Nuclear Endocrinology

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Thyroid

Anatomy

The normal adult thyroid gland weighs:

15–20 g

The thyroid gland is

50–75%

colloid by weight

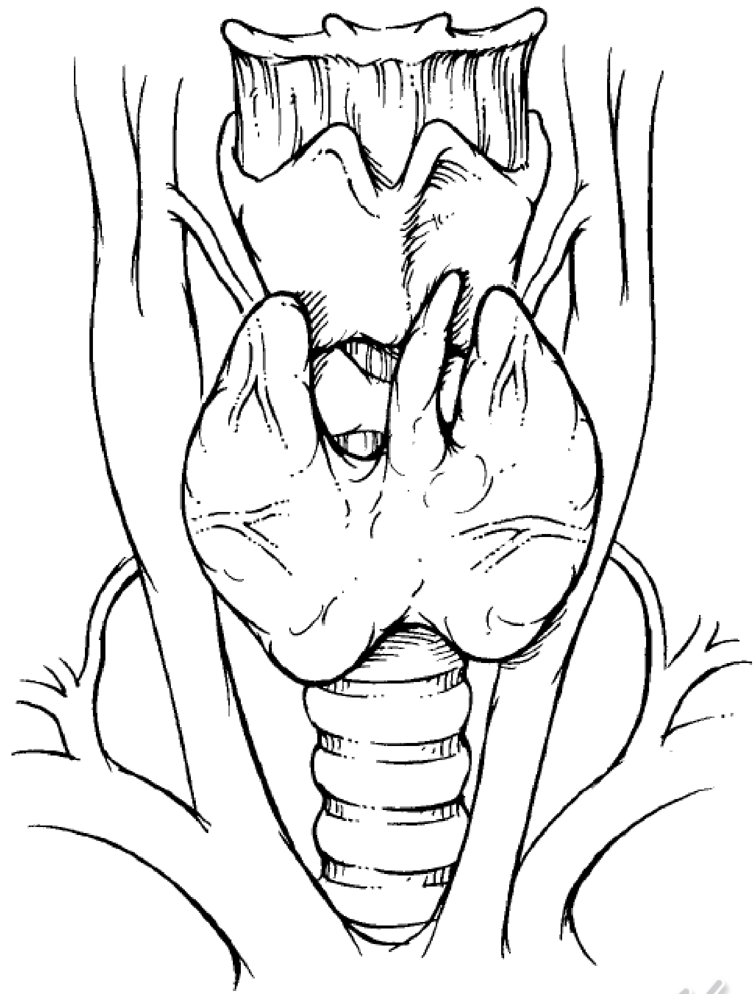


Figure 5-1 Thyroid gland. Anatomical relationship of the thyroid gland to the thyroid and cricoid cartilages and other adjacent anatomical structures.

Physiology

"Thyroid pump": Concentrates iodine intracellularly at **25–500** times the plasma concentration.

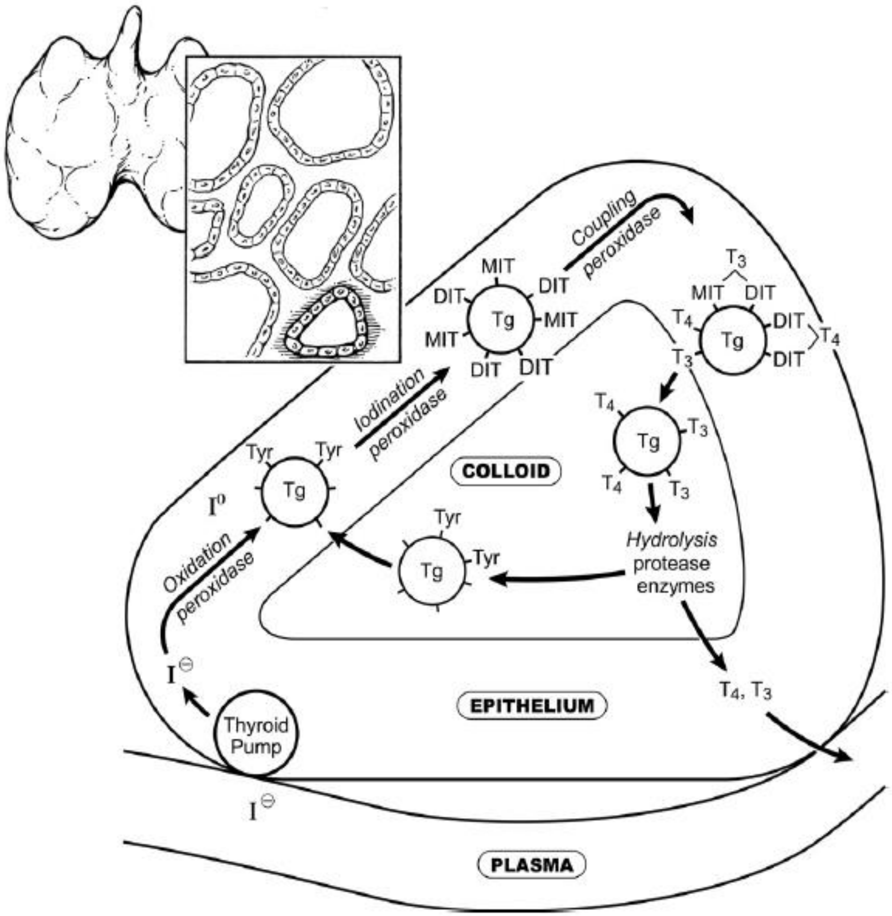


Figure 5-2 Iodine metabolism. The thyroid follicular cell epithelium extracts (traps) iodide from the plasma via the thyroid pump and organifies it. The iodide (I^-) is converted to neutral iodine (I^0) which is then incorporated into thyroglobulin-bound tyrosine molecules as mono or diiodotyrosine (MIT, DIT). Coupling of the iodotyrosines results in T4 and T3 bound to the thyroglobulin which is transported to and stored in the colloid until T4 and T3 are released into the plasma by proteolytic enzymes.

Nuclear Medicine in Thyroid Disease

- In Vitro
  - RIA (Radioimmunoassay) and IRMA (Immunoradiometric assay) tests using I-125
  - Thyroid Function Tests
    - T3, T4, TSH, fT3, fT4, TG, T3RUptake, FTI
    - AntiTG, AntiTSH, AntiTPO,
- In Vivo
  - Thyroid Scan
  - Thyroid Uptake Study
  - Therapy of Benign and Malignant Thyroid disease

Thyroid Scan

- Has functional nature

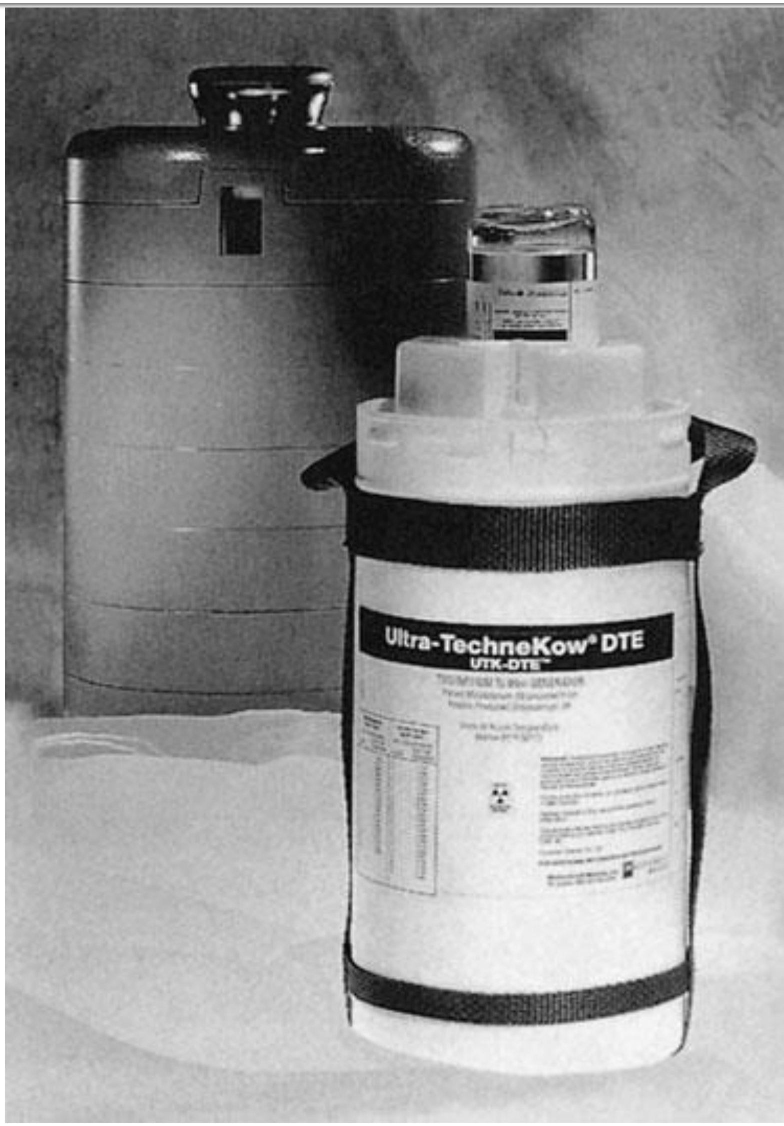
- Provides a mean of documenting the Size, location, shape and functional characteristic of thyroid tissue.

Thyroid Radiopharmaceuticals

Table 5-1 Physical Characteristics of Thyroid Radiopharmaceuticals

	Tc-99m pertechnetate	I-123	I-131
MODE OF DECAY	Isometric transition	Electron capture	Beta minus
PHYSICAL HALF-LIFE ($T_{½}$)	6 hr	13.2 hr	8.1 days
PHOTON ENERGY	140 keV	159 keV	364 keV
ABUNDANCE	89%	83.4%	81%
BETA EMISSIONS			606 keV

Molybdenum-99/Technetium-99m Generator Systems



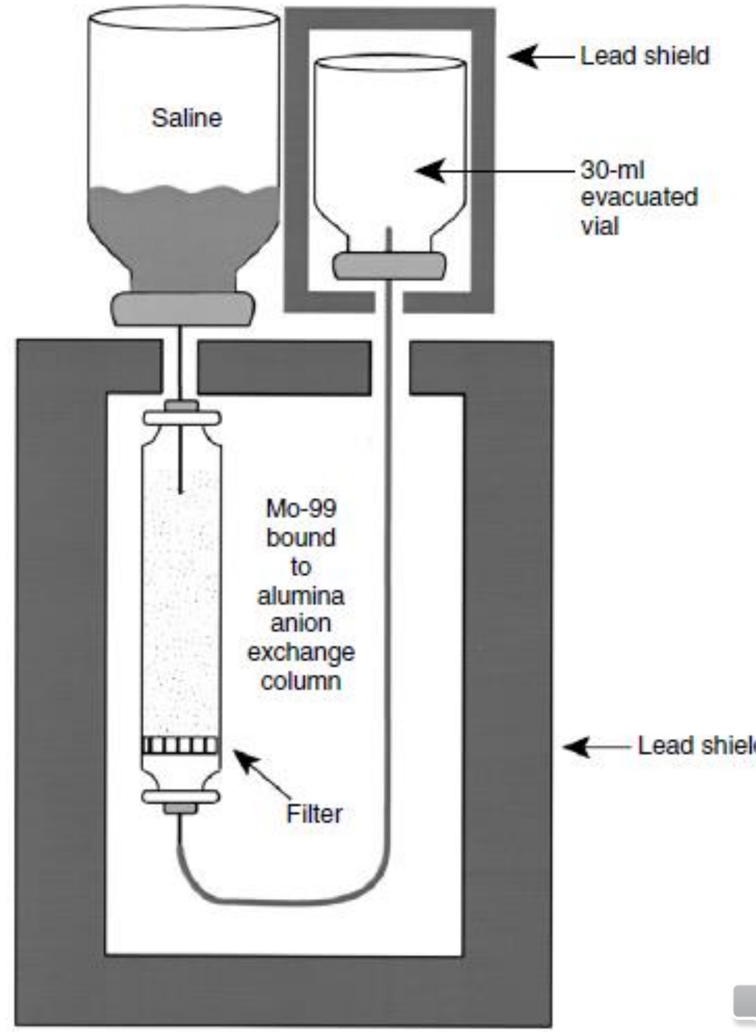


Figure 1-4 "Dry" radionuclide generator system.

Thyroid Scan with Tc-99m Pertechnetate

- **Intravenous**
- **Trapped** by the thyroid in an identical manner as iodide
- **Not organified**
- **Not incorporated** into thyroid hormone
- **Not retained** in the thyroid
- **Imaging** is performed at peak uptake **20–30 minutes** after injection

Box 5-6 Tc-99m Pertechnetate Thyroid Imaging: Protocol Summary

PATIENT PREPARATION

Discontinue any medications that interfere with thyroid uptake of Tc-99m pertechnetate.

Nothing by mouth for 4 hours prior to study.

RADIOPHARMACEUTICAL

Tc-99m pertechnetate, 3–5 mCi (111–185 MBq) intravenously

TIME OF IMAGING

20 min after radiopharmaceutical administration

IMAGING PROCEDURE

Gamma camera with a 3- to 6-mm aperture pinhole collimator and a 20% energy window centered at 140 keV.

Position the patient supine with the chin up and neck extended.

Position the collimator so that the thyroid fills about two thirds of the diameter of the field of view.

Obtain anterior, 45-degree LAO and RAO views (move the collimator rather than the patient).

Obtain 250k counts per view.

Mark the chin and suprasternal notch.

Note the position and mark palpable nodules and surgical scars.

Place marker sources lateral to the thyroid to calibrate size

Normal Thyroid Scan

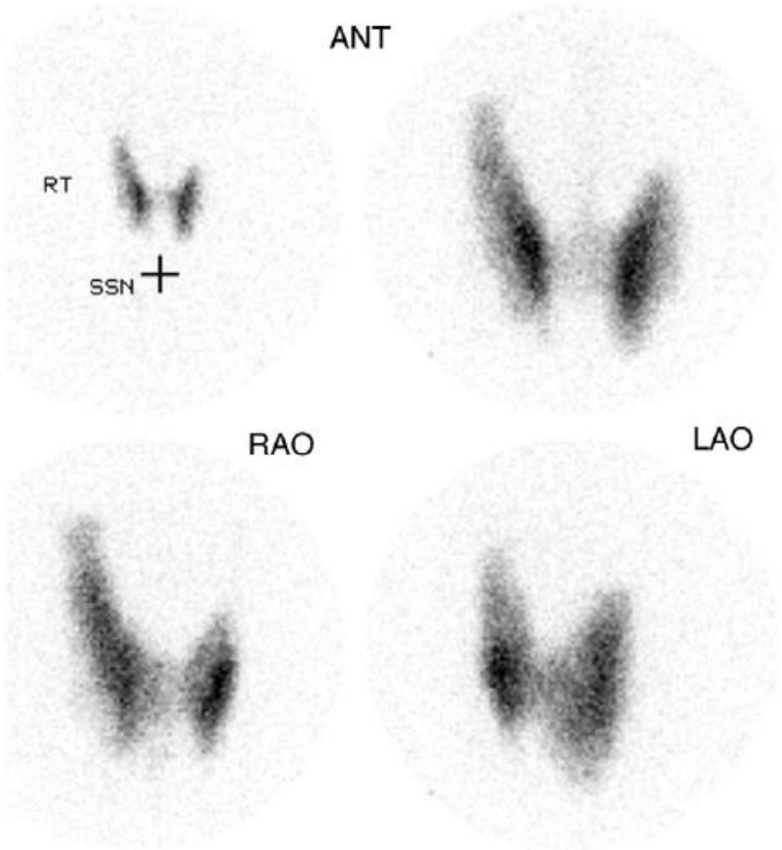


Figure 5-9 Normal I-123 thyroid scan. On the initial image, the collimator is placed at a greater distance from the neck than the other images. A computer cursor marks the suprasternal notch (SSN) and the right side (RT). The collimator is moved closer to the neck to acquire the anterior, right anterior oblique and left anterior oblique views, which have greater magnification and resolution.

- Butterfly shape
- Lobes are connected by an isthmus
- Right lobe is often larger than the left
- Lobes measures:
  - 4–5 cm from superior to inferior poles
  - 1.5–2 cm wide
- Pyramidal lobe ascends from the isthmus or adjacent part of either lobe (more often the left lobe) to the hyoid bone

Normal Thyroid Scan

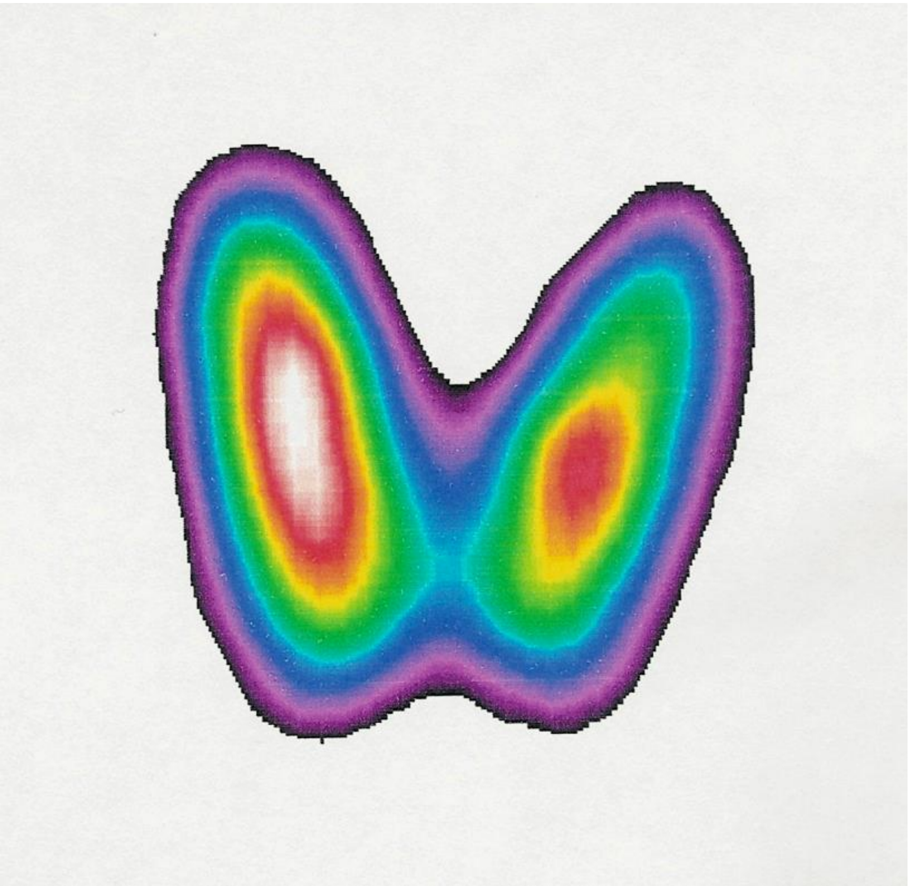
- **Always be correlated with Physical examination of the thyroid gland.**
- **Interpreted with knowledge of :**
  - **Thyroid function studies**
  - **Other imaging studies**

Thyroid Scan: Indications (1)

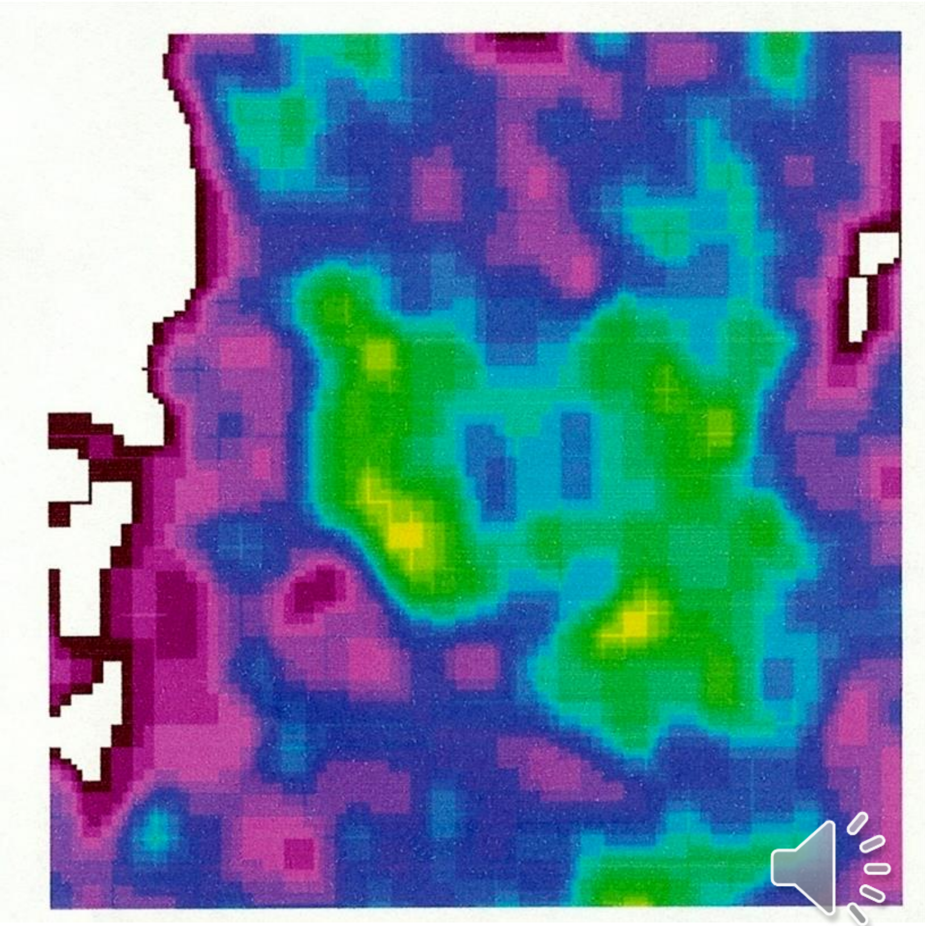
- In a hyperthyroid state:
  - Differentiation of Graves' disease from Thyroiditis or Factious hyperthyroidism
  - Graves' disease with loulated diffuse goiter and Toxic multinodular goiter

Differentiation of Graves' and Thyroiditis

Graves'

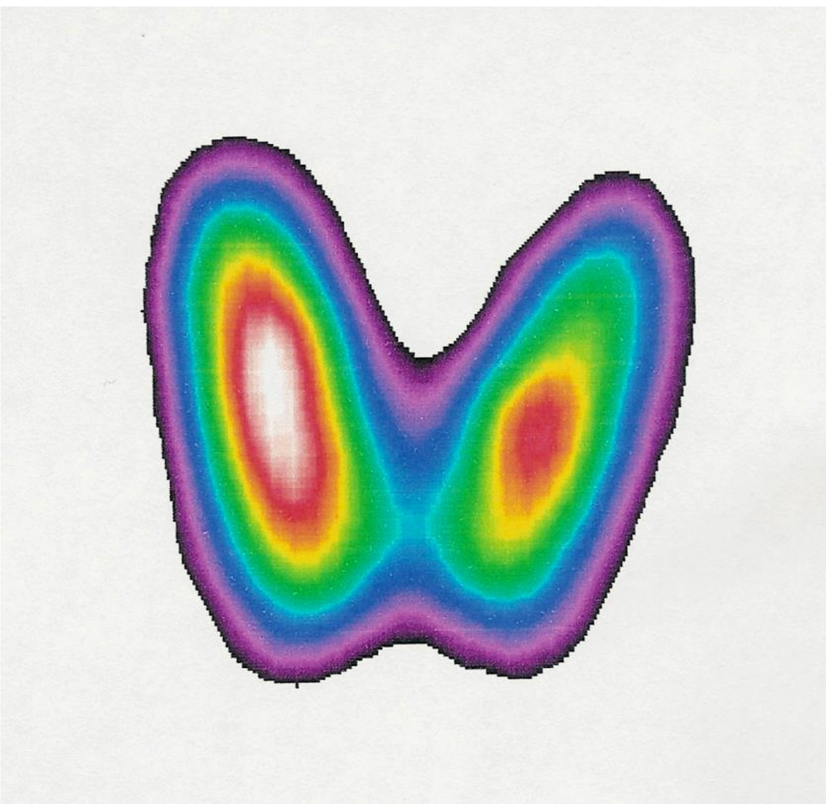


Thyroidits

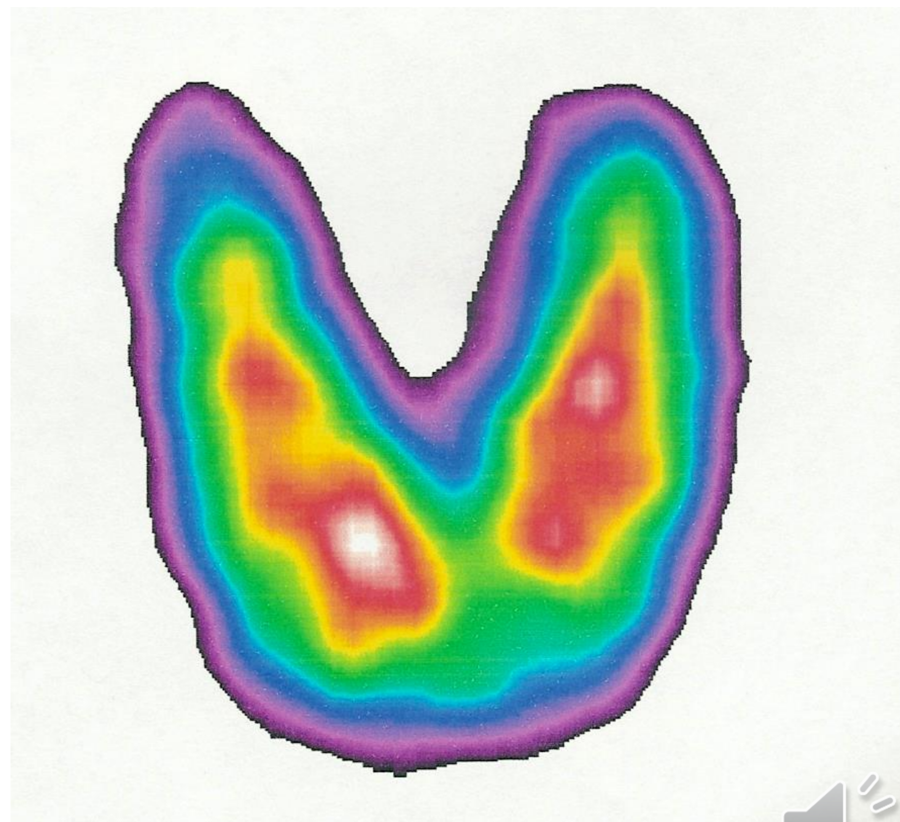


To distinguish between Graves' disease and Toxic multinodular goiter

Graves'



TMNG



Graves' Disease vs. Multinodular Toxic Goiter

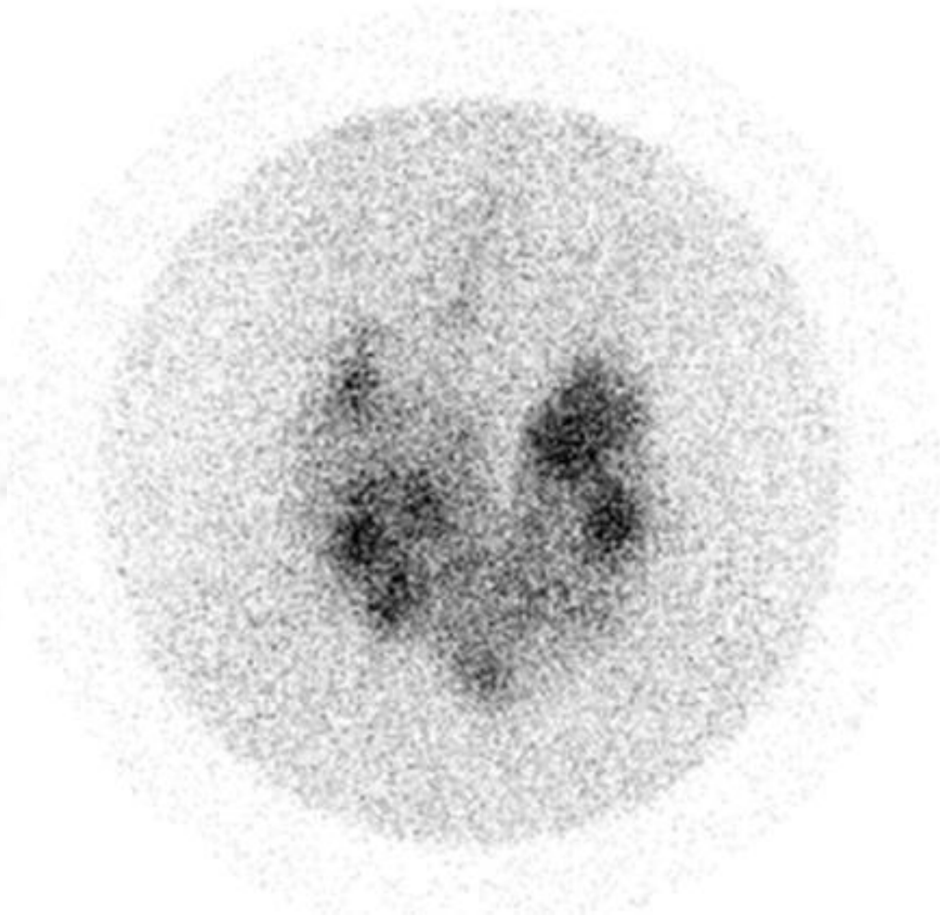
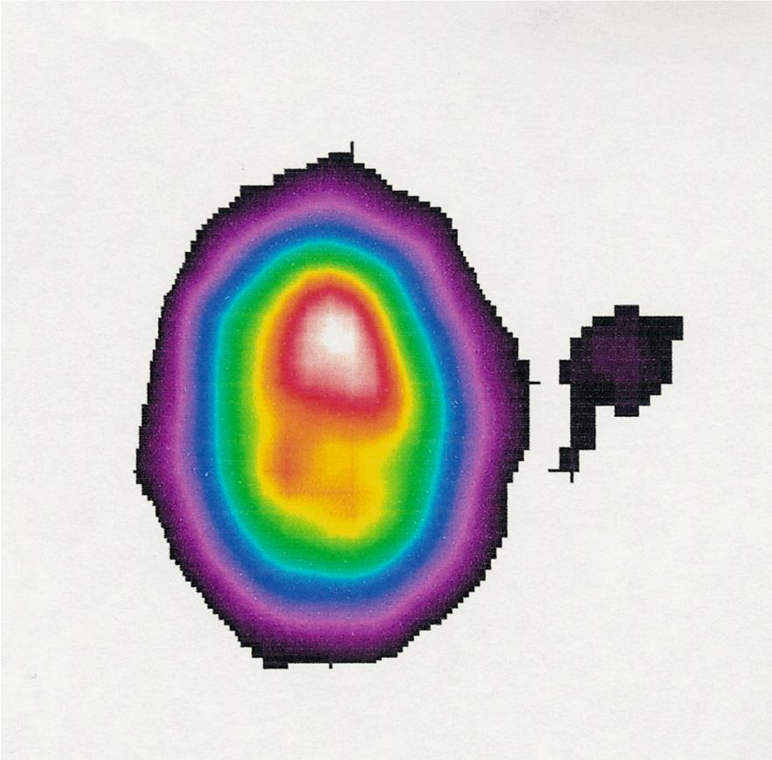


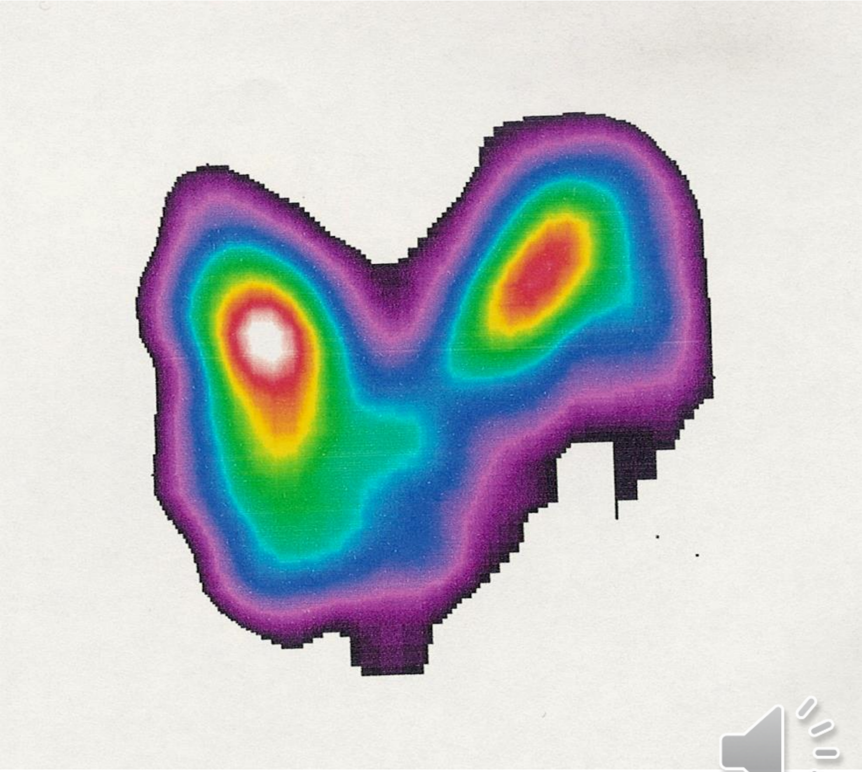
Figure 5-22 Graves' disease. Large goiter with high uptake. The %RAIU was 65%. Note the pyramidal lobe.

Thyroid Scan: Indications (2)

- Determination of functional status of thyroid nodule (cold, hot)

Functional state of a thyroid nodule if FNAB is unavailable or non-diagnostic





Types of Thyroid Nodule by Scan

- Cold (hypofunctioning compared to adjacent normal tissue)
- Hot (hyperfunctioning with suppression of the extranodular gland)
- Warm (increased uptake compared to adjacent tissue but without suppression of the extranodular tissue)
- Indeterminate (palpable but not visualized on scintigraphy, Isoactive)
- Multiple nodules (multinodular goiter)

Thyroid Nodule

- The thyroid scan does not diagnose nodules.
- A nodule is diagnosed by physical examination of the thyroid or detected by an anatomical imaging modality (e.g., ultrasonography,CT, or MRI).
- Thyroid scintigraphy can determine the functional status of a nodule detected by physical examination or anatomical imaging.

Likelihood of Thyroid Cancer in Nodule Based on Thyroid Scan

- **Cold: 15–20%**
- **Indeterminate: 15–20%**
- **Multinodular: 5%**
- **Hot < 1%**

Box 5-11 Differential Diagnosis for Thyroid Nodules

Cold nodules (non-functioning)
- Benign
  - Colloid nodule
  - Simple cyst
  - Hemorrhagic cyst
  - Adenoma
  - Thyroiditis
  - Abscess
  - Parathyroid cyst or adenoma
- Malignant
  - Papillary
  - Follicular
  - Anaplastic
  - Medullary
  - Hürthle cell
  - Lymphoma
  - Metastatic carcinoma
    - Lung
    - Breast
    - Melanoma
    - Gastrointestinal
    - Renal

Functioning nodules (warm or hot)
- Adenomas
- Hyperfunctioning adenomas

Cold Nodule

- > 85–90% of thyroid nodules are cold (hypofunctional) on thyroid scintigraphy.

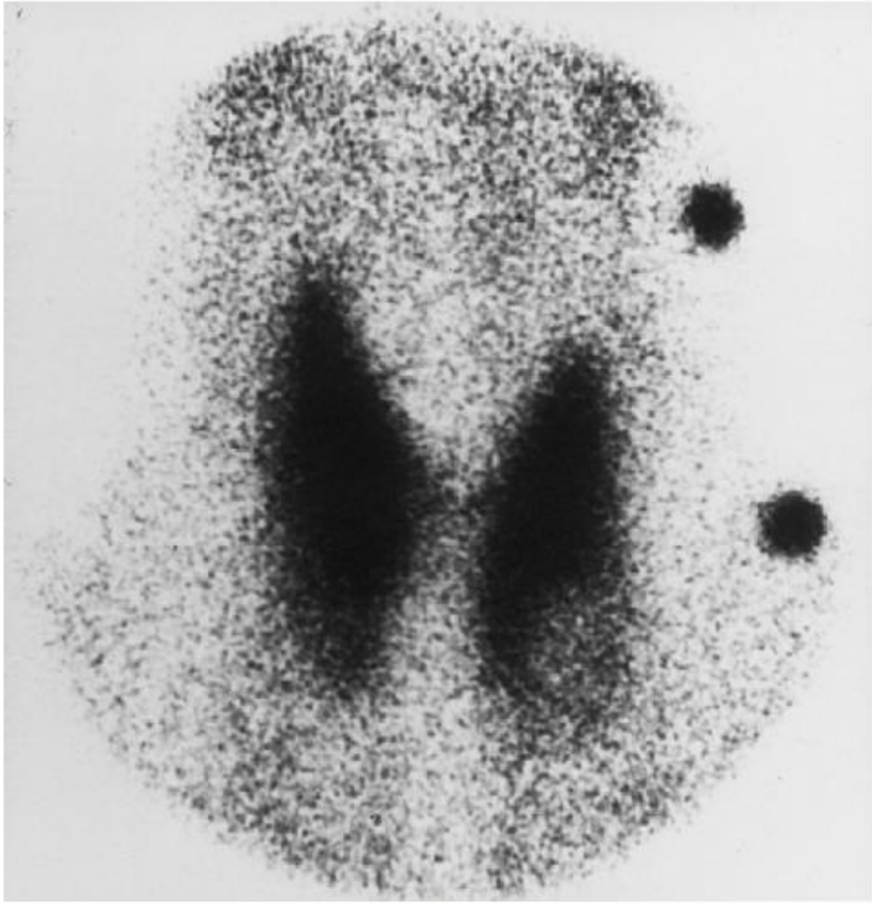
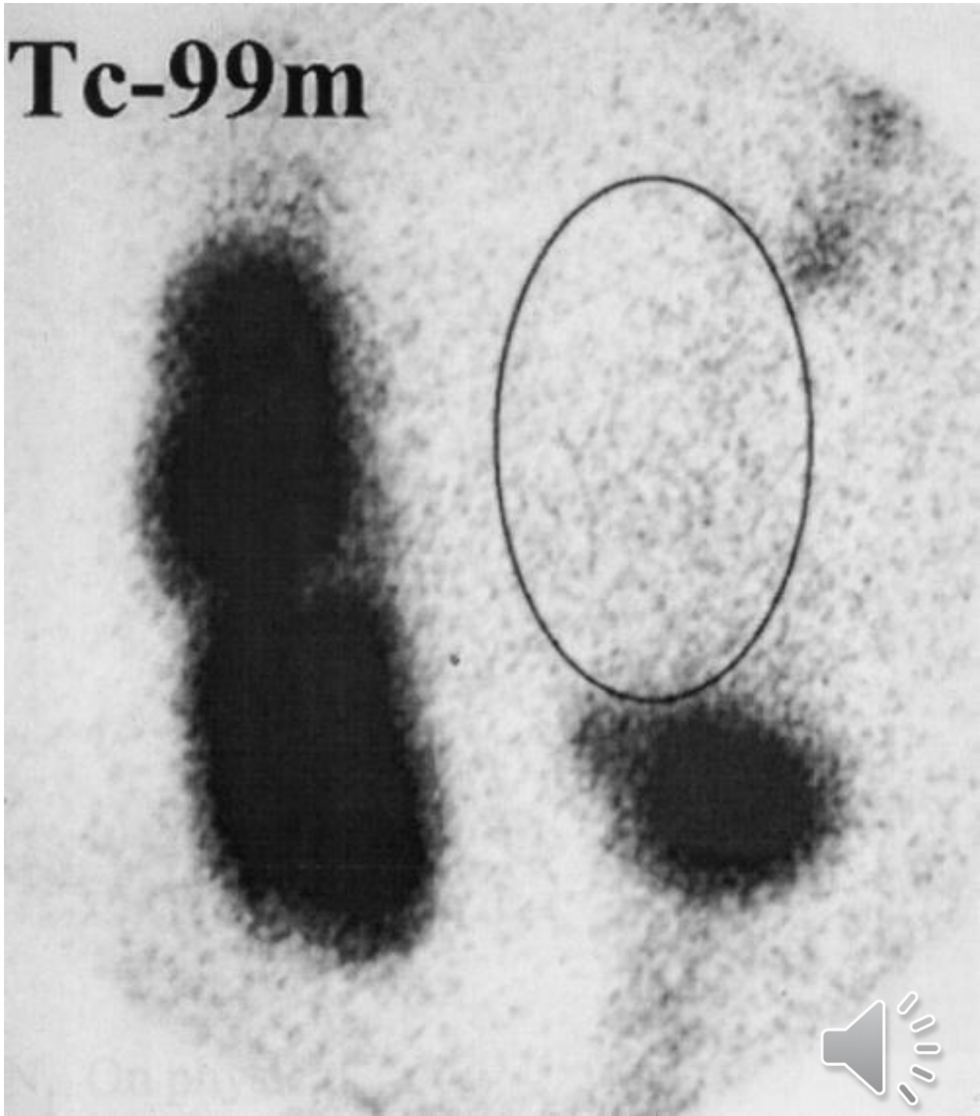


Figure 5-11 Solitary cold nodule. A palpable nodule corresponds to the cold defect in left lower lobe on the thyroid scan. Radioactive markers are placed 4 cm apart on the left side as an aid to approximate the size of gland.

Dominant Cold Nodule in MNG

- With multinodular goiters, the incidence of malignancy in cold nodules is lower, less than 5%.

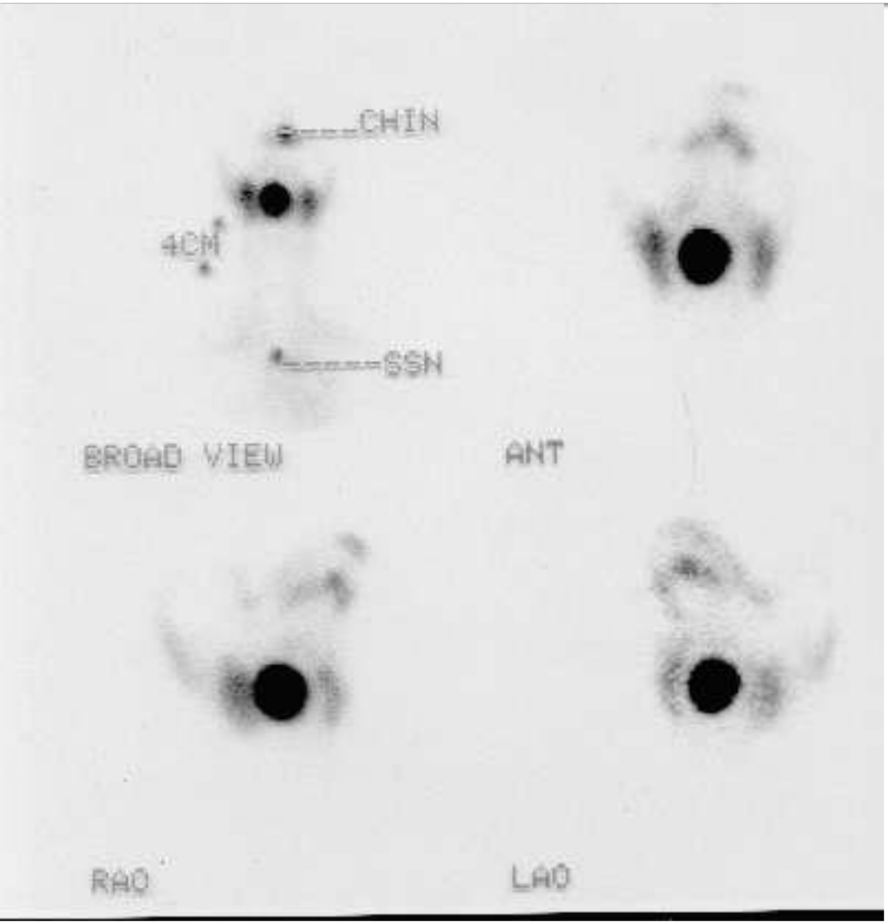
- "Dominant"nodules require further evaluation because of relatively increased risk.

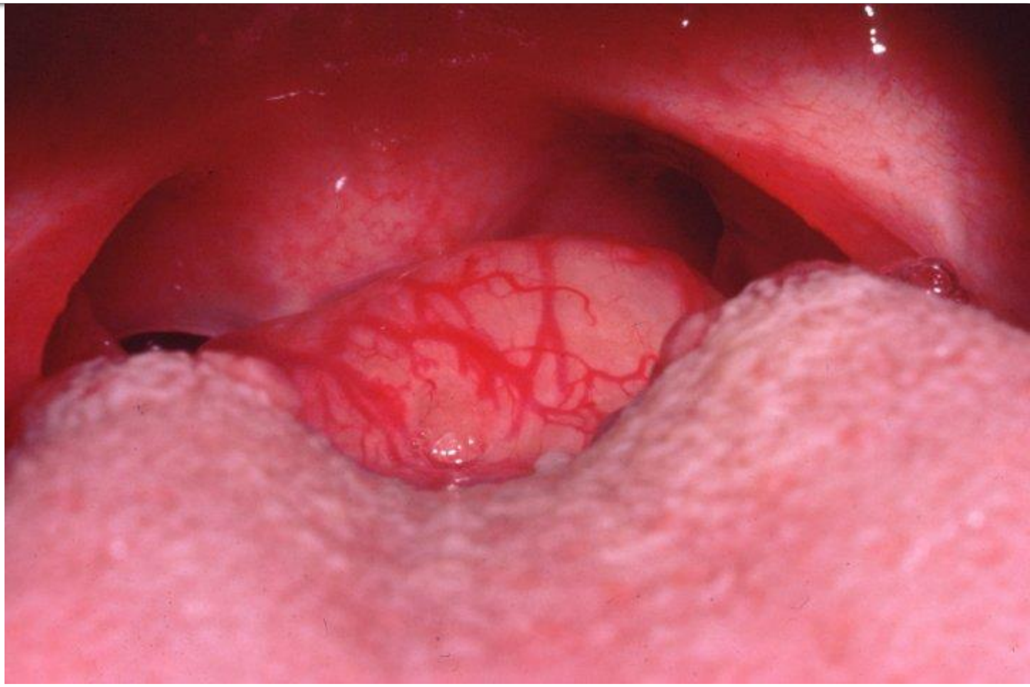


Thyroid Scan: Indications (3)

- **Detection of ectopic thyroid tissue (Lingual Thyroid)**

Lingual Thyroid



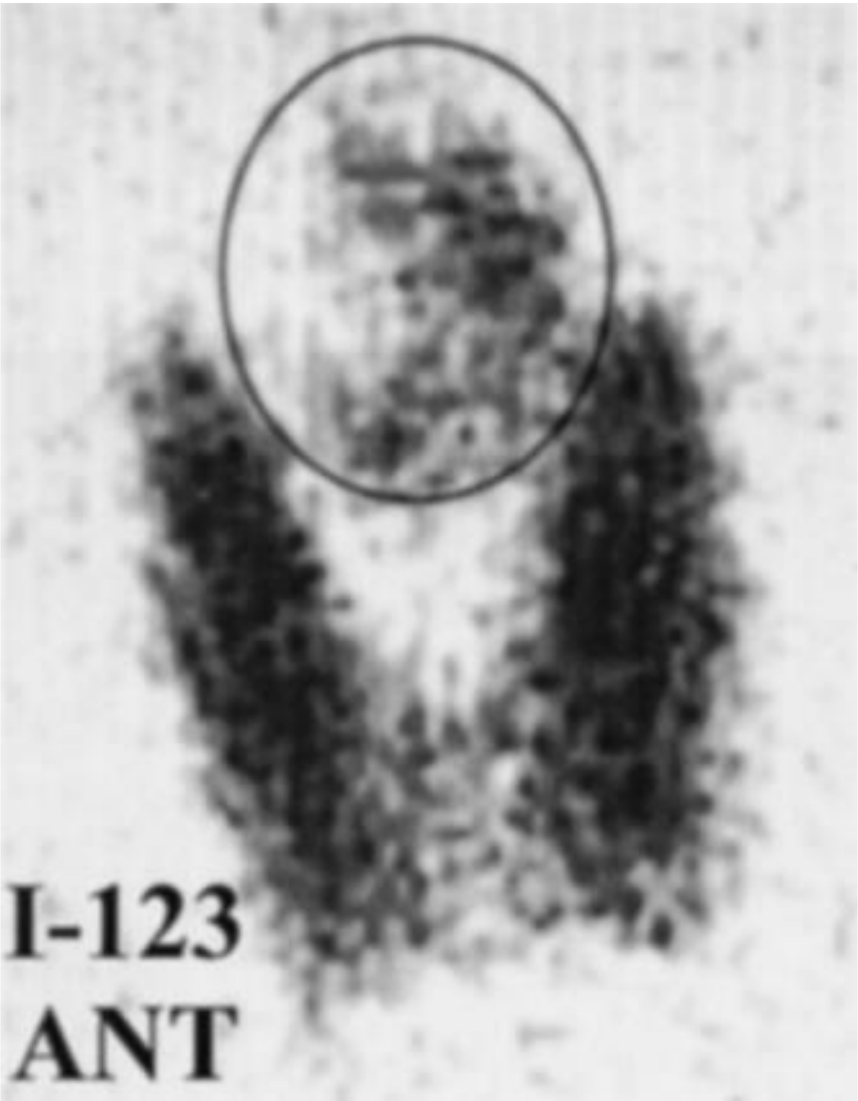


Ectopic Thyroid Tissue

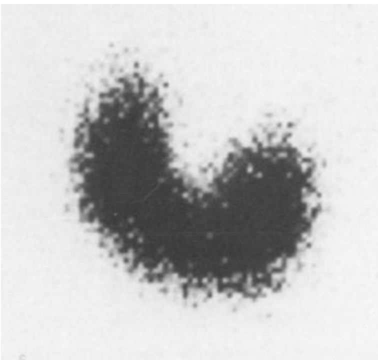
- **Functioning ectopic thyroid tissue should be considered metastatic until proven otherwise.**

Thyroglossal Cyst

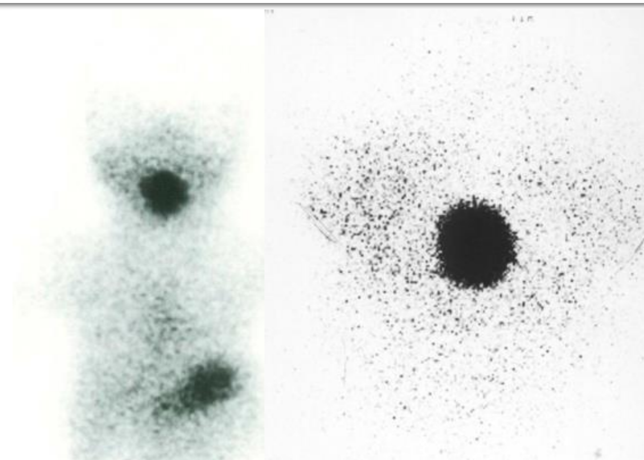
Ectopic Thyroid in Thyroglossal Cyst



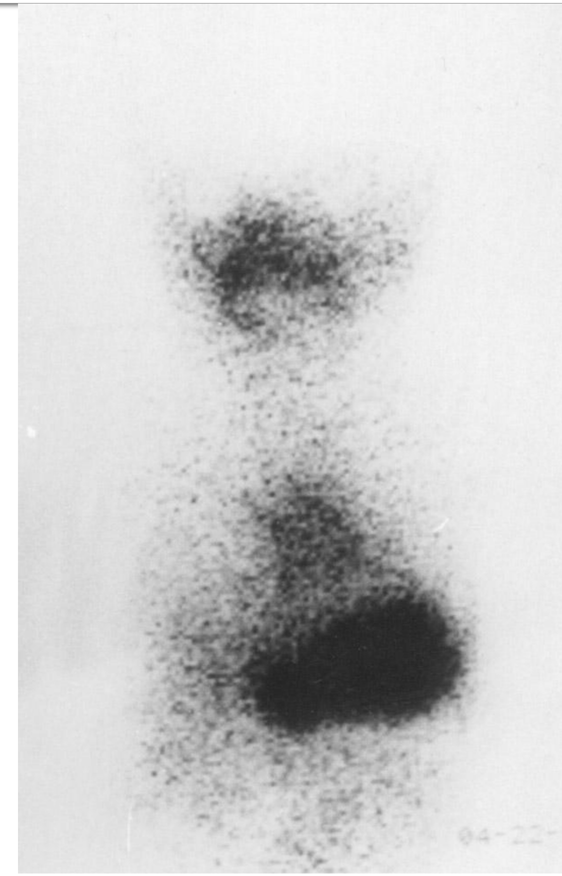
Congenital Thyroid Abnormality



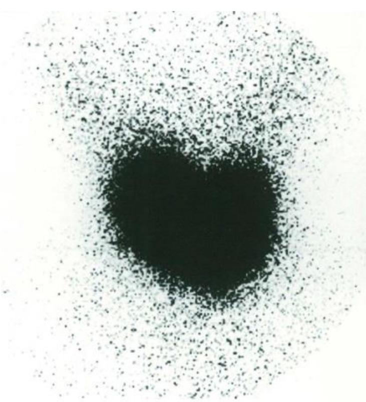
Normal Thyroid



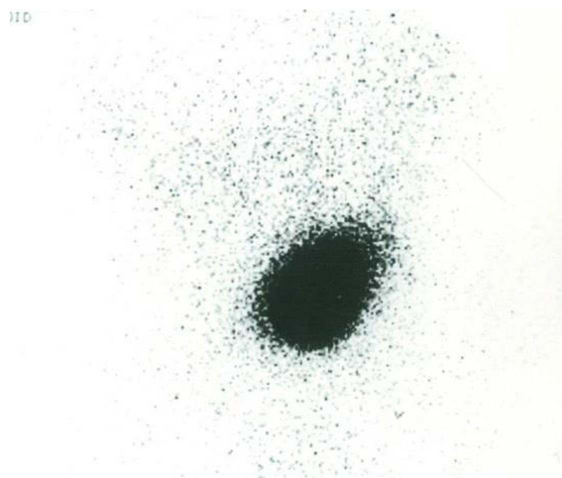
Lingual Thyroid



Agenesis



Dyshormonogenesis
Pendred Syn.



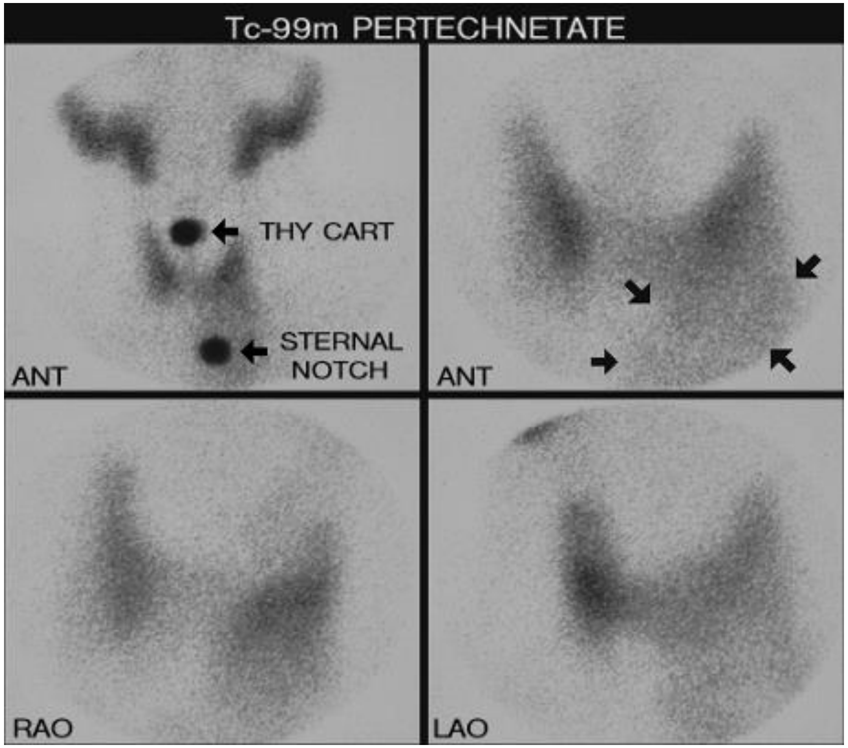
Right Lobe Hemiagenesis

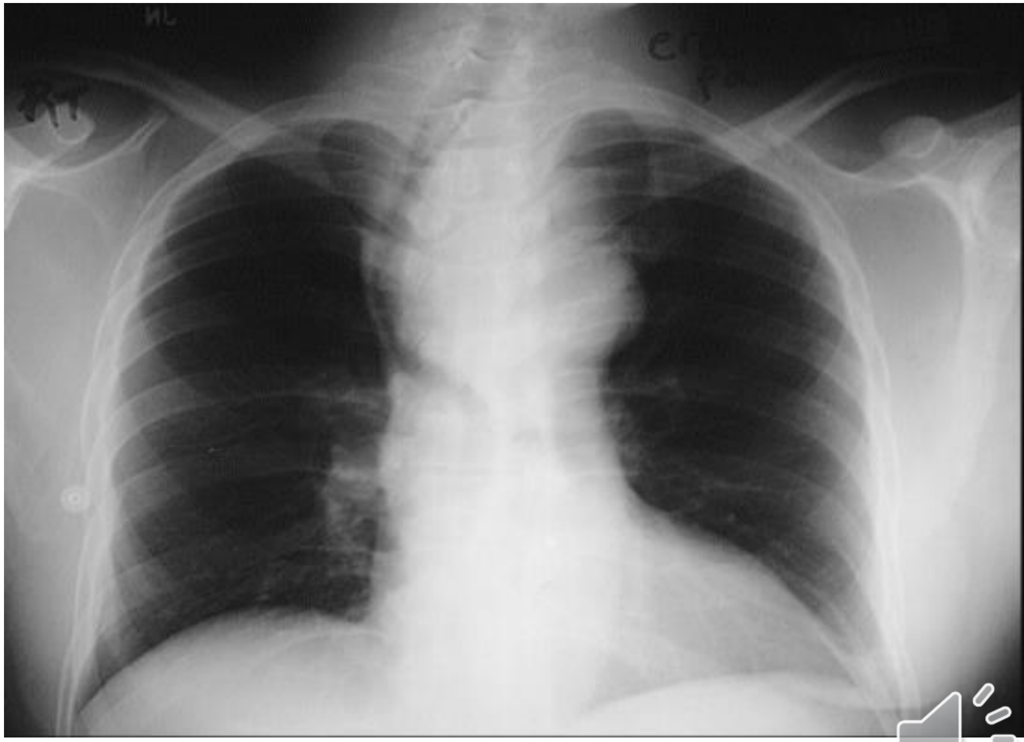
Thyroid Scan: Indications (4)

- **Differential diagnosis of mediastinal masses (substernal goiter)**

Indications of Thyroid Scan

- To determine if a retrosternal mass is a goiter



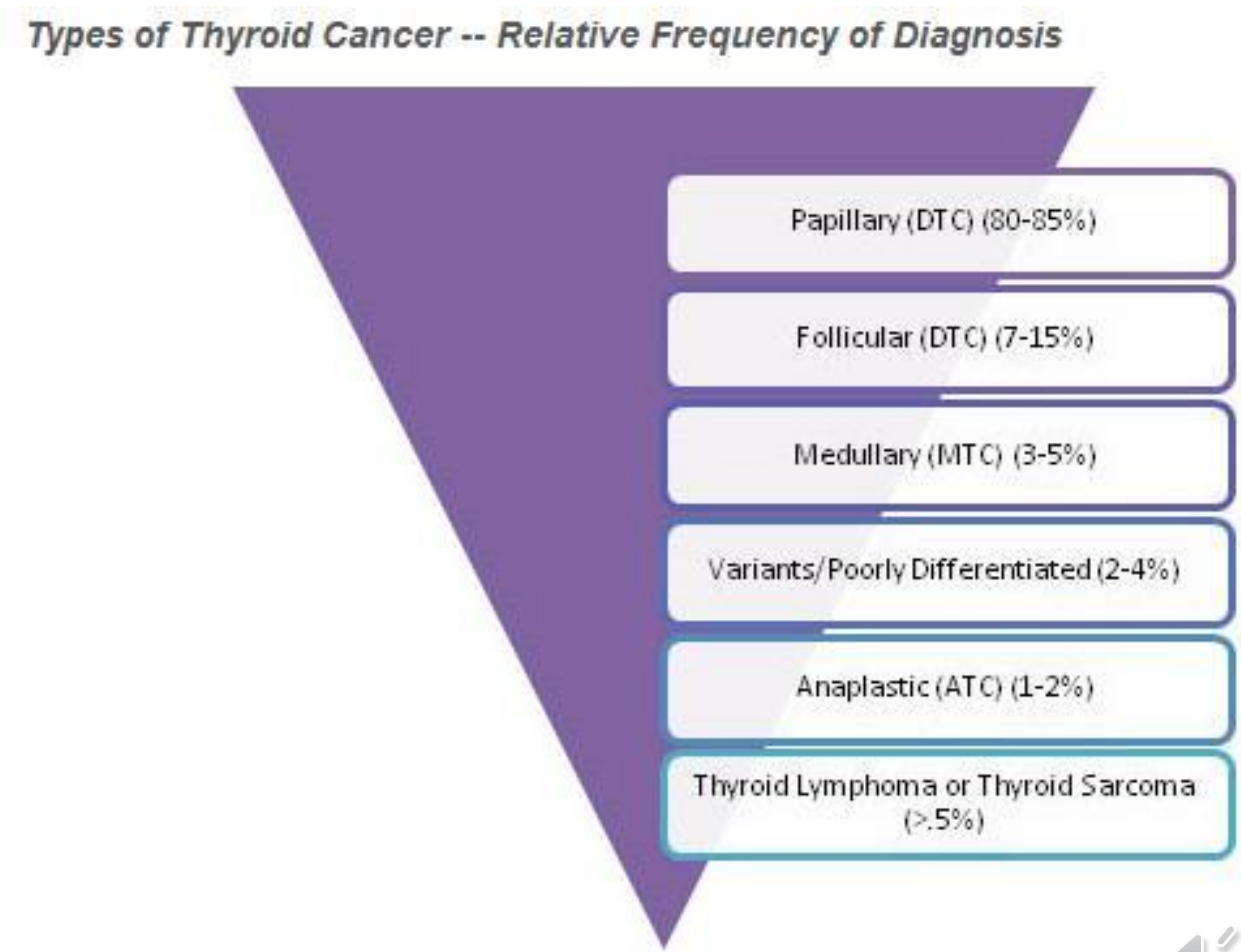


Thyroid Scan: Indications (5)

- Thyroid cancer whole body scan

Thyroid Cancer

- Papillary
- Follicular
- Medullary
- Anaplastic
- Lymphoma
- Sarcoma



Thyroid Cancer Scan

- Thyroid cancer cells are hypofunctional compared to normal thyroid tissue and thus take up radioiodine to a lesser degree.
- This is the reason that cancer nodules appear cold on routine thyroid scans.

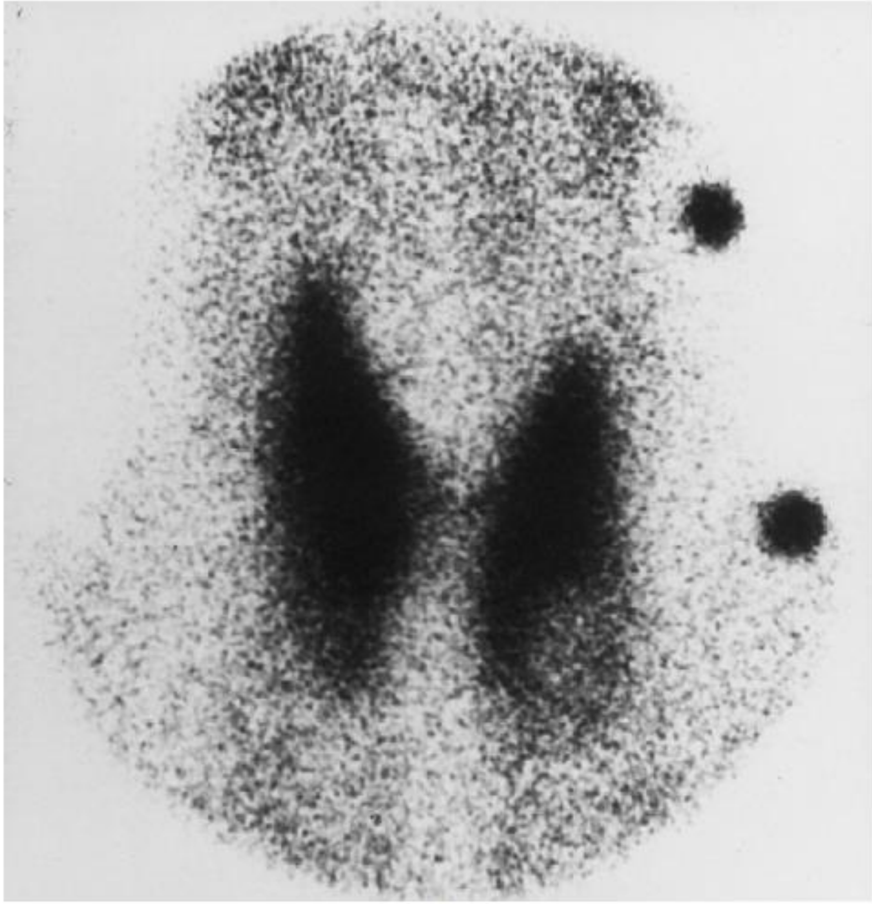


Figure 5-11 Solitary cold nodule. A palpable nodule corresponds to the cold defect in left lower lobe on the thyroid scan. Radioactive markers are placed 4 cm apart on the left side as an aid to approximate the size of gland.

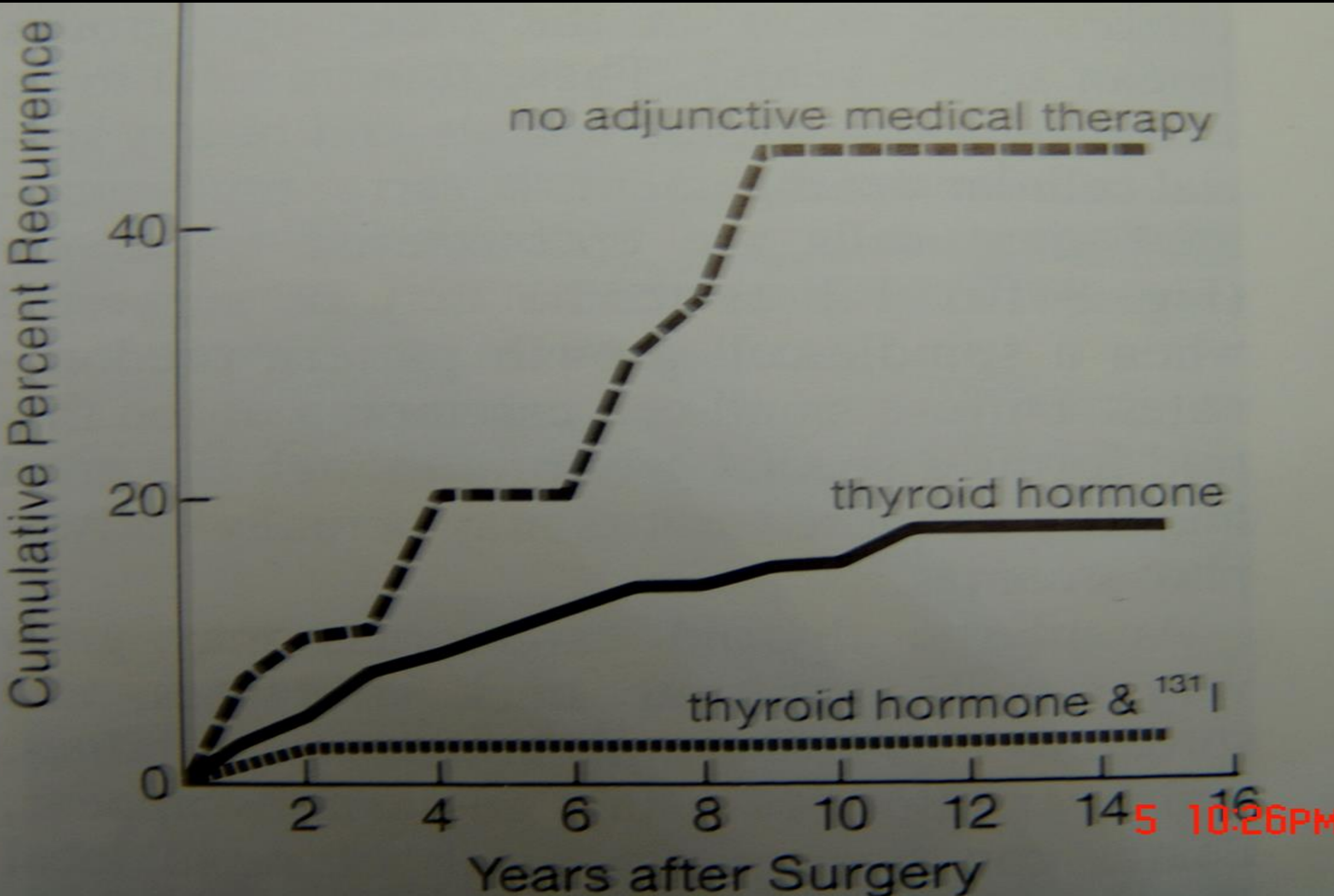
Radioiodine Therapy in DTC

- Surgery
- Radioiodine Therapy
- T_4 suppression therapy

I-131 Treatment in DTC

- Postsurgical ablation of normal thyroid remnants
  - Reduces local recurrences
  - Patient to be followed with serum Tg and I-131 whole body thyroid scans.
- I-131 treatment improves survival in patients with residual or recurrent differentiated thyroid cancer.

Recurrence of PTC
Value of T_4 Suppression and I-131 therapy



Aim of Radioiodine Therapy (RAIT) in DTC

- Selective irradiation of :
  - Thyroid remnants (Ablation)
  - Microscopic DTC
  - Non-resectable DTC
  - Incompletely resectable DTC
  - Disseminated iodine avid lung metastases
  - Other distant metastatic lesions

- Eradicating disease
- Slowing disease progression
- Providing symptomatic relief

Dose consideration in Thyroid carcinoma

- Dose consideration
  - Thyroid bed:100 mCi
  - Cervical LN metastasis: 150 mCi
  - Lungs metastasis: 175 mCi
  - Bones metastasis: 200 mCi

WBS Protocol with I-131

Box 5-13 Iodine-131 Whole Body Imaging for Thyroid Cancer: Protocol Summary

PATIENT PREPARATION

Discontinue thyroid hormone for a sufficient period (T_4 for 6 weeks, T_3 for 2 weeks) to ensure maximum endogenous thyroid-stimulating hormone response (>30 µU/mL).

RADIOPHARMACEUTICAL

Withdrawal: 2 mCi (74 MBq), orally
Thyrogen: 4 mCi (148 MBq)

IMAGING TIME

At 48 hours.

PROCEDURE

Use a wide field-of-view gamma camera with computer acquisition.
Use a high-energy parallel-hole collimator and a 20% window centered at 364 keV.
Whole body scan and a 20-min spot view to include head, neck, and mediastinum.
Calculate a percent radioactive iodine uptake.

Whole Body Thyroid Cancer Scan

- Well-differentiated papillary and follicular thyroid cancer.
  - Post-thyroidectomy prior to radioiodine I-131 therapy
  - For evaluating response therapy

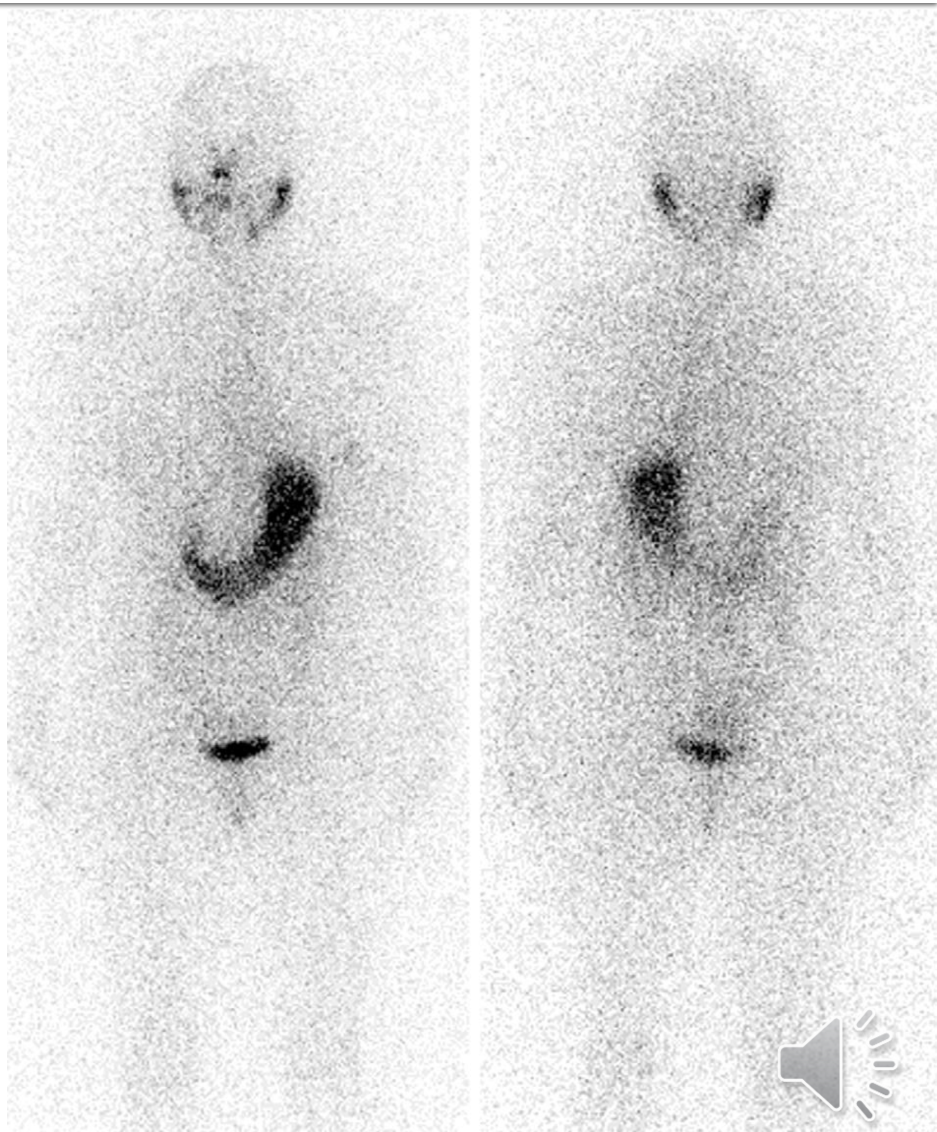
Whole body I-123 thyroid cancer scans pre- and post-I-131 ablation therapy.

Post-Treatment Follow-up

- After therapy, the patient is placed back on thyroid hormone replacement and suppressive therapy.
- Retreatment is usually not considered for at least 6 and usually 12 months to avoid bone marrow damage.

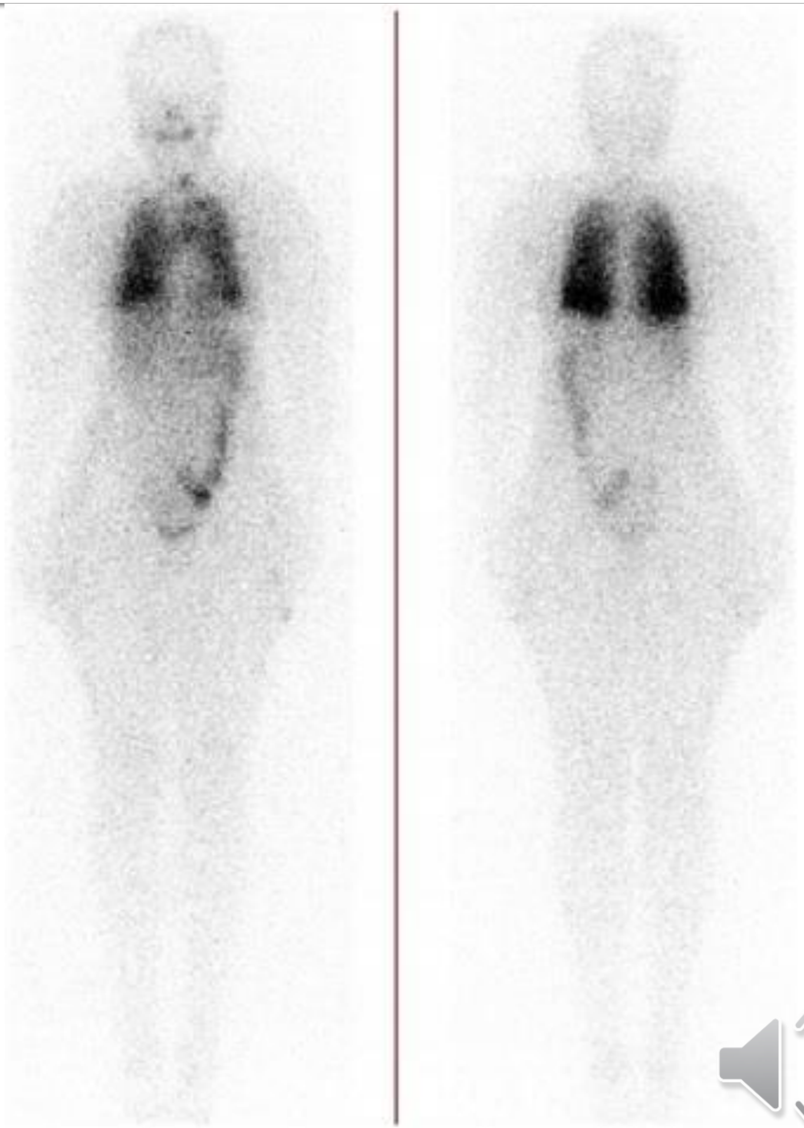
Radioiodine distribution

- I-131 whole body scan
- Post total thyroidectomy
- Thyroid cancer
- Radioactive iodine therapy in the past
- No thyroid is seen
- The distribution at 24 hours is normal with:
  - Salivary gland
  - Gastric uptake
  - Urinary excretion

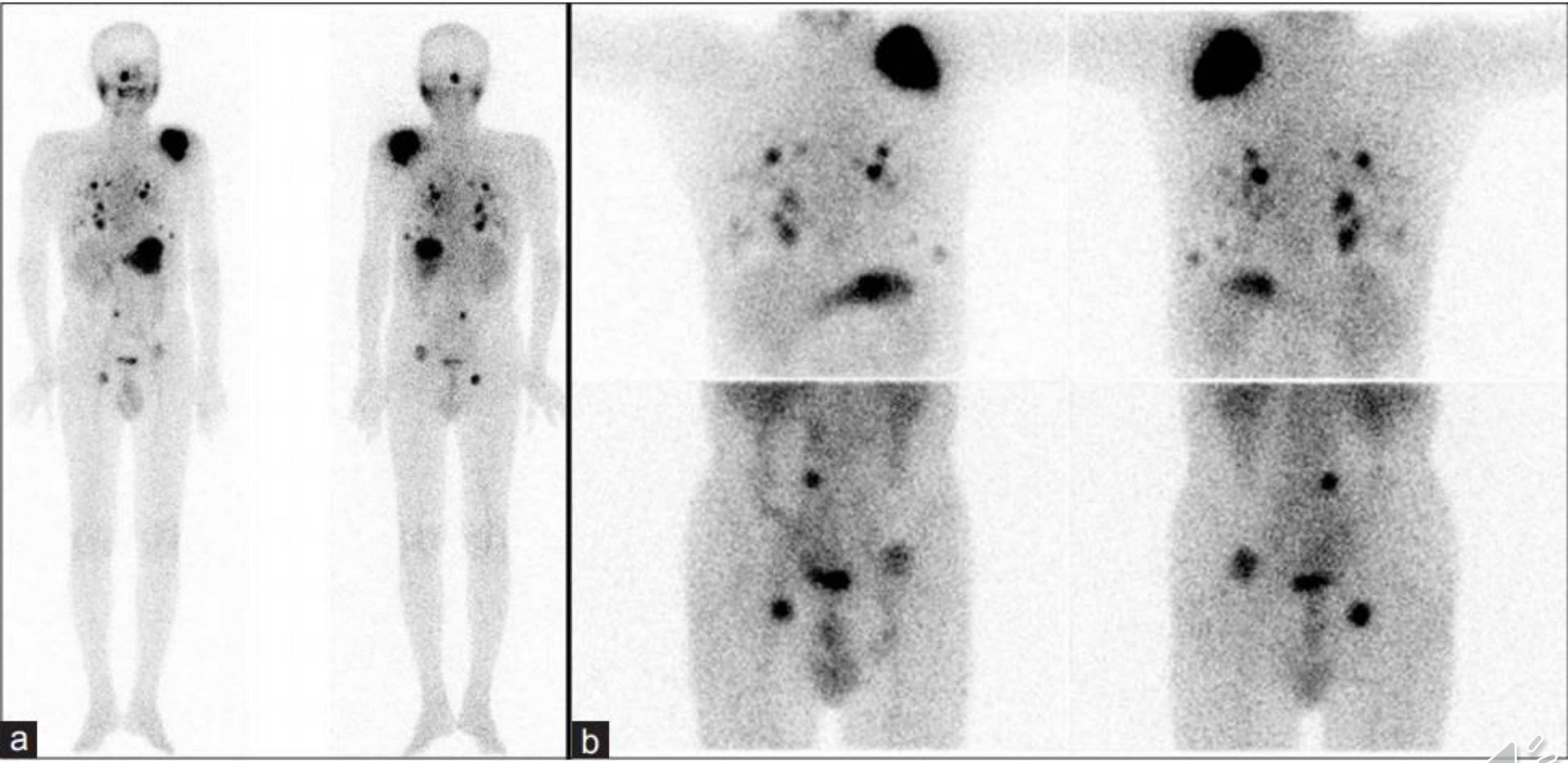


LN and Lung mets

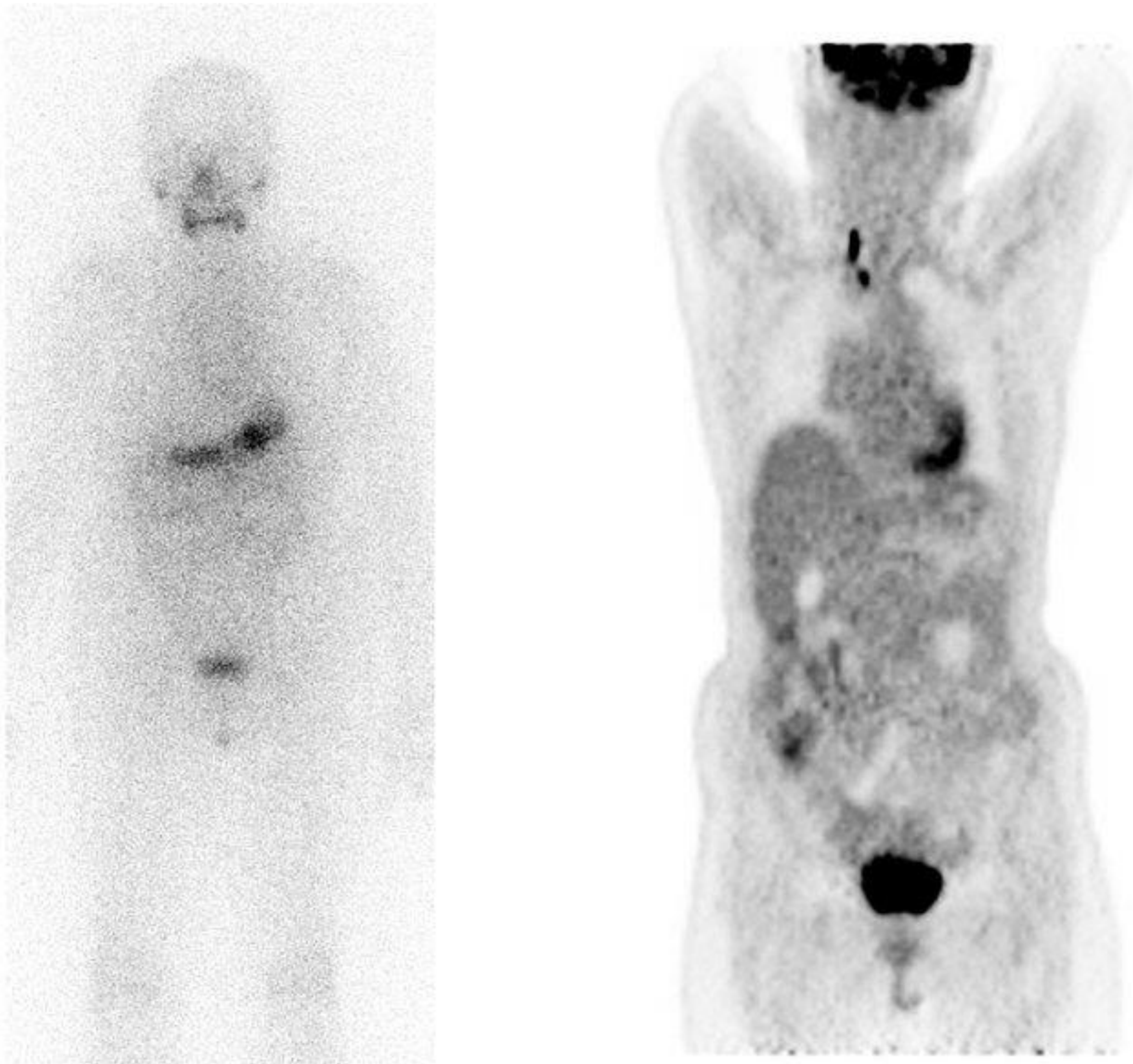
- **Metastases in cervical lymph nodes and the lungs**



DTC with Bone and Lung Metastasis



Tg (+), Radioiodine (-), FDG-PET (+) Dedifferentiated Tumor Metastasis



Medullary TC and Anaplastic TC

- Medullary carcinomas and anaplastic carcinomas do not concentrate radioiodine and are not detected with conventional thyroid scintigraphy.
  - Octreotide
  - MIBG
  - ^{18}F-DOPA-PET
  - 68Ga-DOTA-NOC PET

Anatomy and Embryology of Parathyroid Glands

- Four parathyroid glands
  - Two upper and Two lower
  - Measuring: 6 mm × 3 mm
  - Weighing 35–40 mg

- A fifth gland occurs in 10% of individuals

- Rarely, there may be only two glands or as many as eight.

Figure 5-29 Normal and aberrant location of parathyroid glands. The superior pair of glands (*striped circles*) often lie within the fascial covering of the posterior aspect of the thyroid gland outside the capsule, although rarely intrathyroidal. Most are adjacent to the thyroid or cricothyroid cartilage, rarely retropharyngeal or retroesophageal. Inferior glands (*black circles*) are more variable. Many are located inferior, lateral or posterior to the lower pole of the thyroid gland. They are commonly found in the thyrothymic ligament or even in the cervical thymus. A small percent migrate to the superior mediastinum. Rare ectopic glands are found superiorly. Arrow indicates retraction of the thyroid.

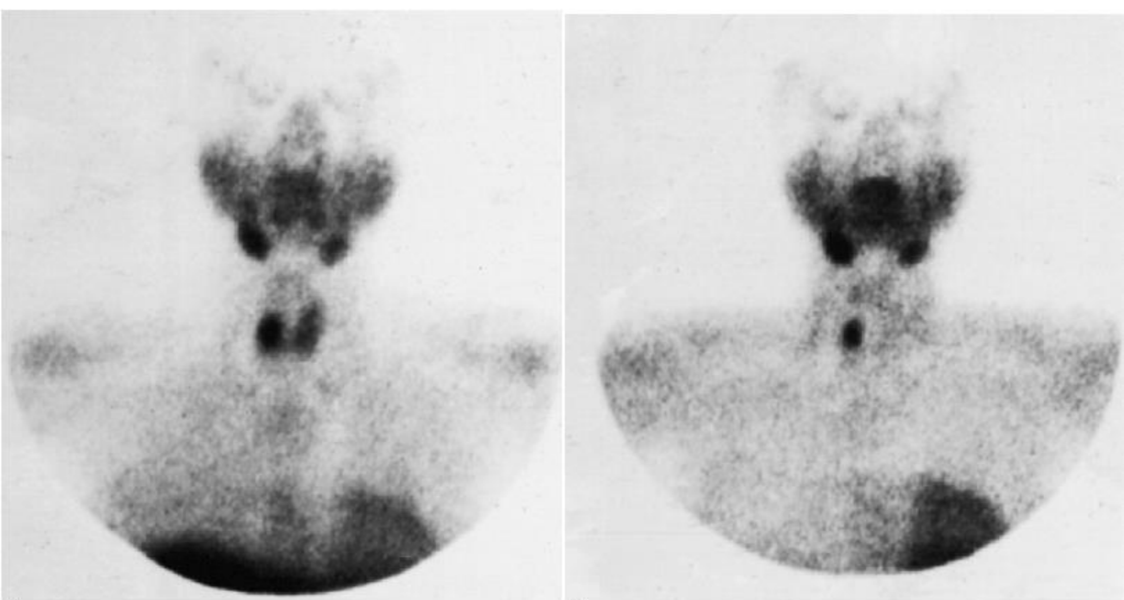
Primary Hyperparathyroidism Diagnosis

- **Primary hyperparathyroidism:**
  - **Elevated PTH with hypercalcemia**
  - **Most other causes of hypercalcemia, except parathyroid carcinoma, have reduced parathormone levels.**

- **Imaging is performed for localization, not diagnosis.**

Methodology

- Two phases
  - Early planar imaging at 15 minutes
  - Late planar imaging at 2 hours after injection
  - Single-photon emission computed tomography (SPECT) is increasingly being performed.
  - Because the length of



A B

Figure 5-31 Tc-99m sestamibi parathyroid scan. Patient has hypercalcemia and increased PTH. **A,** Early imaging at 15 minutes with Tc-99m sestamibi reveals somewhat asymmetrical activity in the region of the thyroid gland. **B,** Delayed imaging at 2 hours demonstrates washout of thyroid activity and a parathyroid adenoma.

Box 5-18 Tc-99m Sestamibi Parathyroid Imaging: Protocol Summary

PATIENT PREPARATION

None

RADIOPHARMACEUTICAL

20 mCi (740 MBq), intravenously

TIME OF IMAGING

Early scans at 15 minutes
Delayed scans at 2 hours

IMAGING PROCEDURE

Planar

Use a high-resolution collimator and a 20% window centered at 140 keV.

Position the patient supine with the chin up and neck extended.

Place markers on the chin and sternal notch.

Obtain anterior and 45-degree left and right anterior oblique views, 300k counts per view.

SPECT IMAGING

Position patient as above.

Use a high-resolution collimator and a 20% window centered at 140 keV.

Use dual-headed SPECT camera: 360-degree contoured acquisition arc, 3-degree angular

Sampling increment, 15–30 sec per view, 128 × 128 matrix with 1.5 zoom, Hanning or Butterworth filter.

Reconstruct transaxial, coronal, and sagittal planes.

Reproject images at each sampling angle.

Eutopic Left Inferior Parathyroid Adenoma in Fused SPECT/CT

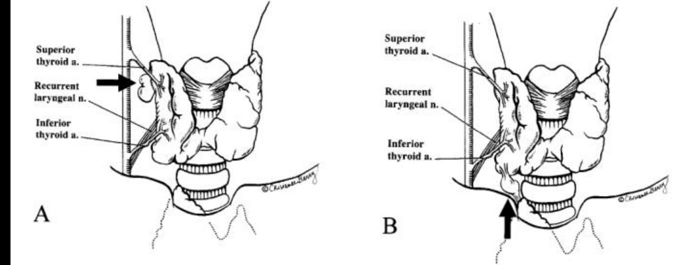


FIGURE 2. (A) Anatomic orientation of a superior parathyroid adenoma (arrow). (B) Anatomic orientation of an inferior parathyroid adenoma (arrow).

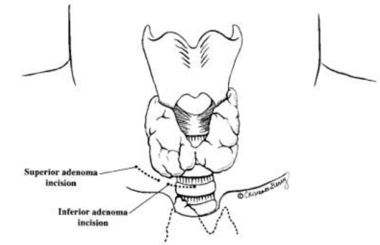
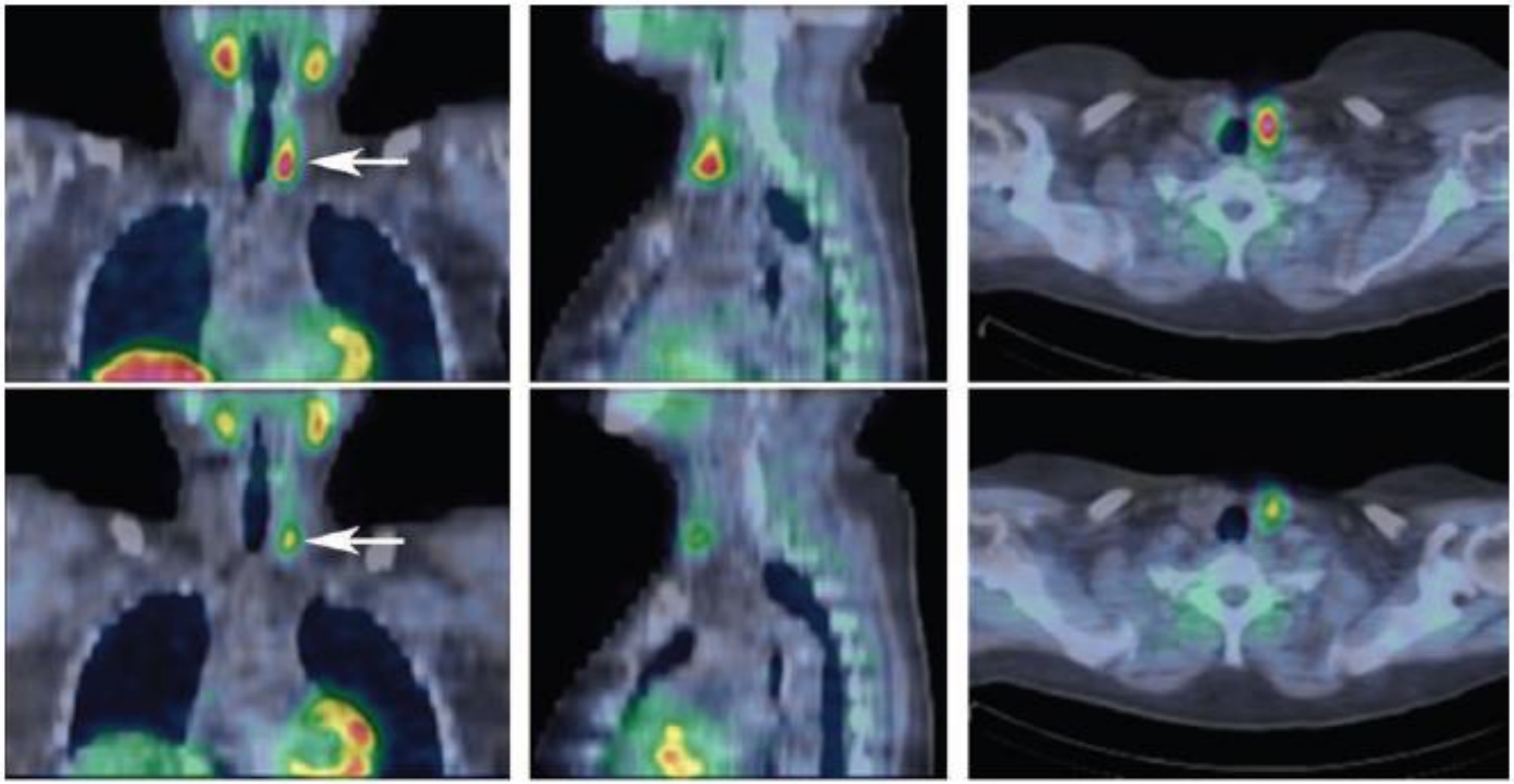


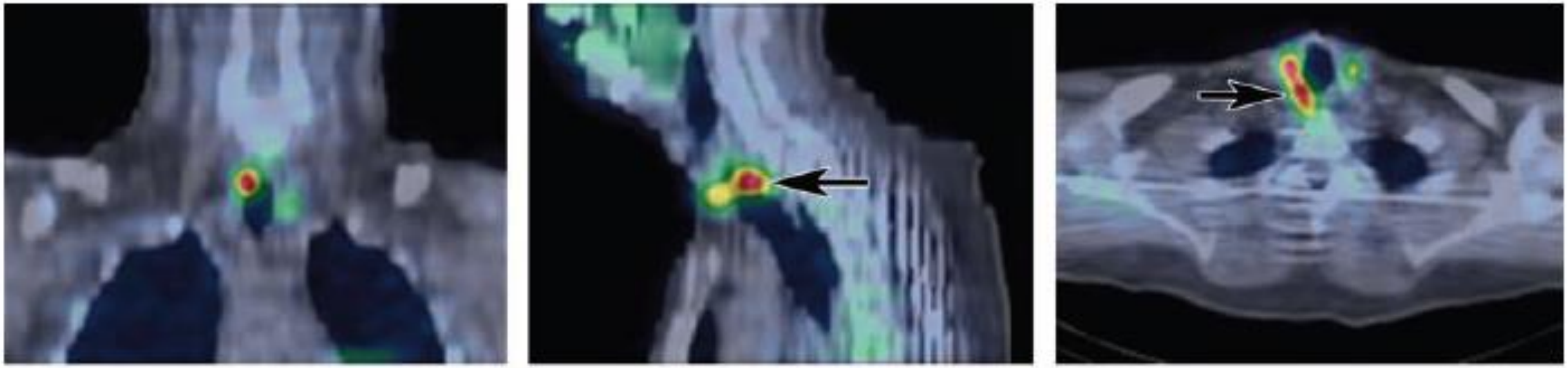
FIGURE 1. Incision sites for the minimally invasive parathyroidectomy.



a. b. c.

Figure 5. Eutopic left inferior parathyroid adenoma with delayed washout. Early-phase (top) and delayed-phase (bottom) coronal (**a**), sagittal (**b**), and axial (**c**) fused SPECT/CT images demonstrate the classic findings of a left inferior parathyroid adenoma (arrow in **a**) with a slightly anterior location at the level of the lower third of the thyroid gland.

Ectopic right Superior Parathyroid Adenoma



a. b. c.

Figure 6. Ectopic right superior parathyroid adenoma. Early-phase coronal (**a**), sagittal (**b**), and axial (**c**) fused SPECT/CT images depict typical findings of an ectopic superior parathyroid gland, with a focal area of intense ^{99m}Tc sestamibi accumulation (arrow in **b** and **c**) to the right of and posterior to the middle third of the thyroid lobe and posterolateral to the trachea.

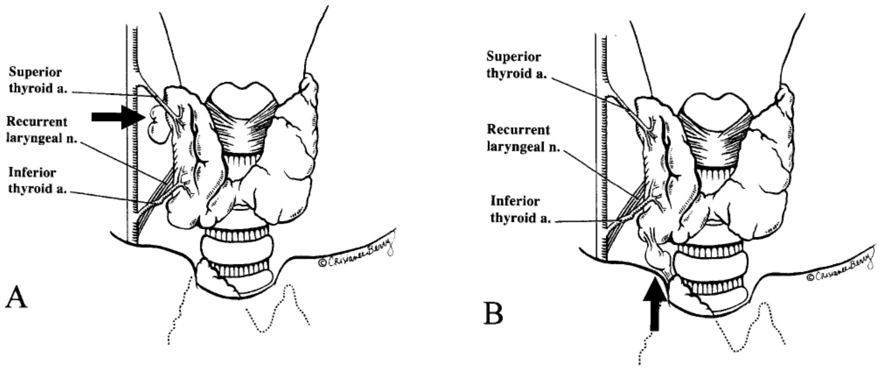


FIGURE 2. (A) Anatomic orientation of a superior parathyroid adenoma (arrow). (B) Anatomic orientation of an inferior parathyroid adenoma (arrow).

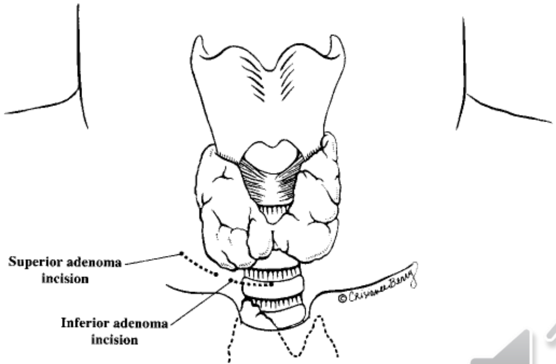


FIGURE 1. Incision sites for the minimally invasive parathyroid-ectomy.

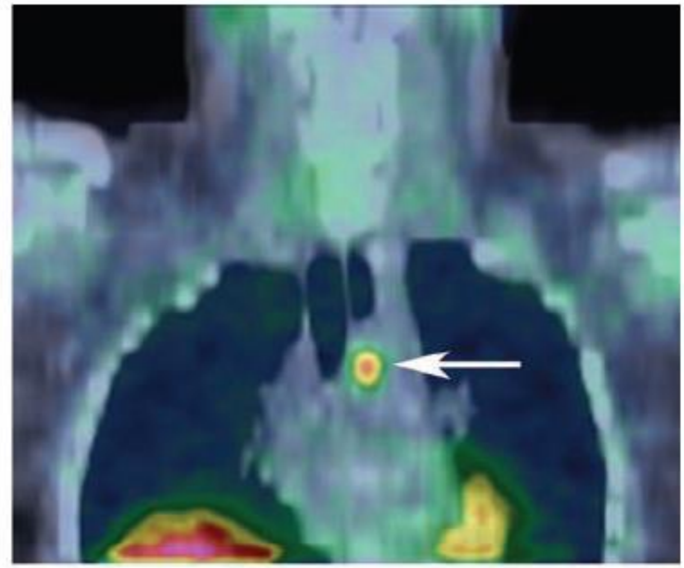
Accuracy of Tc99m-MIBI

- The sensitivity for detection of parathyroid adenomas larger than 300 mg in size is greater than 85–90% but is less for smaller adenomas.
- The most common cause for a false negative study is the small size of the adenoma.
- The sensitivity for detection of hyperplasia is considerably lower than adenoma (~50–60%).
- The most common cause for a false positive study is a thyroid adenoma.

Ectopic Mediastinal Parathyroid Adenoma

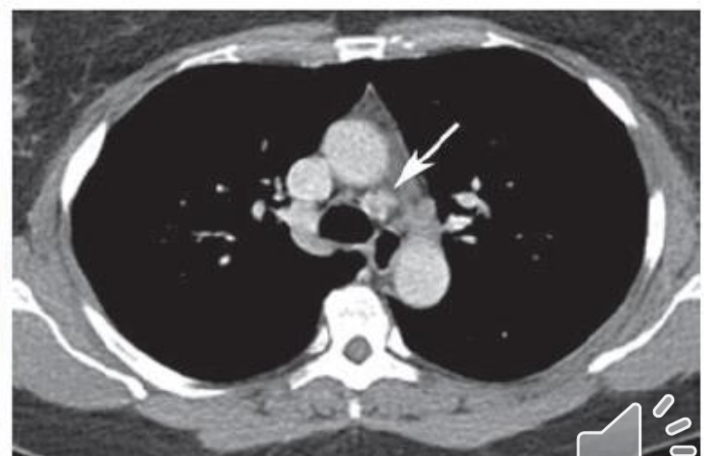
CT plays a particularly important role in the localization of ectopic mediastinal parathyroid adenomas (Fig 10).

Figure 10. Mediastinal parathyroid adenoma in a 52-year-old woman with persistent primary hyperparathyroidism after three-gland excision. **(a, b)** Coronal **(a)** and axial **(b)** fused early-phase SPECT/CT images depict a paratracheal mass (arrow in **a**) at the left tracheobronchial angle. **(c)** Axial CT image subsequently obtained with intravenous contrast material depicts an enhancing 12 × 13-mm left paratracheal mass (arrow) suggestive of a parathyroid adenoma. A 1.3-g adenoma was resected with a median sternotomy.



a.

b.



c.

Good Luck

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Thank YOU!