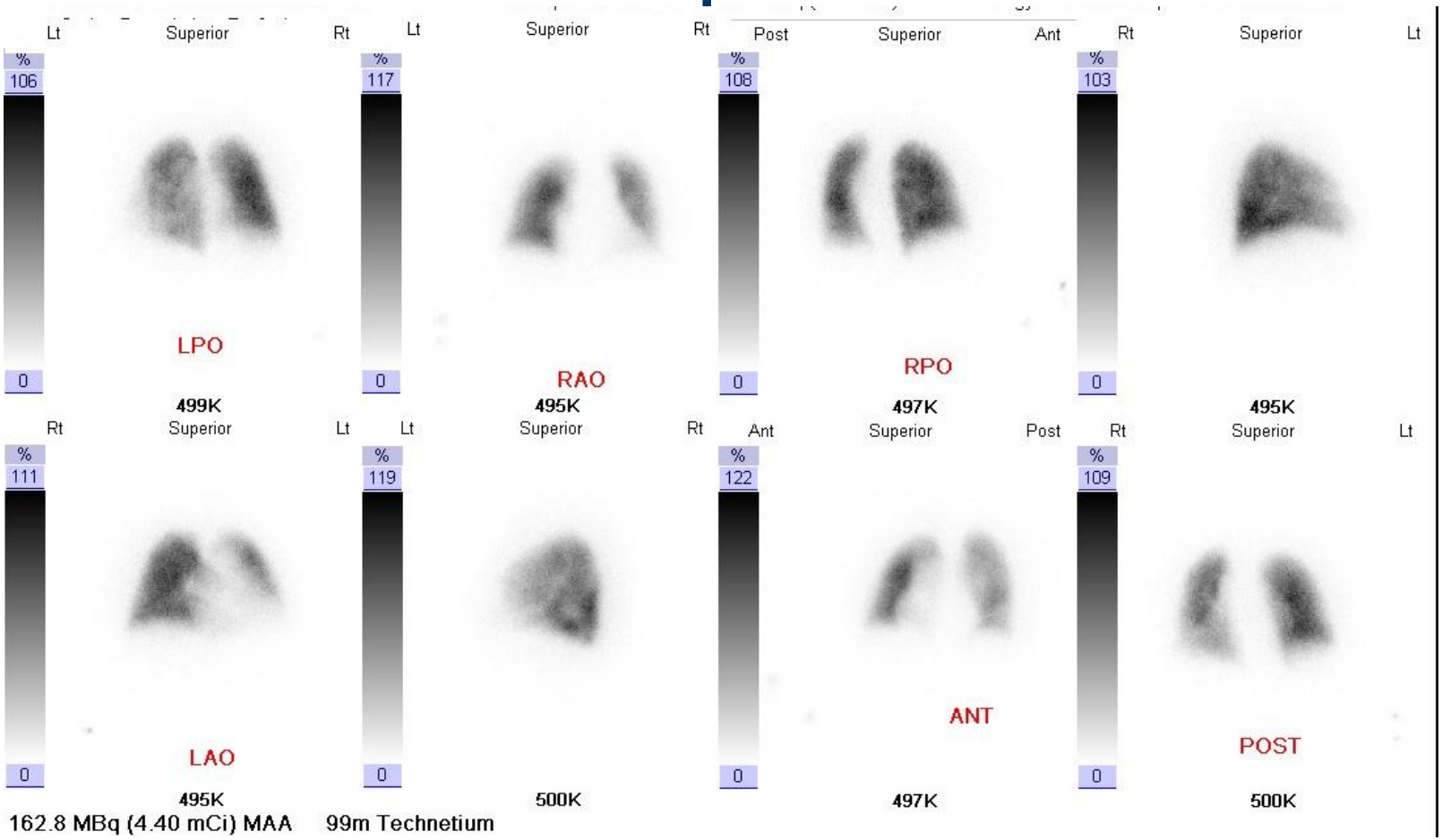
- **When do we order the study?** When we're worried about PE but don't want to get a CTPA
- **What is the clinical question?** Does the patient have a pulmonary embolism?
  - Lower-radiation than the other option, a CTPA; also used with contrast allergies and renal failure
  - The perfusion scan in particular is also used to assess relative lung perfusion before surgery
- **What are we studying?** Lung ventilation and perfusion
  - Alone among pulmonary pathologies, the PE damaged perfusion *but not* ventilation
- This test is interpreted together with a **chest X-ray**



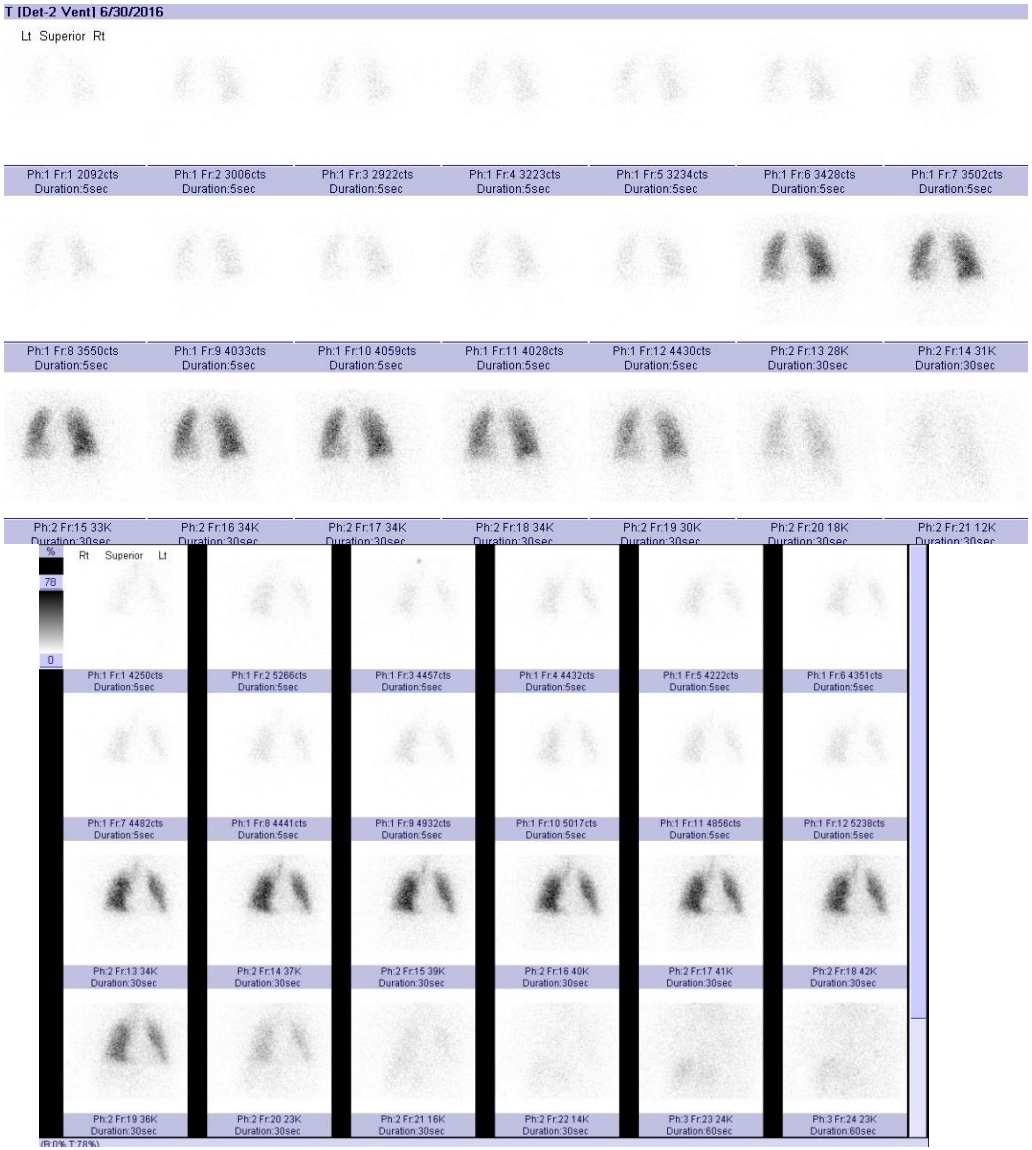
PXR, plain X-ray; CTPA, computed tomography pulmonary angiogram; V/Q scan, ventilation/perfusion scan; US, Ultrasonography.

What if the CTPA is nondiagnostic?

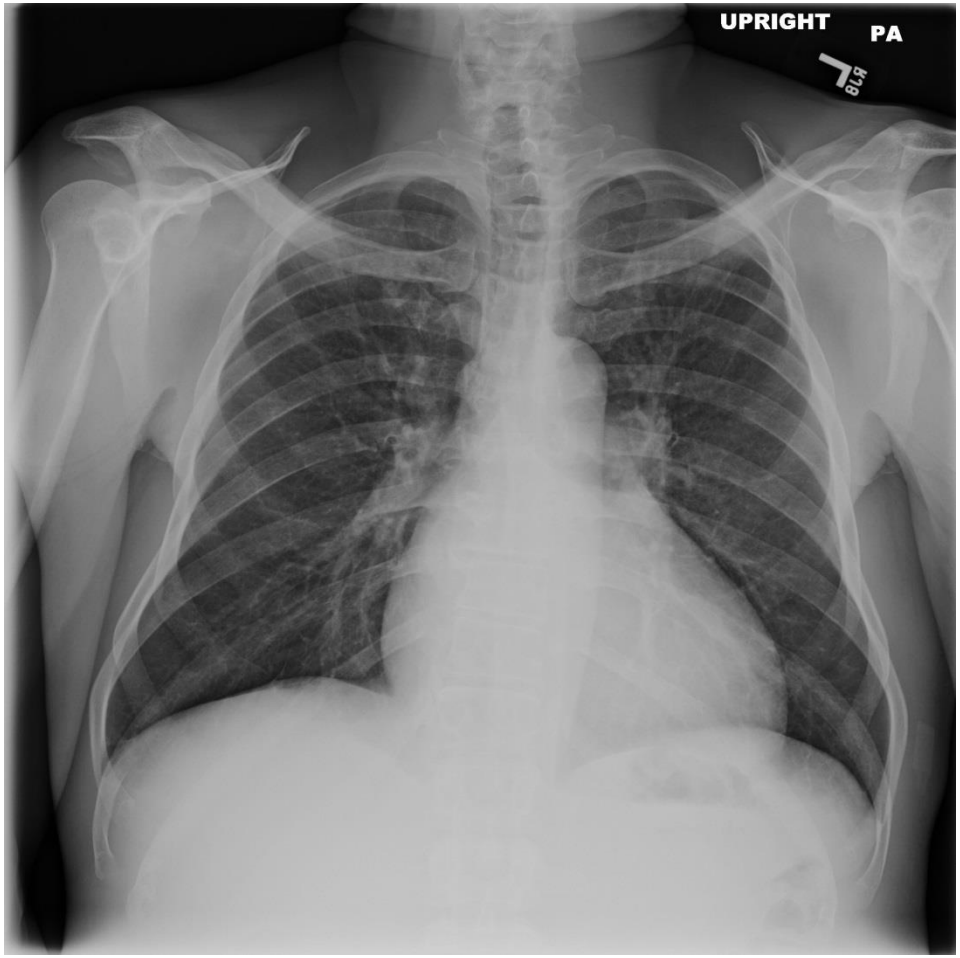
Normal perfusion



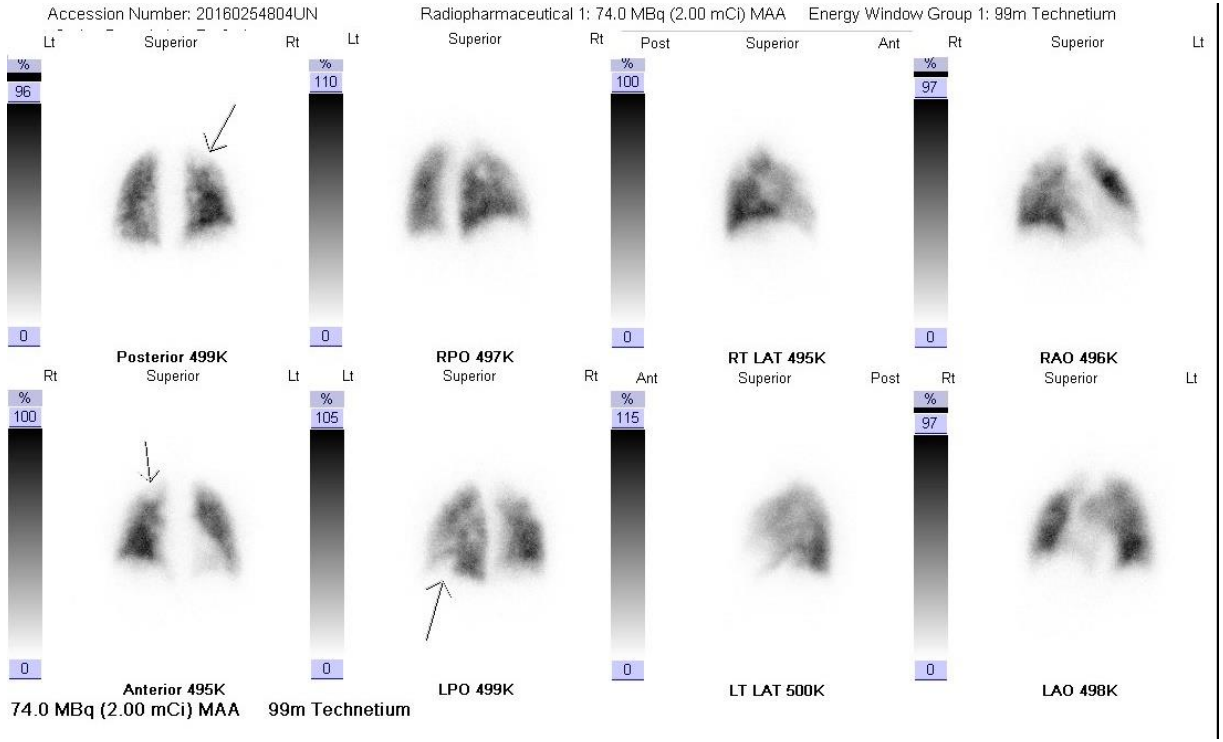
Normal ventilation



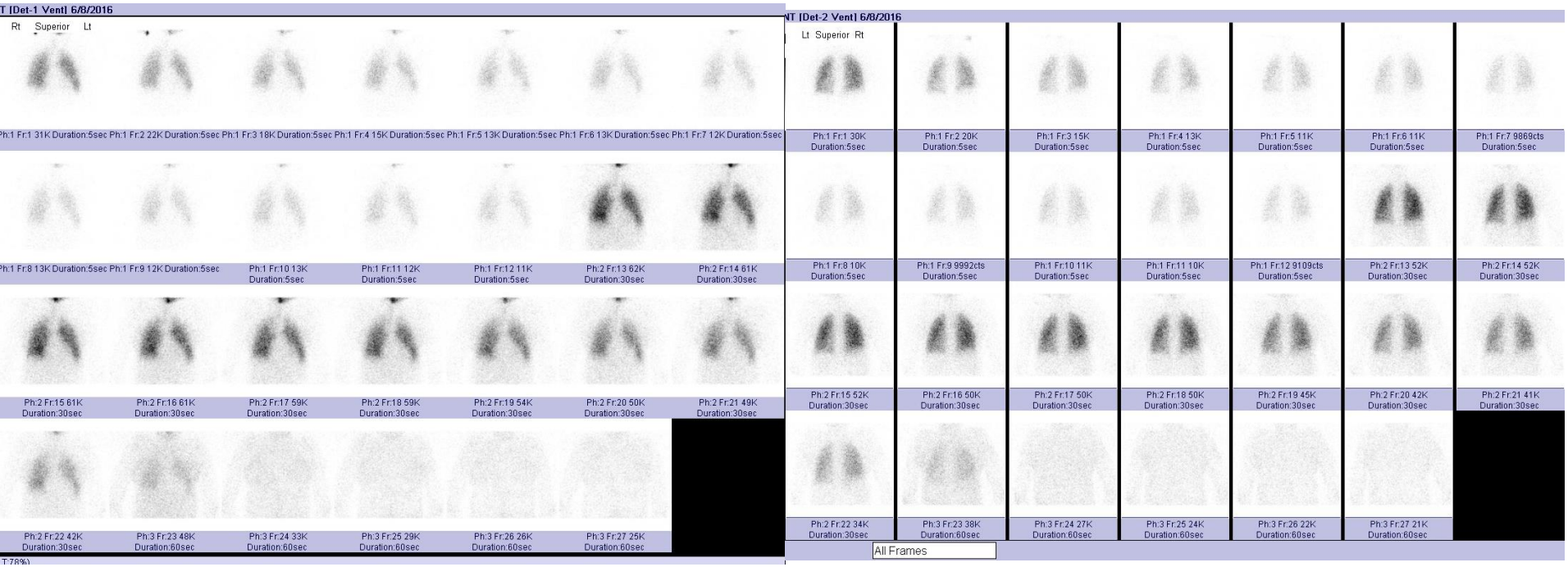
Normal CXR



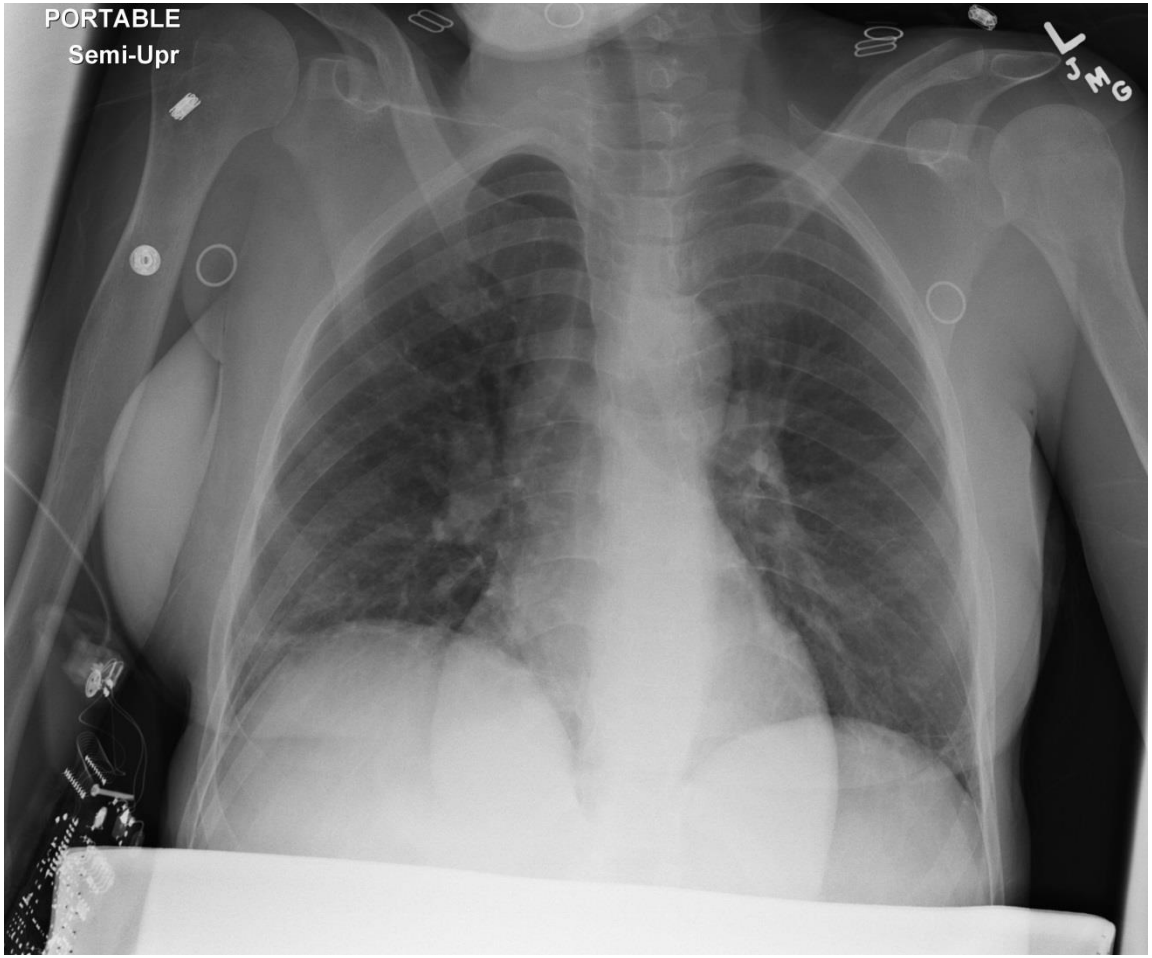
VQ: abnormal perfusion



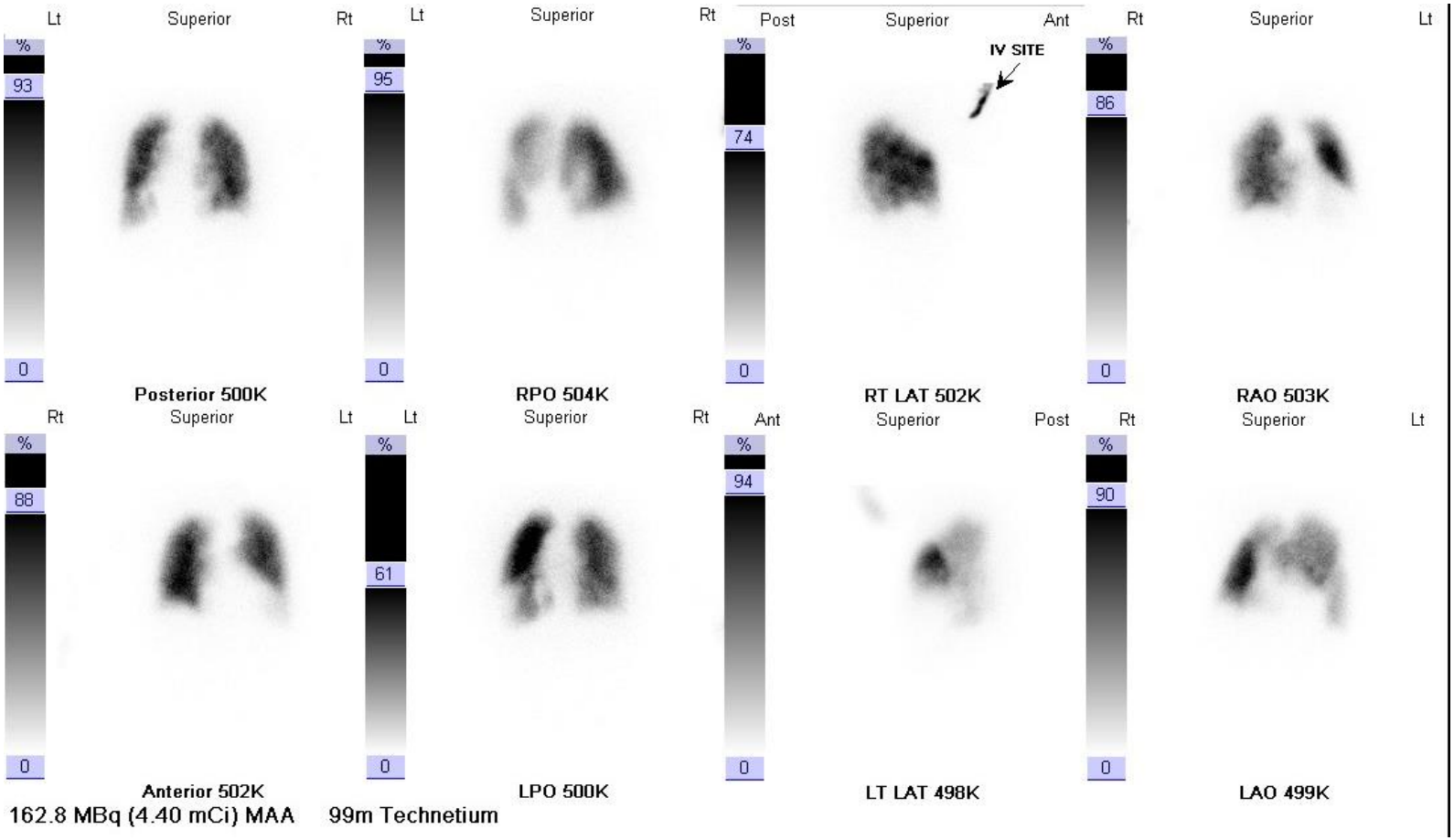
VQ: normal ventilation



Normal CXR



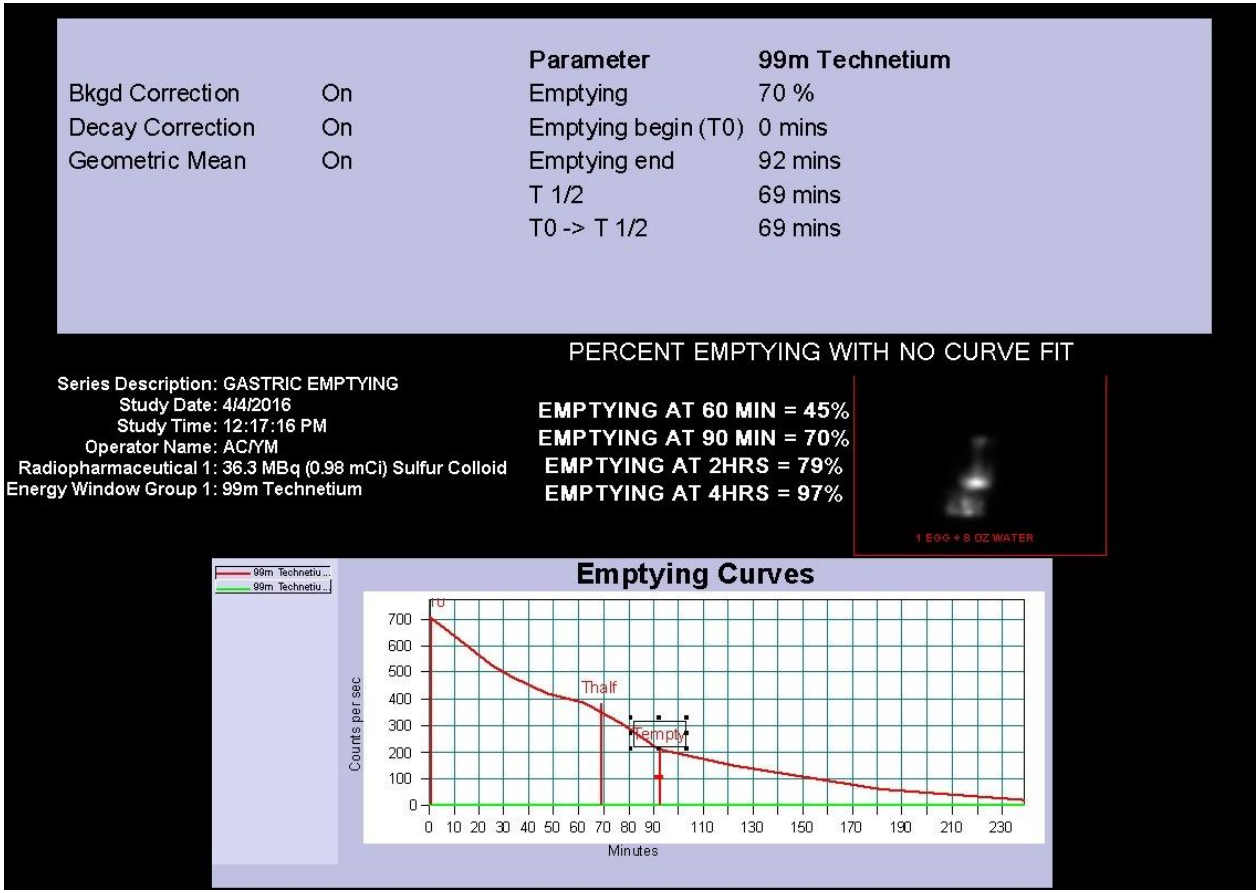
Perfusion defect: left lower lobe



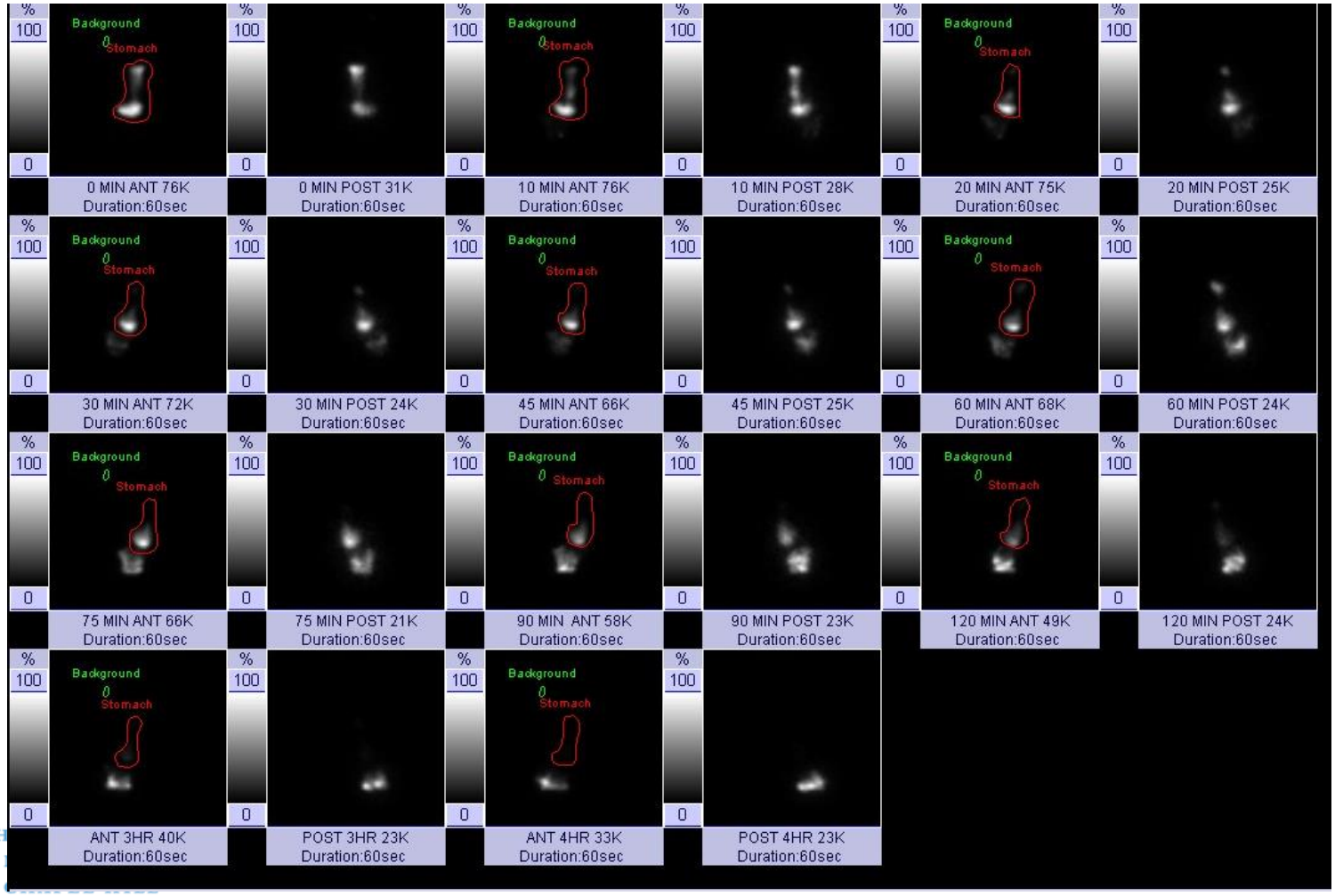
Gastric emptying scan

- **When do we order the study?** When clinicians are worried about rapid or delayed gastric emptying (vomiting, nausea, abdominal pain, GI sx in DM)
- **What is the clinical question?** Is gastric emptying too slow, too fast, or just right?
- **What are we studying?** Movement of radiotracer (and thus presumably food) out of the stomach

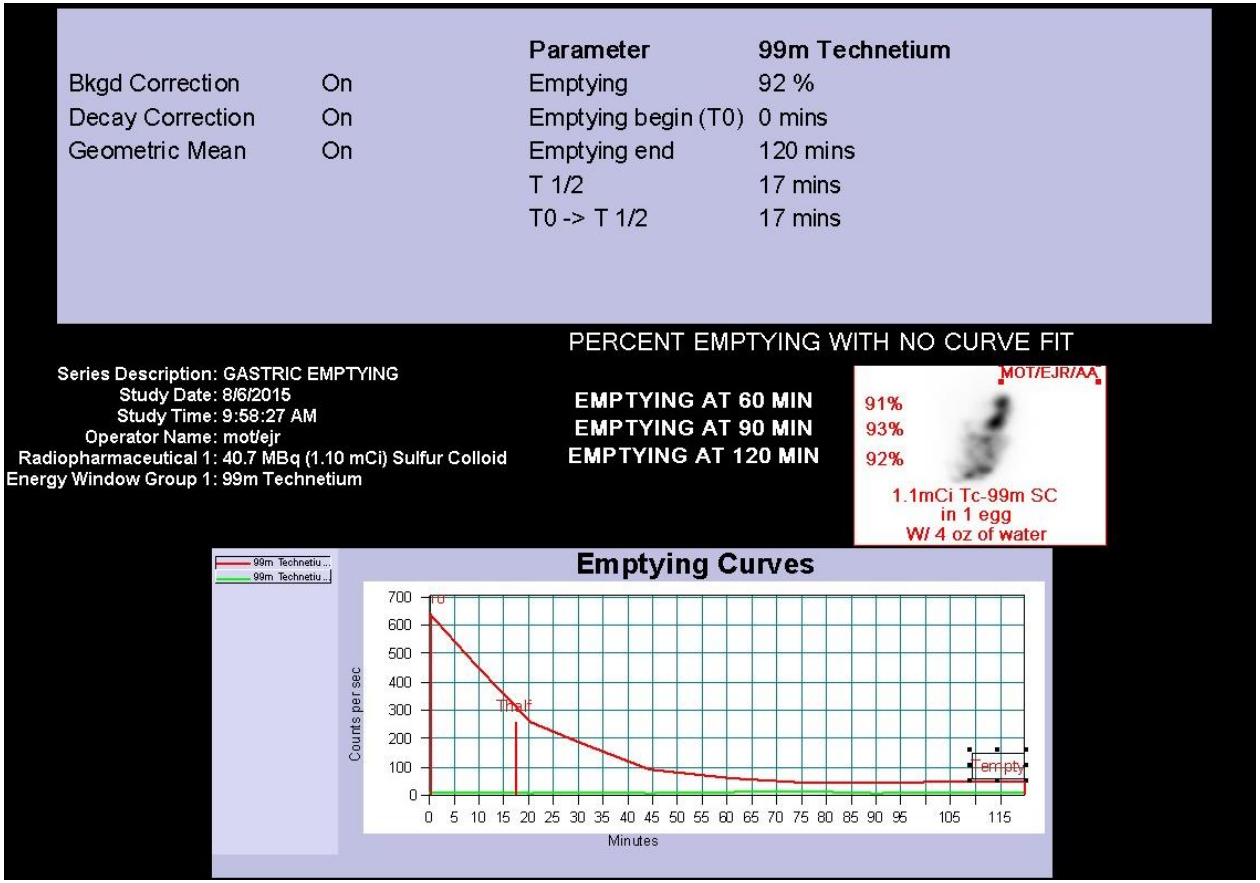
Normal gastric emptying study



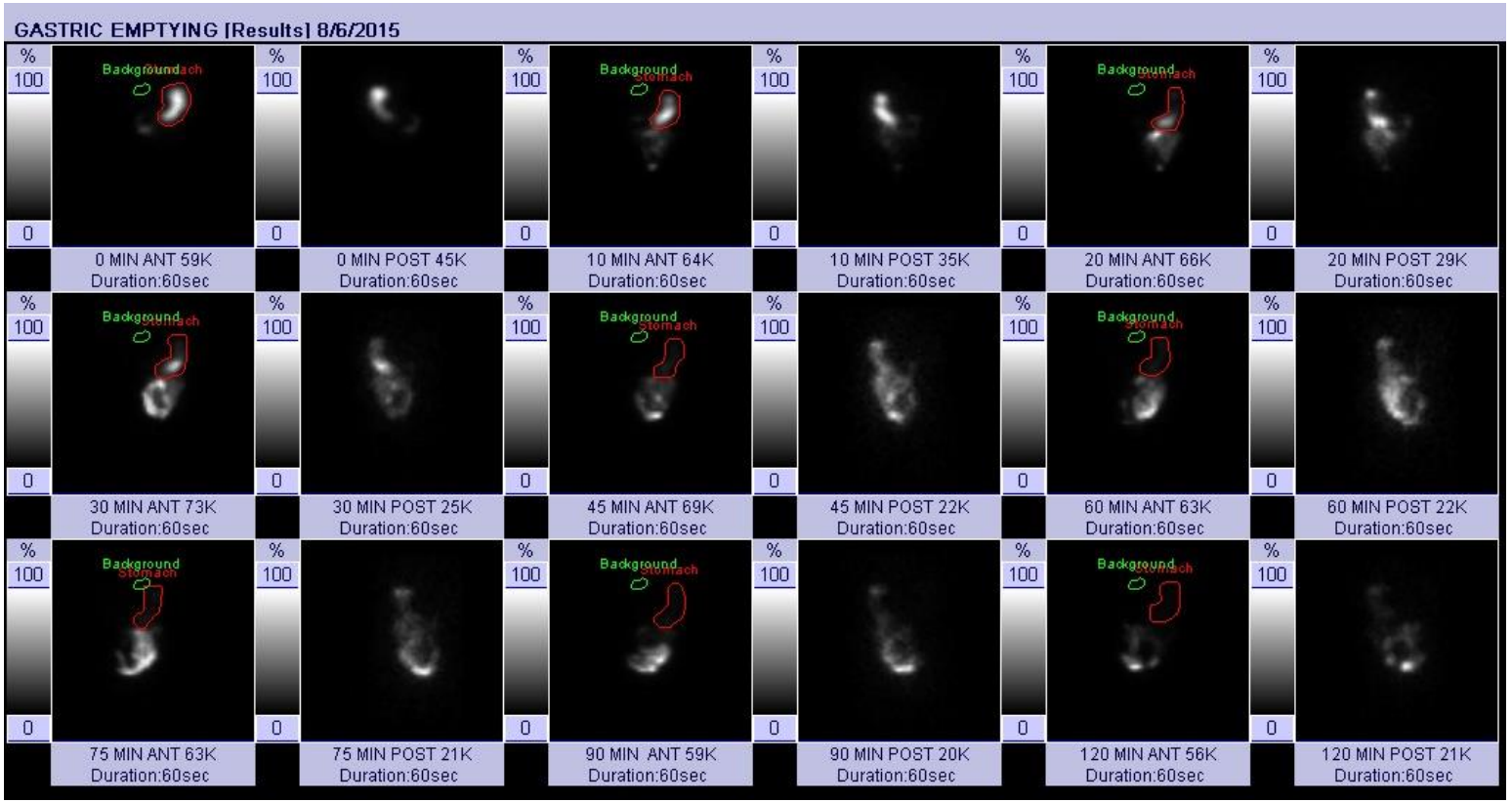
Normal gastric emptying scan: images



Rapid gastric emptying scan

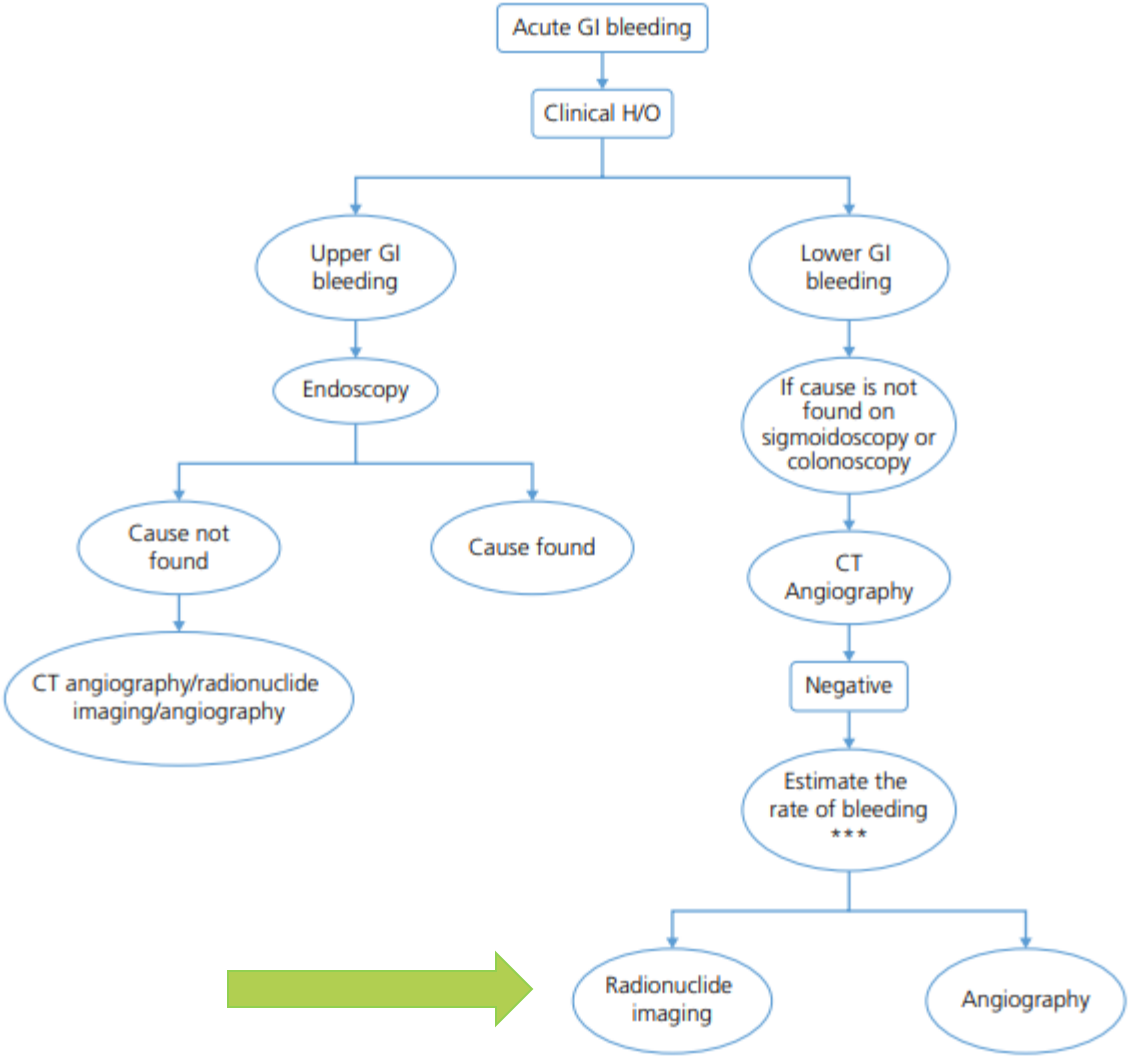


Rapid gastric emptying scan: images



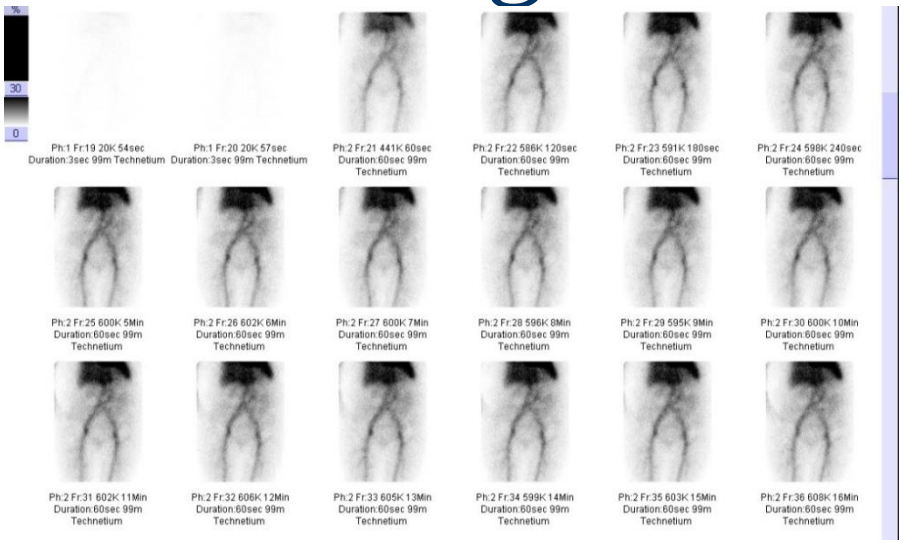
GI: GI bleed study

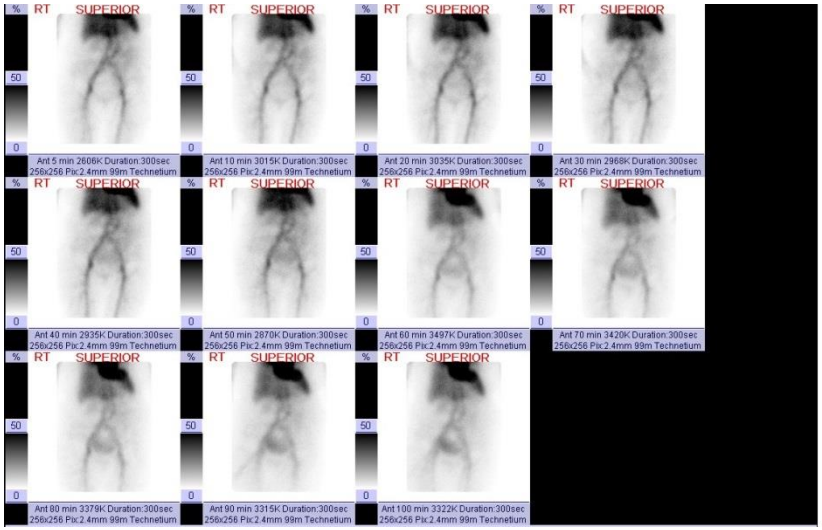
- When do we order the study? When we believe there is an active slow GI bleed
- What is the clinical question? Does the patient have an **active** lower GI bleed?
    - This study is not sensitive for upper GI bleeds
- What are we studying? Extravasation of tracer from the vasculature of the GI tract



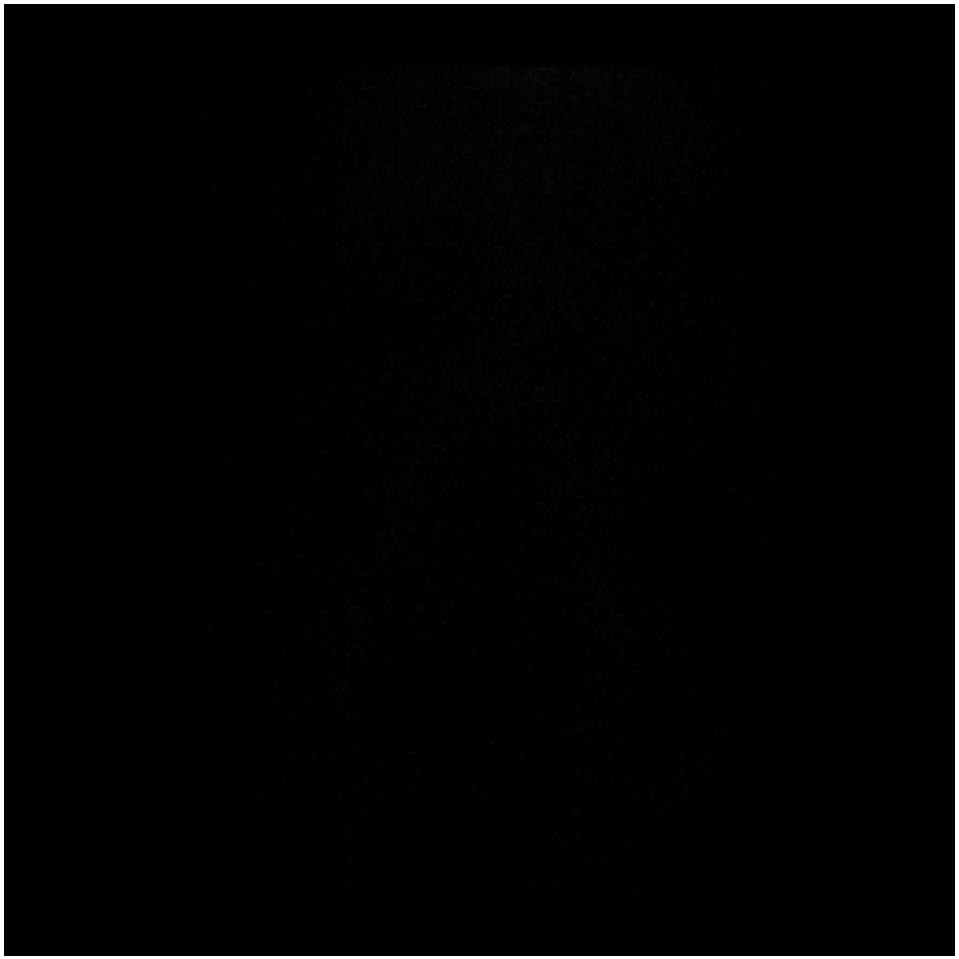
CT, computed tomography.

GI bleed: negative study

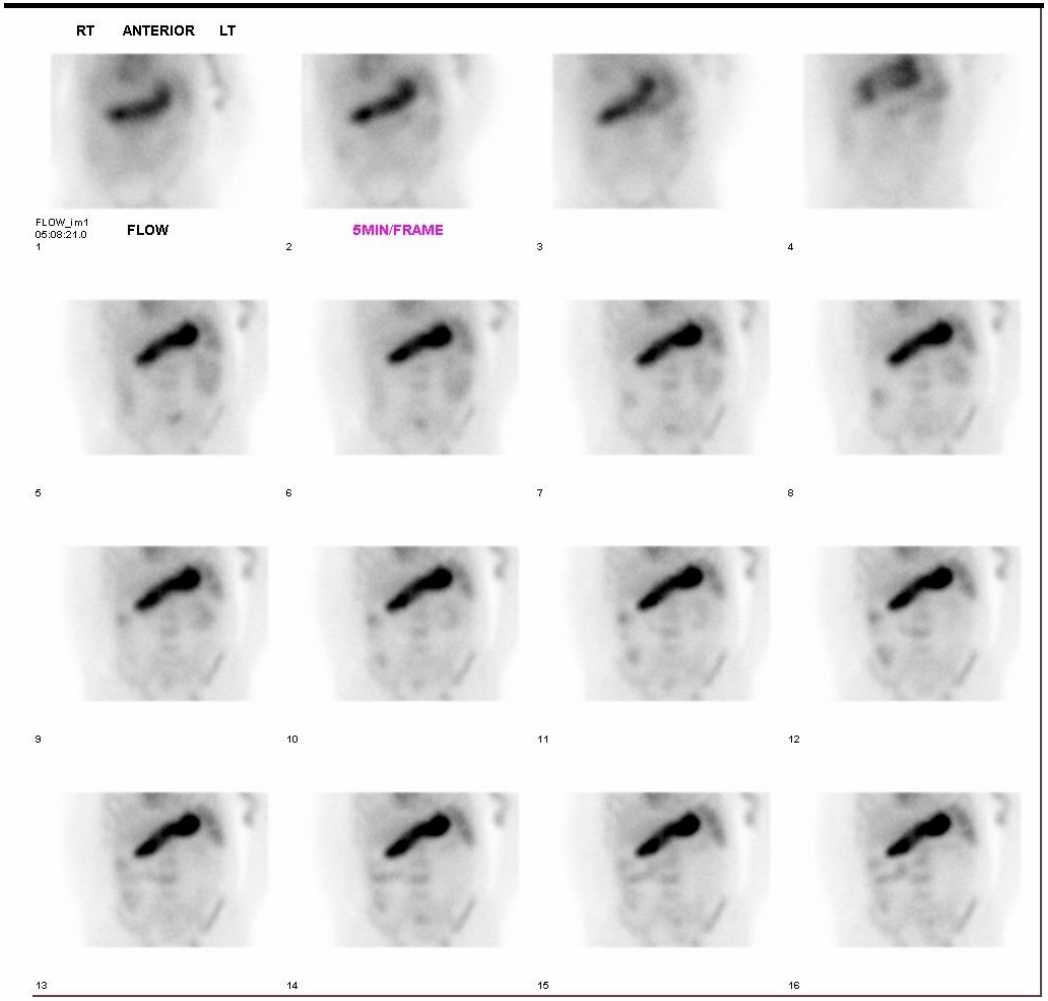




GI bleed: negative cine



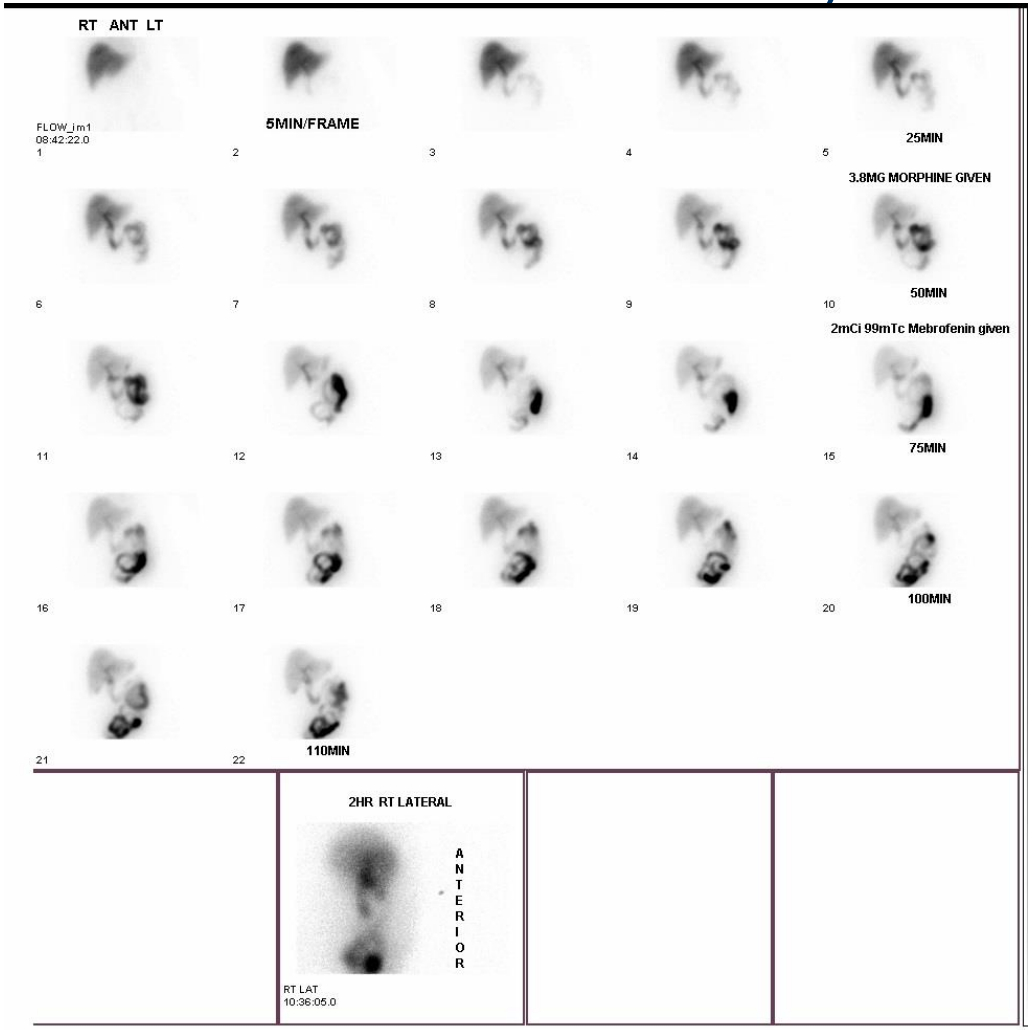
Gl bleed: positive study



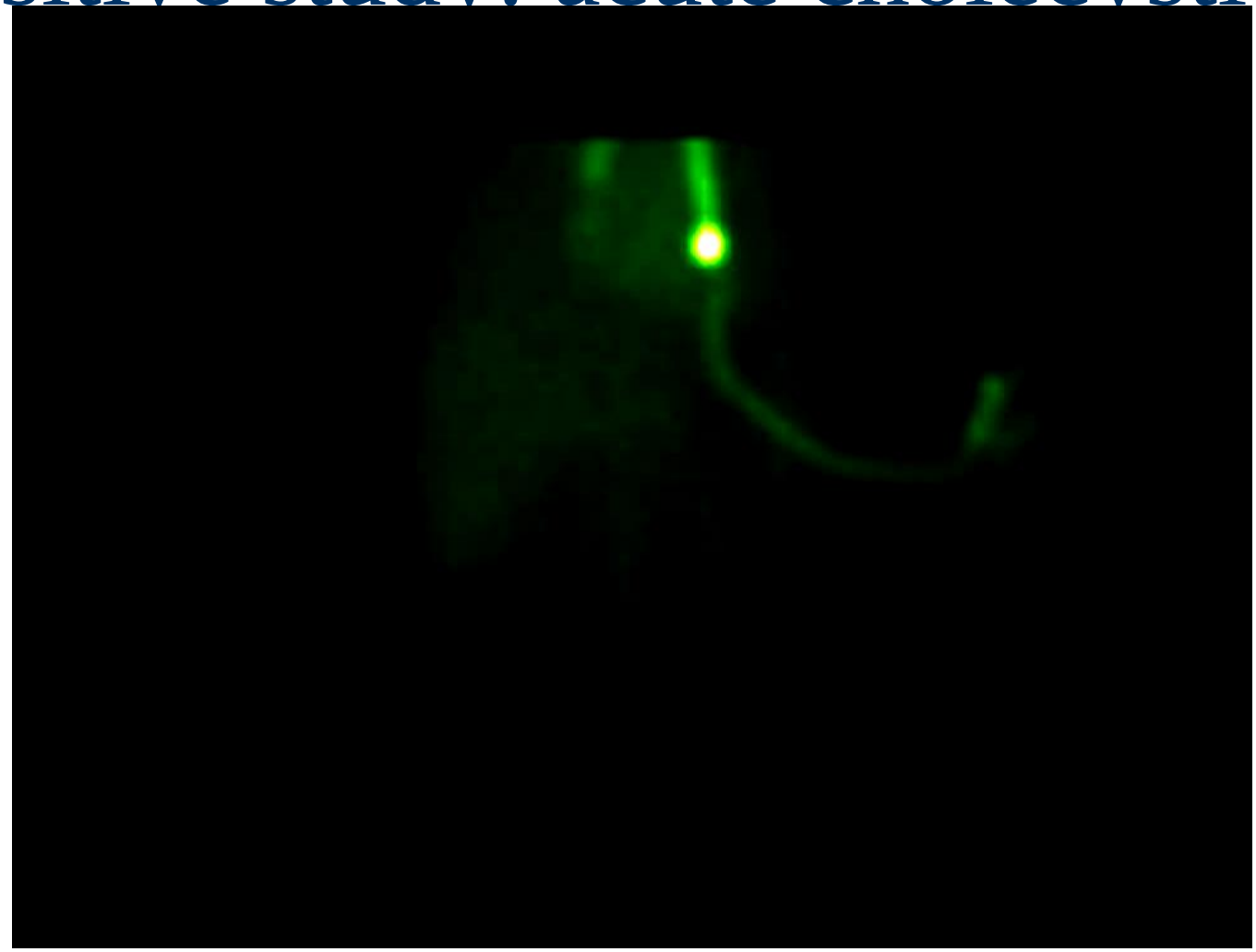
GI: HIDA scan

- When do we order the study? When US is inconclusive and we are still worried about cholecystitis
- What is the clinical question? Does the patient have cholecystitis?
  - Used if ultrasound (or CT) is inconclusive; good sensitivity
  - Can also be used to look for biliary patency, biliary atresia, gallbladder function, and biliary leaks
- What are we studying? Movement of bile through the biliary system

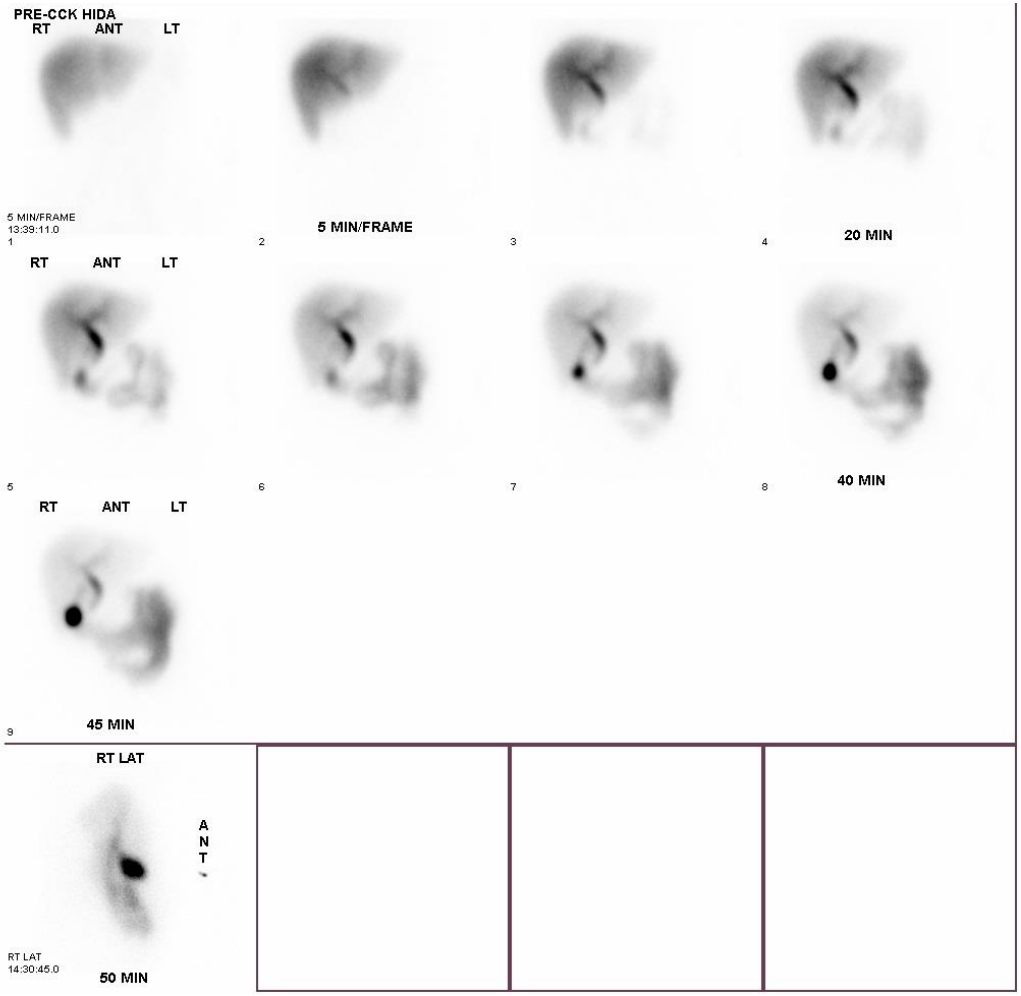
Positive study

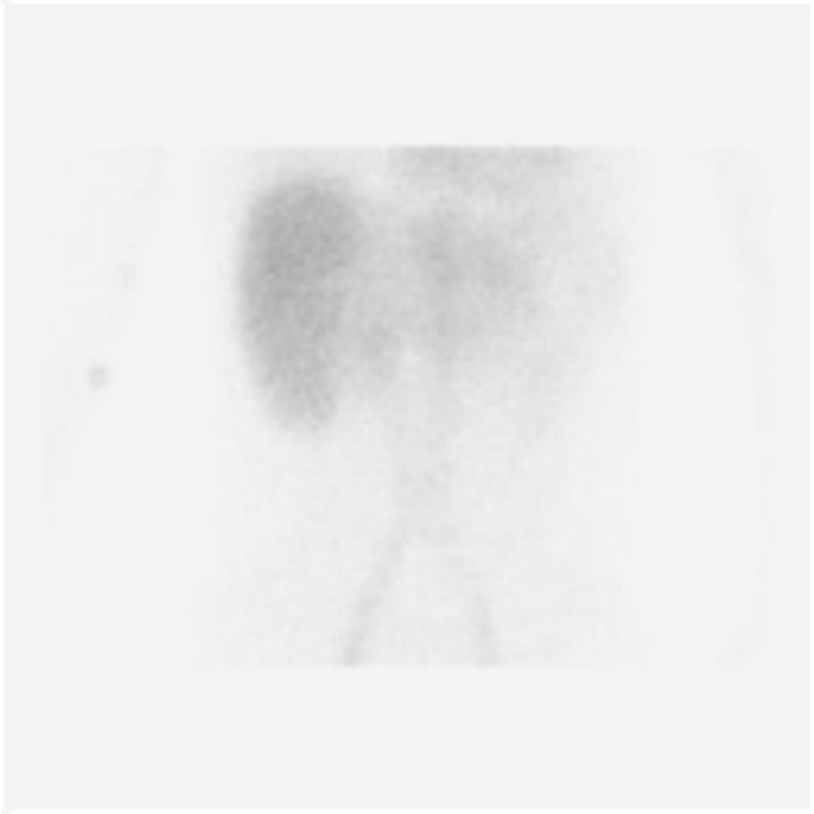


Positive study: acute cholecystitis



Negative study





MAG-3 scan

- **When do we order the study?** Usually before or after urologic surgery to relieve obstruction
- **What is the clinical question?** Are the kidneys able to excrete urine, or is it stuck in the collecting system?
- **What are we studying?** Presence of functioning renal proximal tubules

Normal MAG-3: images

Normal MAG-3: graph

Table of Result Summary

Parameters	Left	Right	Total
Split Function (%)	41.8	58.2	
Kidney Counts (cpm)	26536	36994	63530
Time of Max (min)	5.502	3.502	
Time of ½ Max (min)	9.670	7.413	
Time from Max to ½ Max (min)	4.168	3.910	

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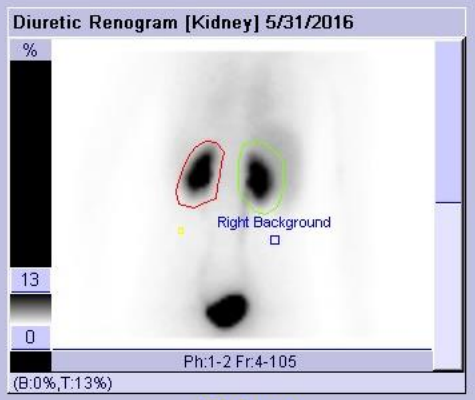
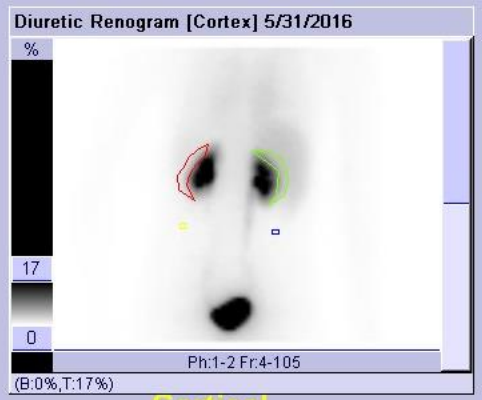
Table of Result Summary

Parameters	Left	Right	Total
Split Function (%)	32.8	67.2	
Cortical Counts (cpm)	5309.2	10860	16169





Kidney

--Left--

--Right--

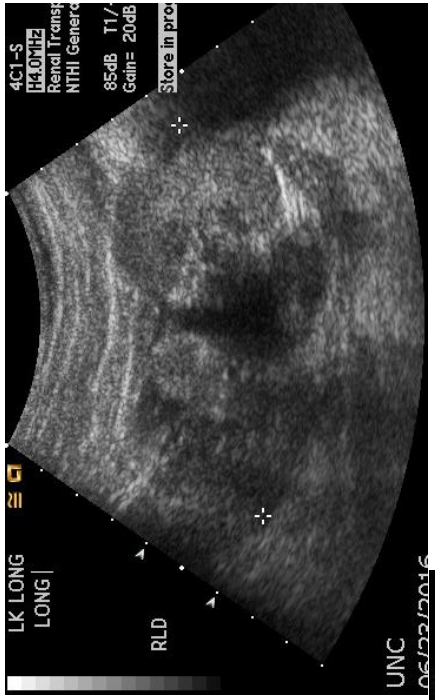
Cortical

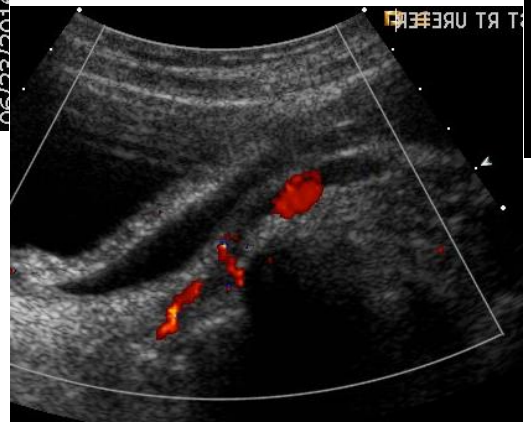
--Left--

--Right--

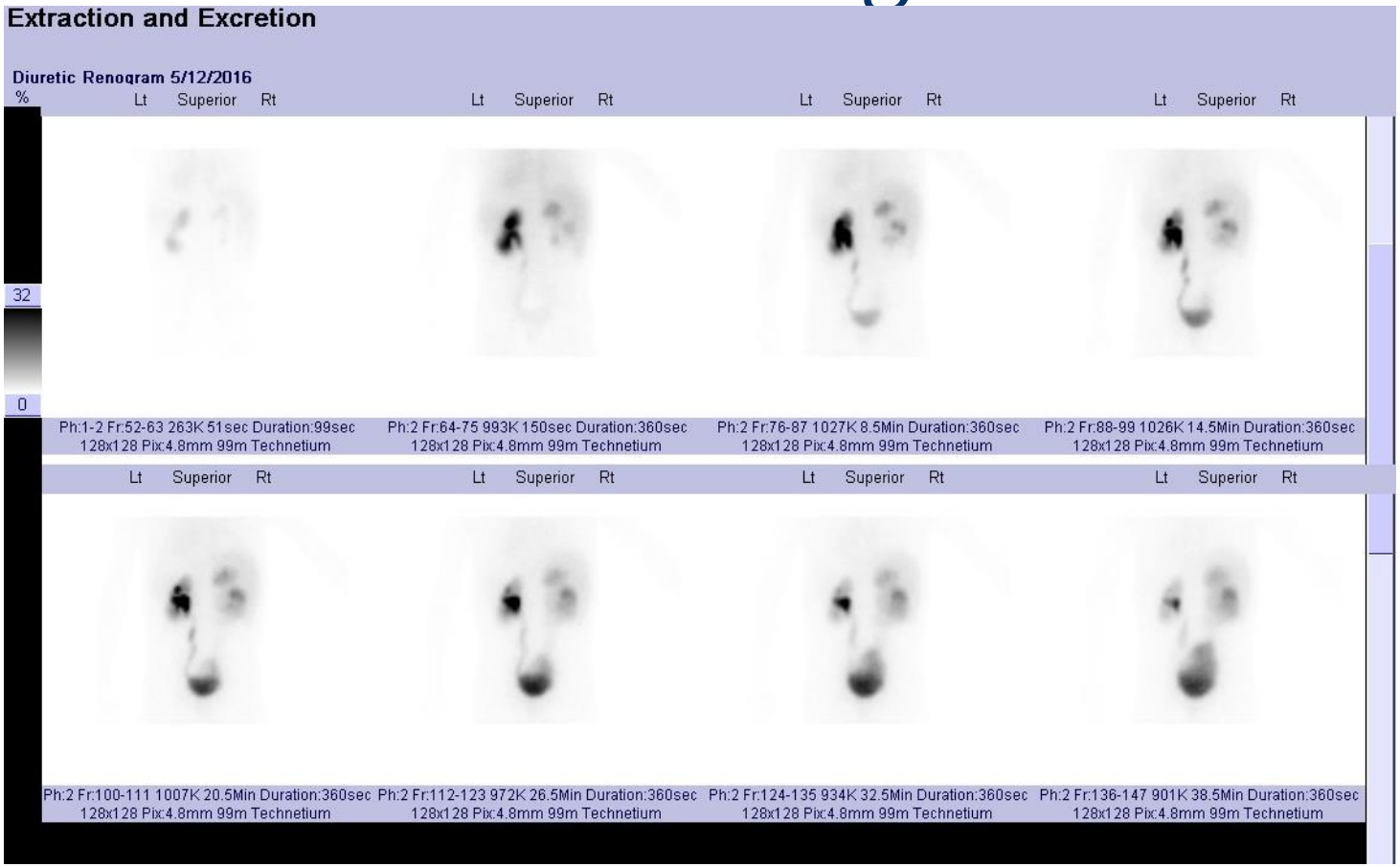
Normal MAG3-movie

Bilateral hydronephrosis (and unilateral hydroureter): obstruction?





Obstructed (and partially obstructed) MAG-3: images



Obstructed (and partially obstructed) MAG-3: graph

Table of Result Summary

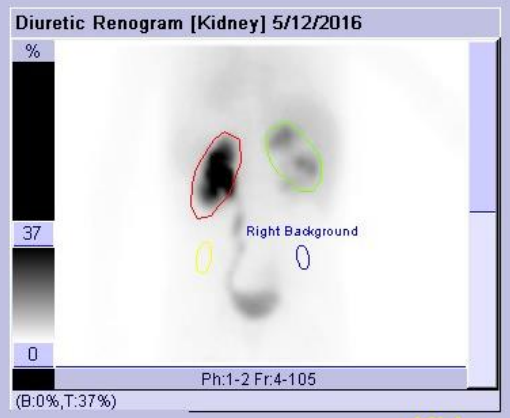
Parameters	Left	Right	Total
Split Function (%)	67.1	32.9	
Kidney Counts (cpm)	22706	11155	33860
Renal Retention	0.826		
Time of Max (min)	12.5	24.0	
Time of ½ Max (min)	32.0	48.3	
Time from Max to ½ Max (min)	19.5	24.3	

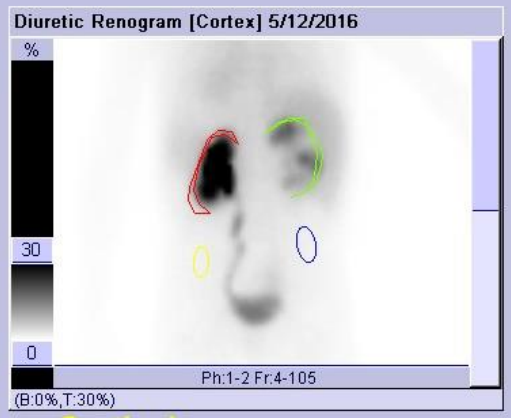
Table of Result Summary

Parameters	Left	Right	Total
Split Function (%)	67.1	32.9	
Kidney Counts (cpm)	22706	11155	33860
Time of Lasix (min)			23.0
Time of ½ Lasix (min)	35.7	48.3	
Time from Lasix to ½ Lasix (min)	12.7	25.3	

Table of Result Summary

Parameters	Left	Right	Total
Split Function (%)	56.8	43.2	
Cortical Counts (cpm)	3782.9	2875.1	6658.0

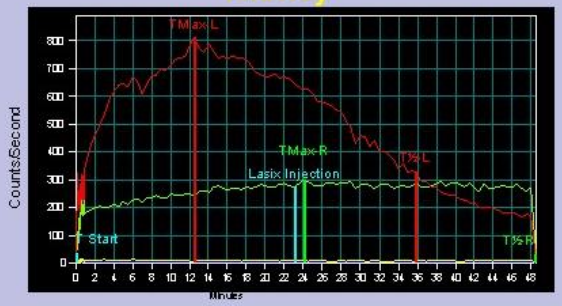




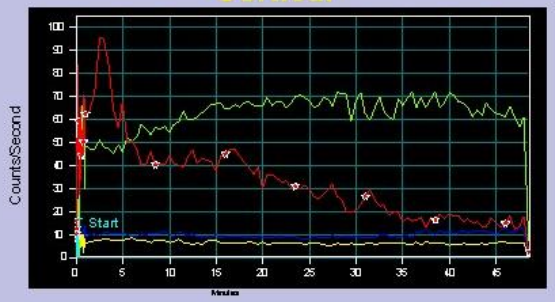
Kidney

--Left----

--Right---



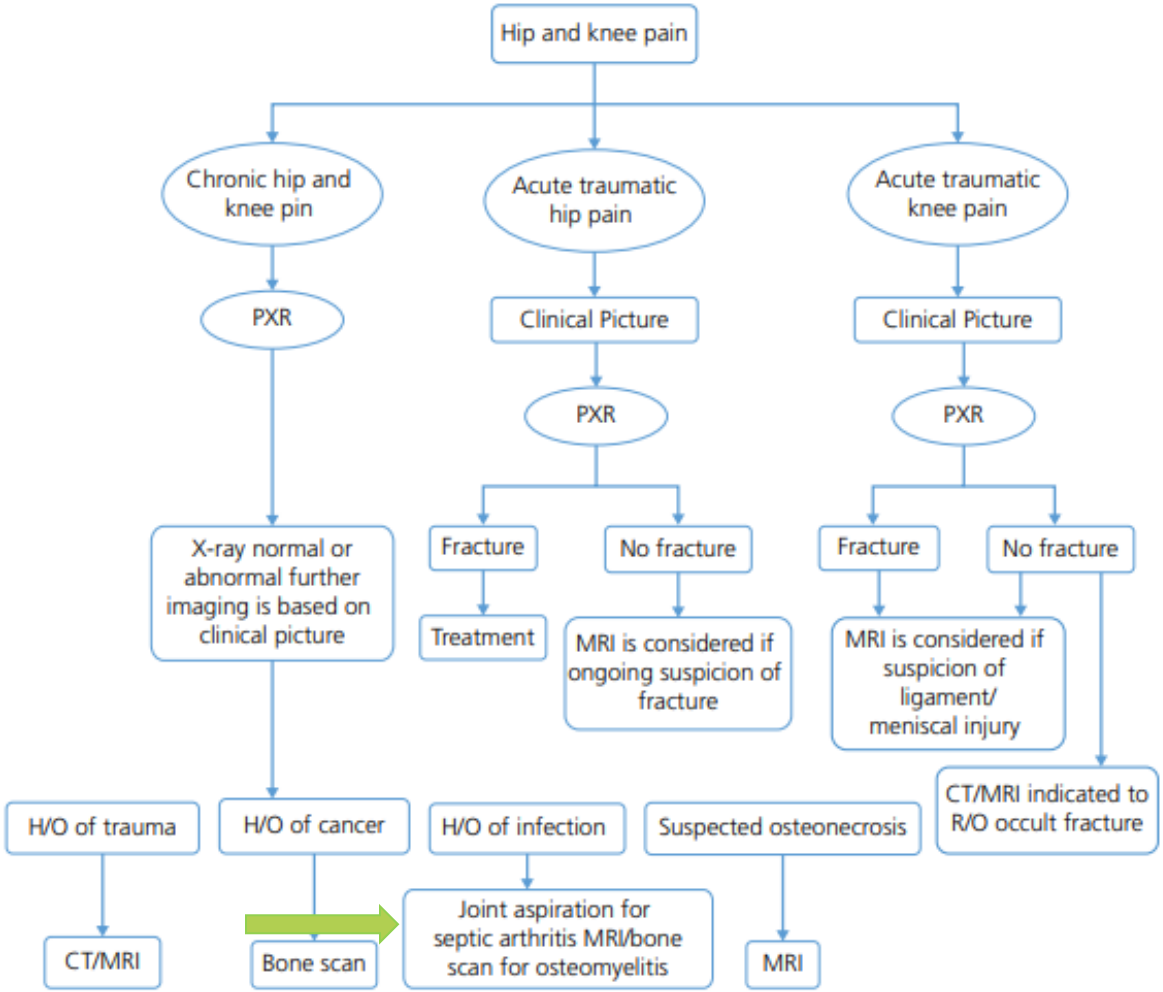
Cortical



Obstructed (and partially obstructed) MAG-3: movie

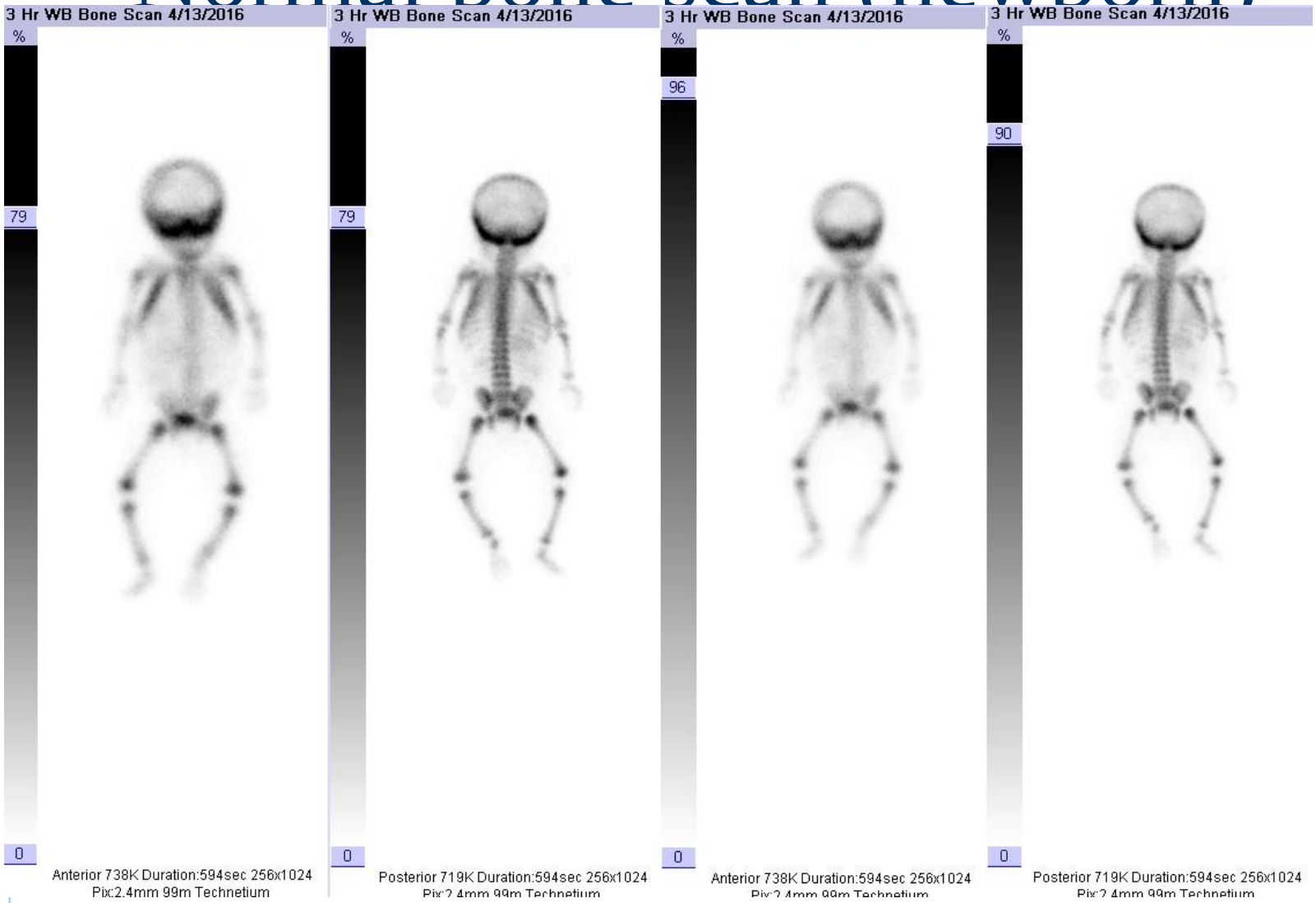
Bone scan

- **When do we order the study?** Most commonly when staging breast or prostate cancer (which have metastases that may not be seen on CT)
  - Also has applications looking for osteomyelitis, joint prosthesis loosening, and spondyloylsis
- **What is the clinical question?** Are there metastases to bone?
  - It's also used in some orthopedic applications such as looking for osteomyelitis or joint prosthesis loosening
- **What are we studying?** New bone formation

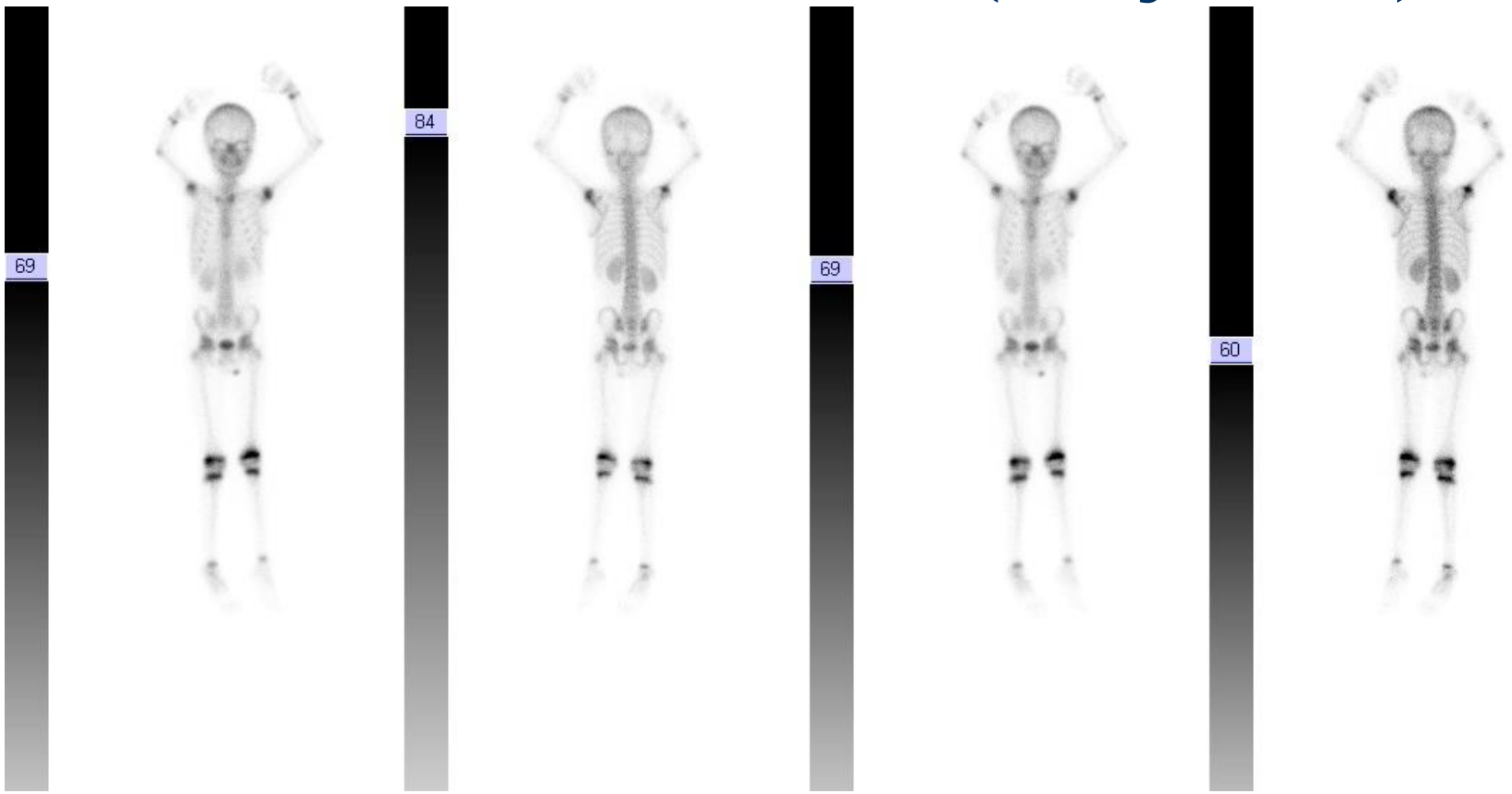


CT, computed tomography; MRI, magnetic resonance imaging.

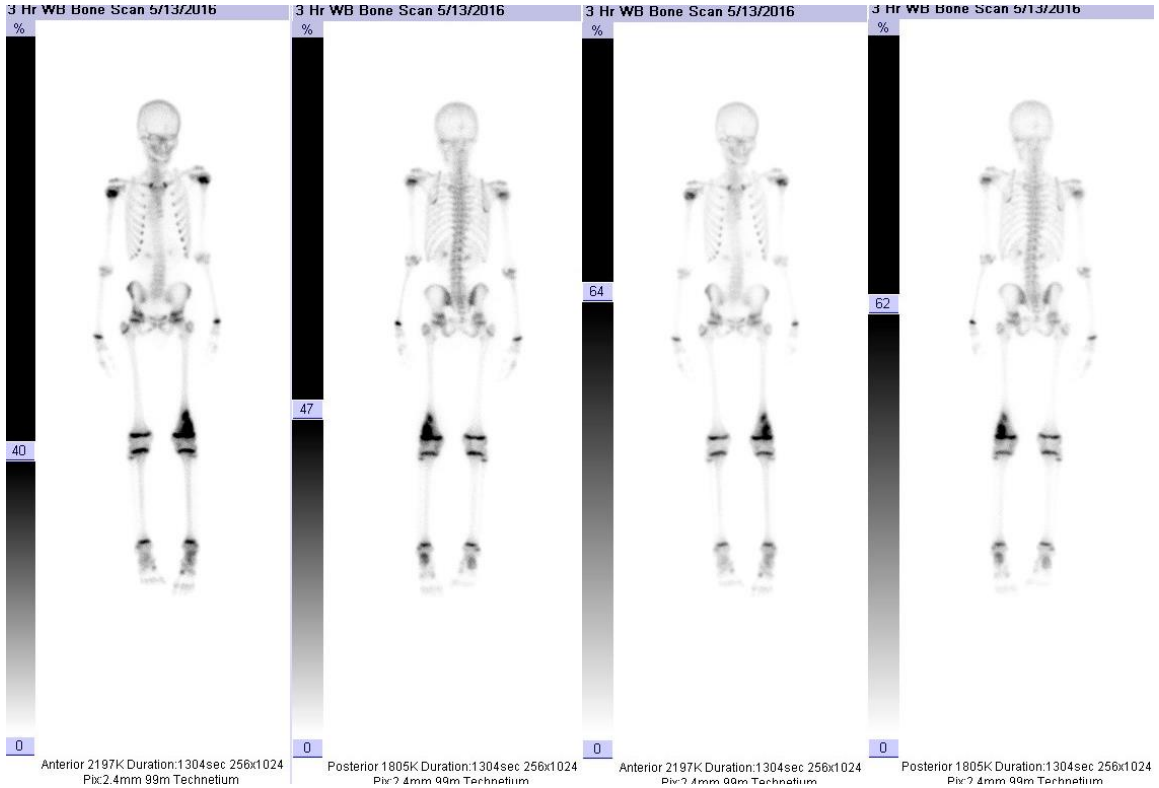
Normal bone scan (newborn)



Normal bone scan (11 yr old)



Positive bone scan (osteosarcoma)



Positive bone scan (diffuse mets)