Introduction to Nuclear Medicine
Objectives

• What is nuclear medicine?
• Pros and cons
• Safety
• Indications
• A few sample types of studies
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 uptake)
Normal FDG PET scan

Anterior

Posterior
FDG PET for widespread lymphoma
Solitary pulmonary nodule

- Comparison with previous films
  - Definitely benign
    - No further investigation
  - Possibly malignant
    - CT with out contrast
      - Indeterminate appearance

  - Calculate pretest probability for malignancy
    - For indeterminate lesions > 8–10 mm
      - Low probability
        - Serial CT scanning at 3, 6, 12, and 24 months
      - Intermediate probability
        - FDG–PET scanning (>20mm), contrast-enhanced CT scanning, transthoracic needle aspiration, and/or transbronchial needle aspiration
      - High probability
        - Surgical resection

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
Infarct
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**
Suspected pulmonary embolism

CTPA
- Unstable
  - Negative: Other diagnosis
  - Positive: Treatment
- Stable
  - PXR
    - Clinical score
      - Low-to-moderate pretest probability
        - D-dimer
          - Negative
          - Positive: CTPA or V/Q scan
        - Radionuclide V/Q scan
          - Low/intermediate probability
            - Consider CTPA
          - High probability for PE
          - Negative and low or medium probability for PE
            - No further test
      - High pretest probability
        - Large body habitus allergic to contrast non-cooperative
        - Abnormal PXR previous chronic lung diseases
          - CTPA
            - Negative and high probability for PE
              - Lower limb US +/- radionuclide scan
            - Positive for PE
              - Treatment

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

162.8 MBq (4.40 mCi) MAA 99m Technetium
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

Parameter | Value
--- | ---
Bkgd Correction | On
Decay Correction | On
Geometric Mean | On

Series Description: GASTRIC EMPTYING
Study Date: 4/4/2016
Study Time: 12:17:16 PM
Operator Name: ACYM
Radiopharmaceutical 1: 35.3 MBq (0.99 mC) Sulfur Colloid
Energy Window Group 1: 99m Technetium

EMPTYING AT 60 MIN = 45%
EMPTYING AT 90 MIN = 70%
EMPTYING AT 2HRS = 78%
EMPTYING AT 4HRS = 97%

Emptying Curves
Normal gastric emptying scan: images
Rapid gastric emptying scan

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<tr>
<td>Emptying</td>
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<tr>
<td>Emptying begin (T0)</td>
<td>0 mins</td>
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<tr>
<td>Emptying end</td>
<td>120 mins</td>
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<tr>
<td>T 1/2</td>
<td>17 mins</td>
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<tr>
<td>T0 -&gt; T 1/2</td>
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Series Description: GASTRIC EMPTYING
Study Date: 8/5/2015
Study Time: 9:58:27 AM
Operator Name: motlejr
Radiopharmaceutical: 40.7 MBq (1.10 mCi) Sulfur Colloid
Energy Window Group: 99m Technetium

PERCENT EMPTYING WITH NO CURVE FIT

EMPTYING AT 60 MIN
91%
EMPTYING AT 90 MIN
93%
EMPTYING AT 120 MIN
92%

Emptying Curves

1.1mCi Tc-99m SC in 1 egg
W/ 4 oz of water
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
Acute GI bleeding

Clinical H/O

Upper GI bleeding

Endoscopy

Cause not found

CT angiography/radionuclide imaging/angiography

Cause found

Lower GI bleeding

If cause is not found on sigmoidoscopy or colonoscopy

CT

Angiography

Negative

Estimate the rate of bleeding

Radionuclide imaging

Angiography

CT, computed tomography.
Gl 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

- Normal MAG-3: graph

- THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL
Normal MAG3-movie
Bilateral hydronephrosis (and unilateral hydroureter): obstruction?
Obstructed (and partially obstructed) MAG-3: images
Obstructed (and partially obstructed) MAG-3: graph

![Diuretic Renogram](image)

**Table of Result Summary**

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<th>Right</th>
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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
Hip and knee pain

Chronic hip and knee pain
- PXR
  - X-ray normal or abnormal further imaging is based on clinical picture
    - Fracture
      - Treatment
    - No fracture
      - MRI is considered if ongoing suspicion of fracture

Acute traumatic hip pain
- Clinical Picture
  - PXR
    - MRI is considered if suspicion of ligament/meniscal injury

Acute traumatic knee pain
- Clinical Picture
  - PXR
    - CT/MRI indicated to R/O occult fracture

H/O of trauma
- CT/MRI

H/O of cancer
- Bone scan

H/O of infection
- Suspected osteonecrosis
  - Joint aspiration for septic arthritis
  - MRI/bone scan for osteomyelitis

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)