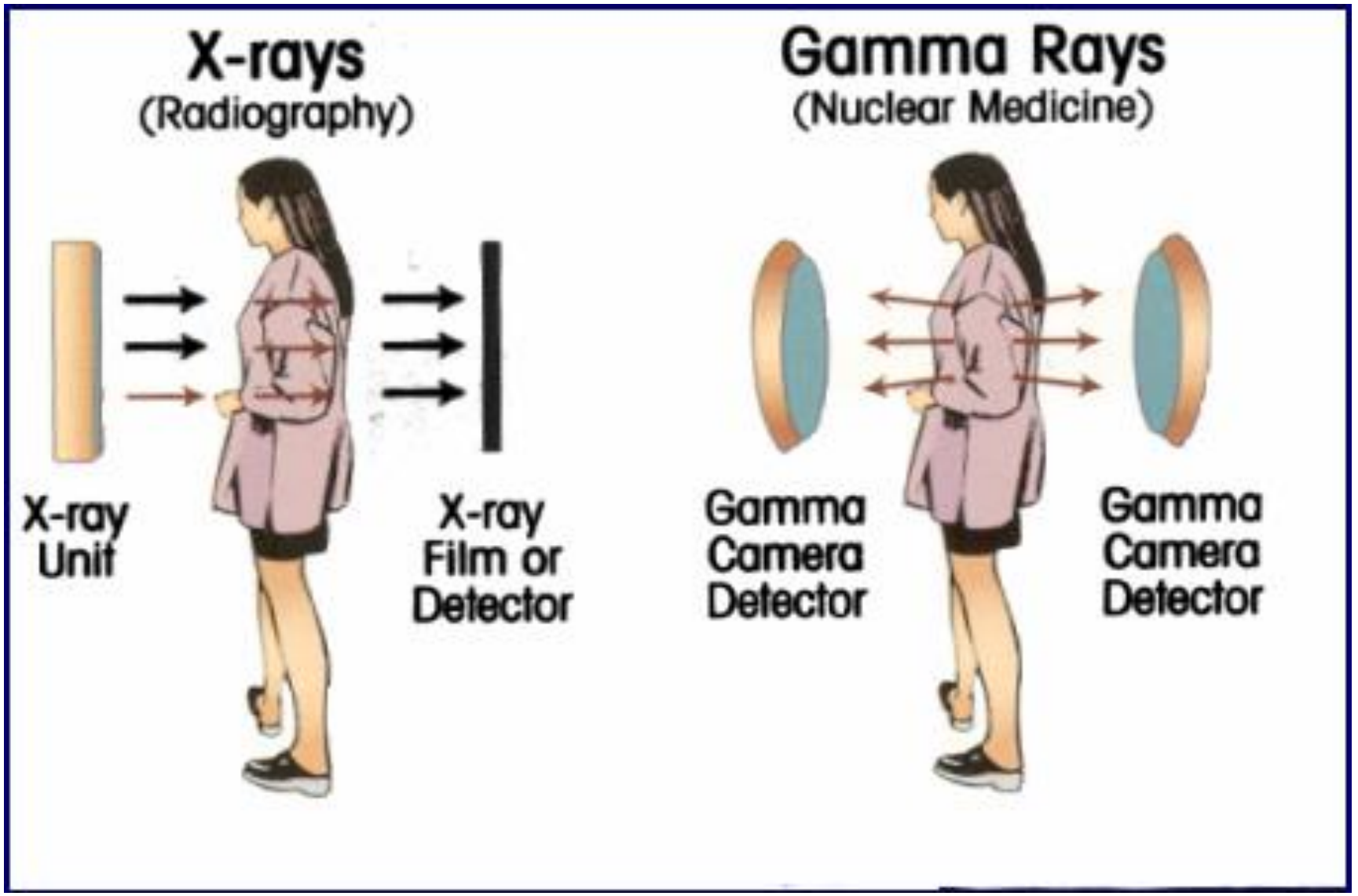
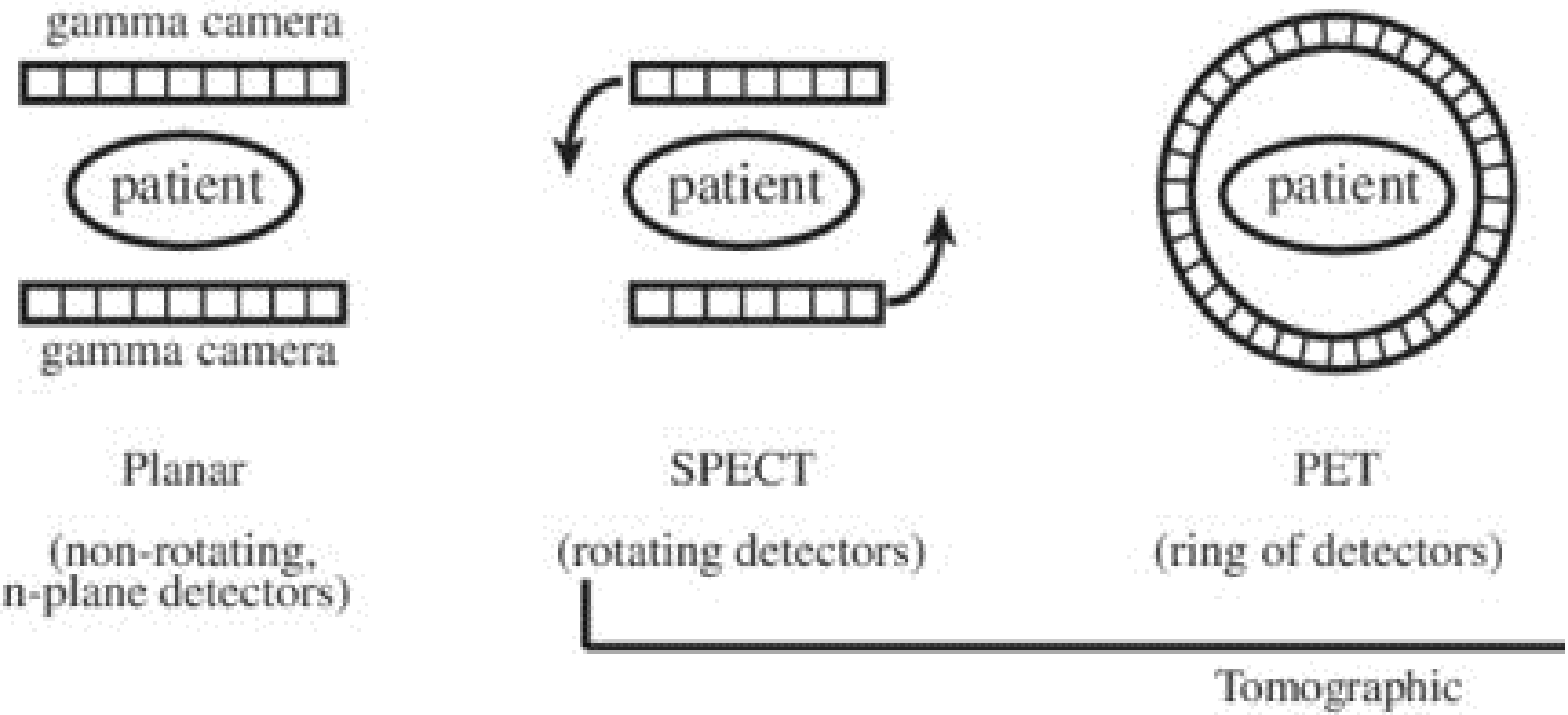
Introduction to Nuclear Medicine

October 2023


X-rays
(Radiography)
X-ray
Unit
X-ray
Film or
Detector
Gamma Rays
(Nuclear Medicine)
Gamma
Camera
Detector
Gamma
Camera
Detector


gamma camera
patient
gamma camera
patient
patient
Planar
(non-rotating,
in-plane detectors)
SPECT
(rotating detectors)
PET
(ring of detectors)
Tomographic

The key distinction between nuclear medicine and almost all other imaging modalities – images may indicate dynamic information – ***function***, not just structure

What is a radiopharmaceutical?

A **radionuclide** (radioactive and emits something we can detect, usually gamma rays)

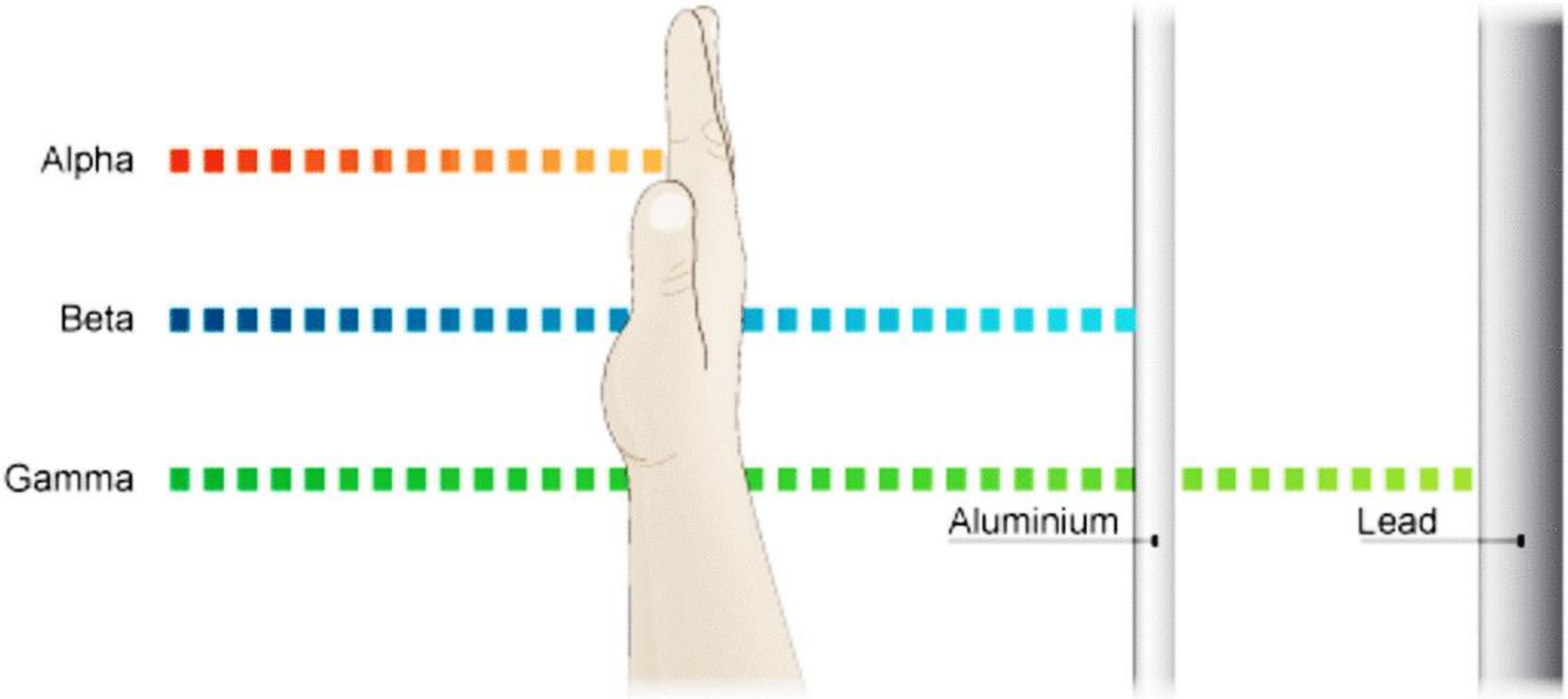
A **pharmaceutical** (which gives the physiologic function)

For example, we attach technetium-99m to DTPA, which is filtered by the kidney, to calculate glomerular filtration rate.

Or we can attach it to MDP, which is taken up by the bone, to do a bone scan.

Ideal diagnostic radiopharmaceutical

- Pure Gamma Emitter
  - Alpha and Beta Particles are unimageable and deliver high radiation dose
- Energy of Gamma Rays
  - Ideal: 100 - 250 keV
    - ^{99m}Tc, ^{123}I, ^{111}In
  - Suboptimal: < 100 keV
    - ^{201}Tl
  - > 250 keV
    - ^{67}Ga, ^{131}I
- Photon abundance to minimize imaging time
- High target to non-target ratio
- Easily available
- Suitable effective half life


Alpha
Beta
Gamma
Aluminium
Lead

Radionuclide Production

Characteristics	Production Method			
	Cyclotron	Reactor (Fission)	Reactor (Nuclear Activation)	Generator
Examples	^{201}T, ^{123}I, ^{18}F	^{99}Mo, ^{131}I	^{125}I	^{99m}Tc, ^{68}Ga

^{99m}Tc (99-metastable-Technitium)

Most used radionuclide

Pure gamma radiation

140 keV energy level

Half life of 6 hours

90% photon abundance

Available

Cheap

Produced by a generator from ^{99}Mo

Thyroid Scintigraphy

^{99m}Tc-pertechnetate and ^{131}I

Indications

- Low TSH
  - Diffuse toxic goiter (Graves' disease)
  - Single toxic nodule
  - Toxic multi-nodular goiter
- Evaluate nodule (hot vs. cold)

^{131}I Uptake

Radioactive Iodine (RAI) is used for thyroid uptake.

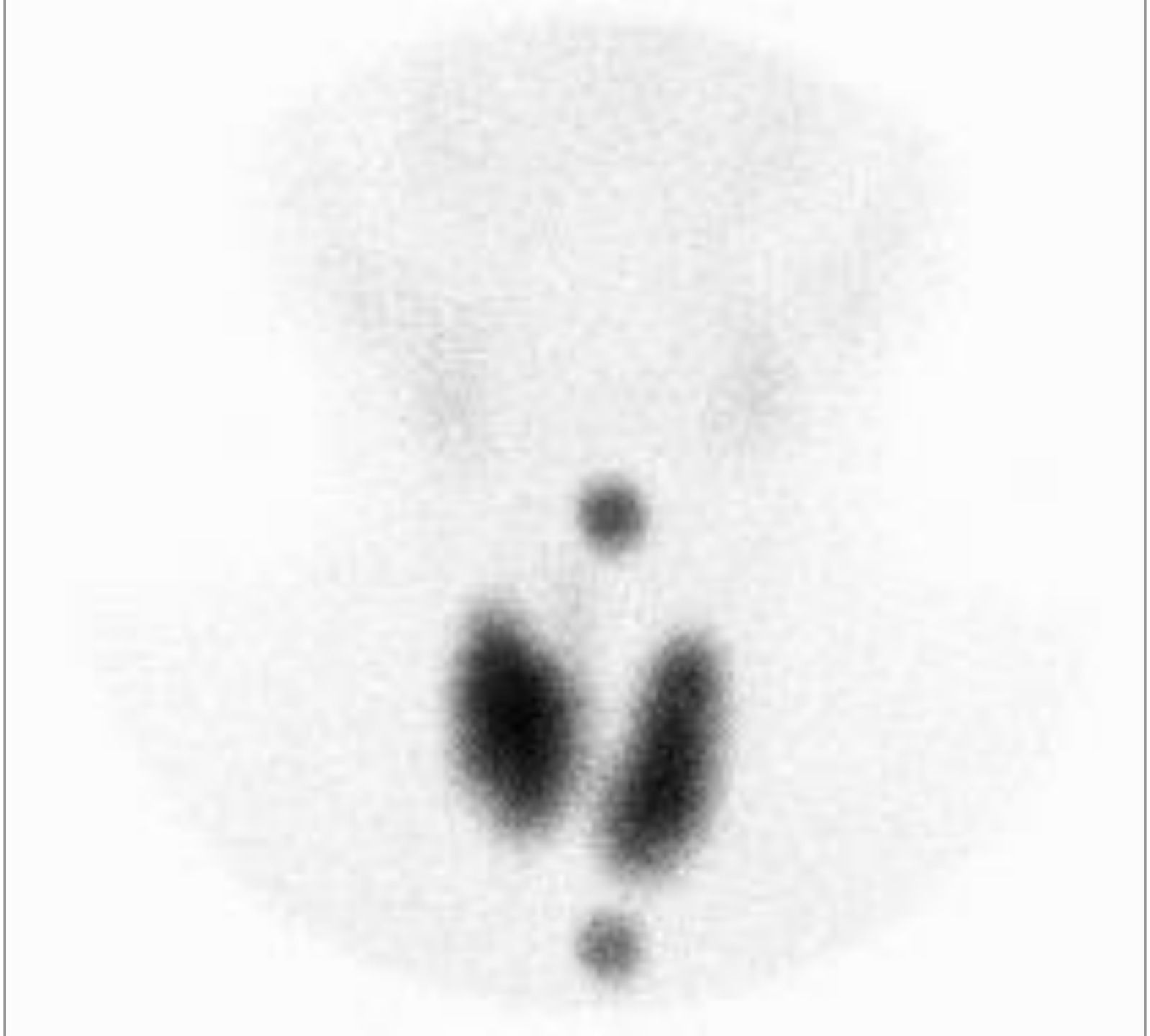
RAI is given orally

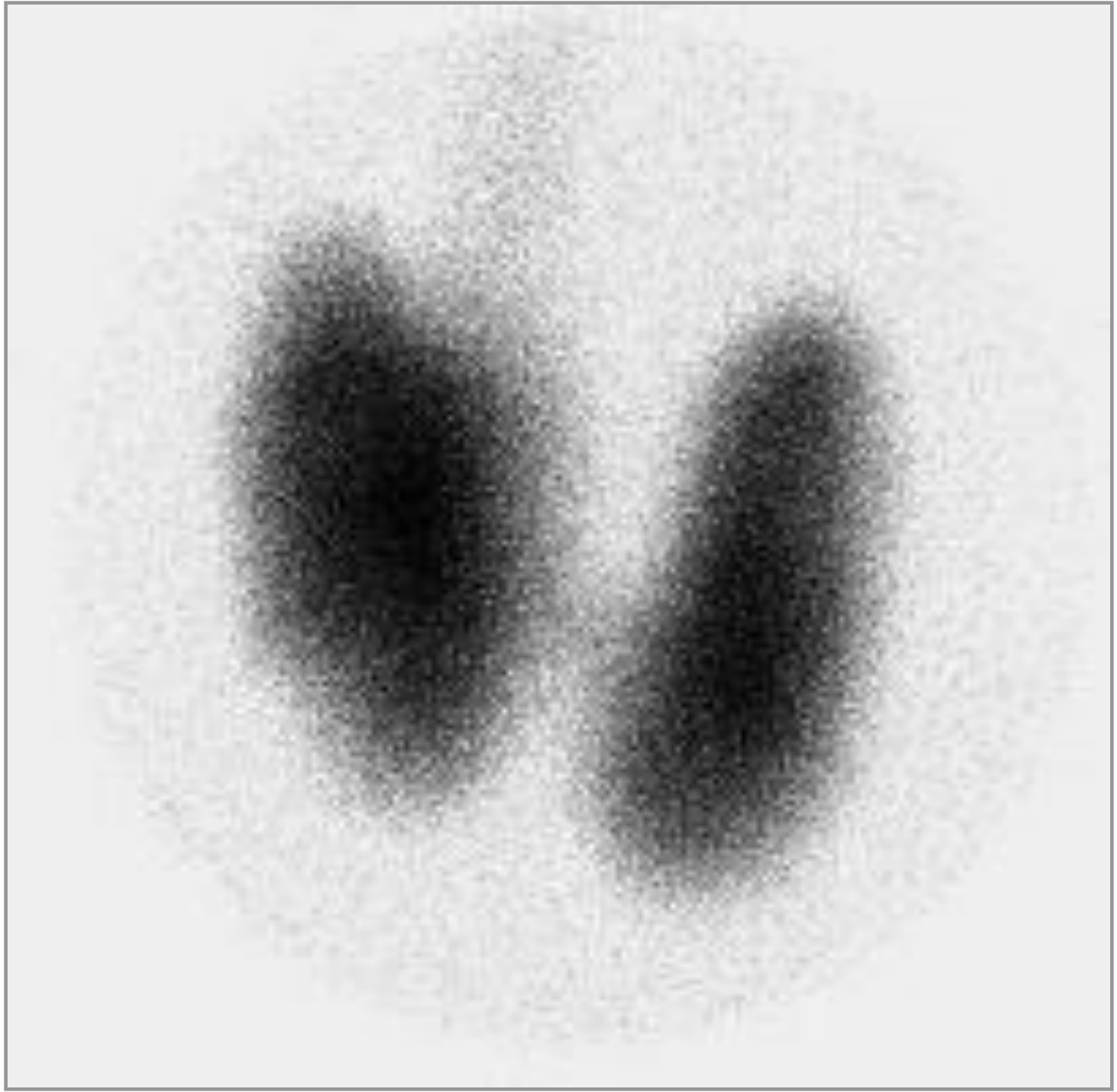
Follicular cell traps Iodine and organifys it to be incorporated with thyroid hormone.

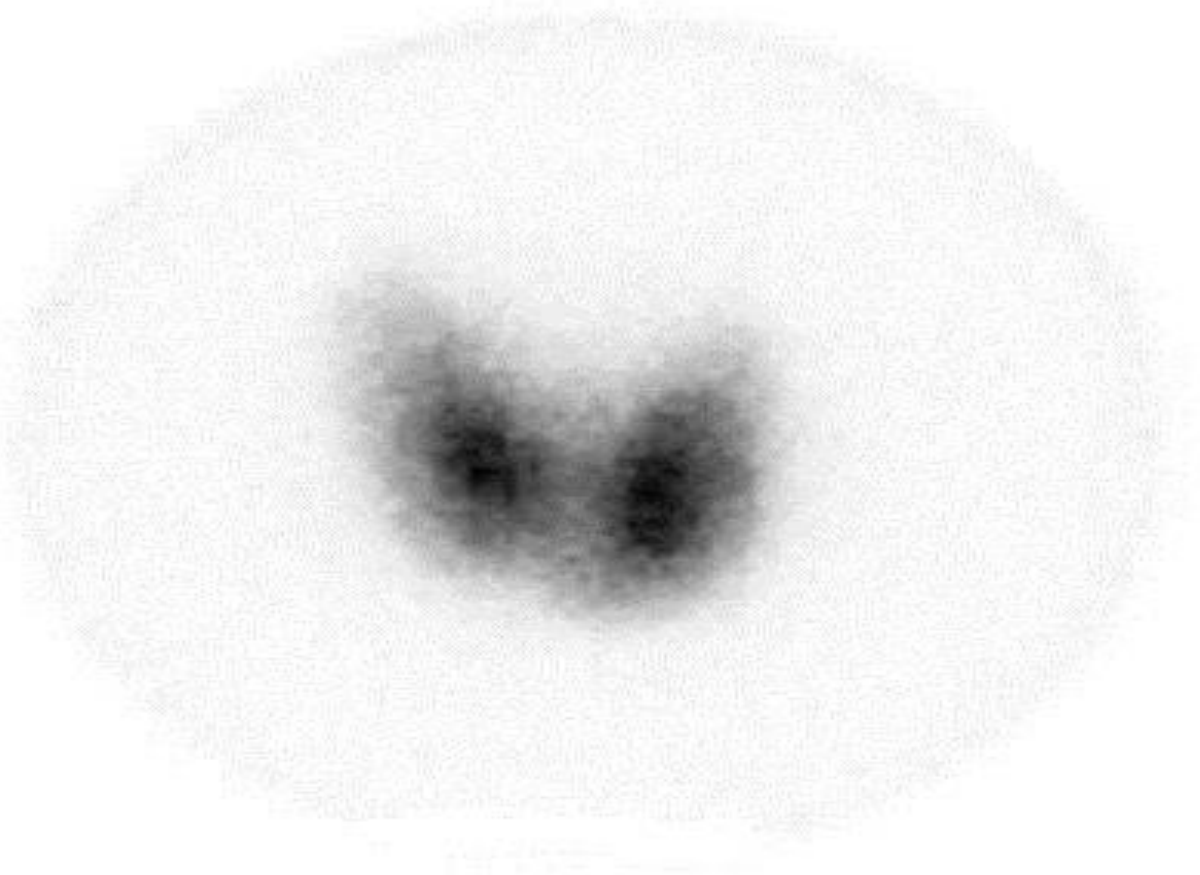
Uptake are obtained after 24 hours

- Measure photons in the given RAI by a special probe (uptake probe) just before taking RAI.
- After 24 hours, measure photons in the neck (thyroid gland).
- Calculate % of photons concentrated in thyroid gland.

Norma range = 10 – 30%

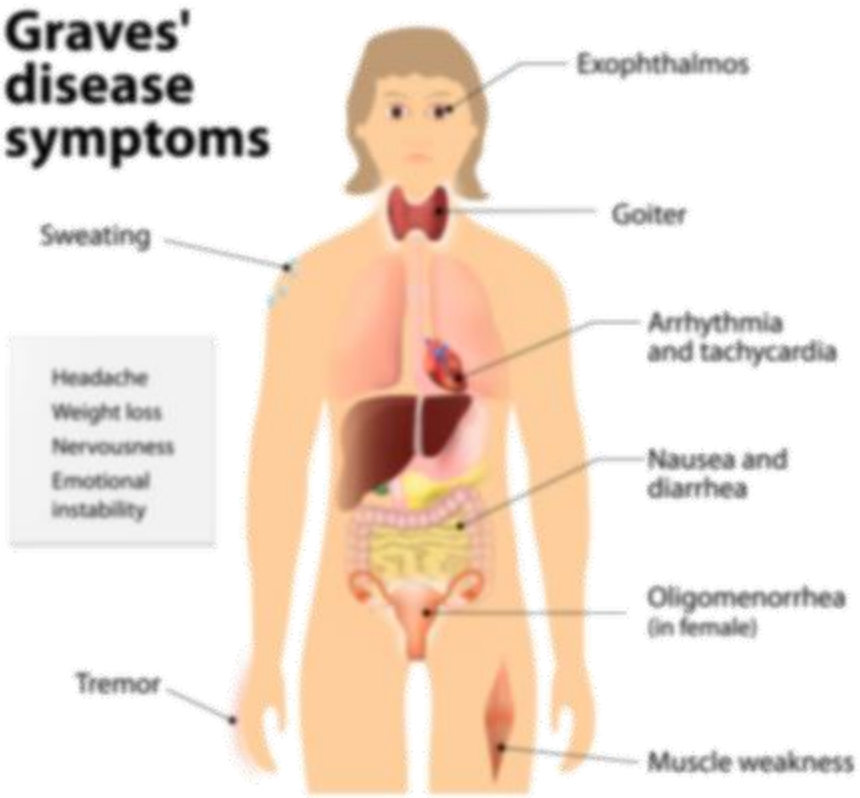


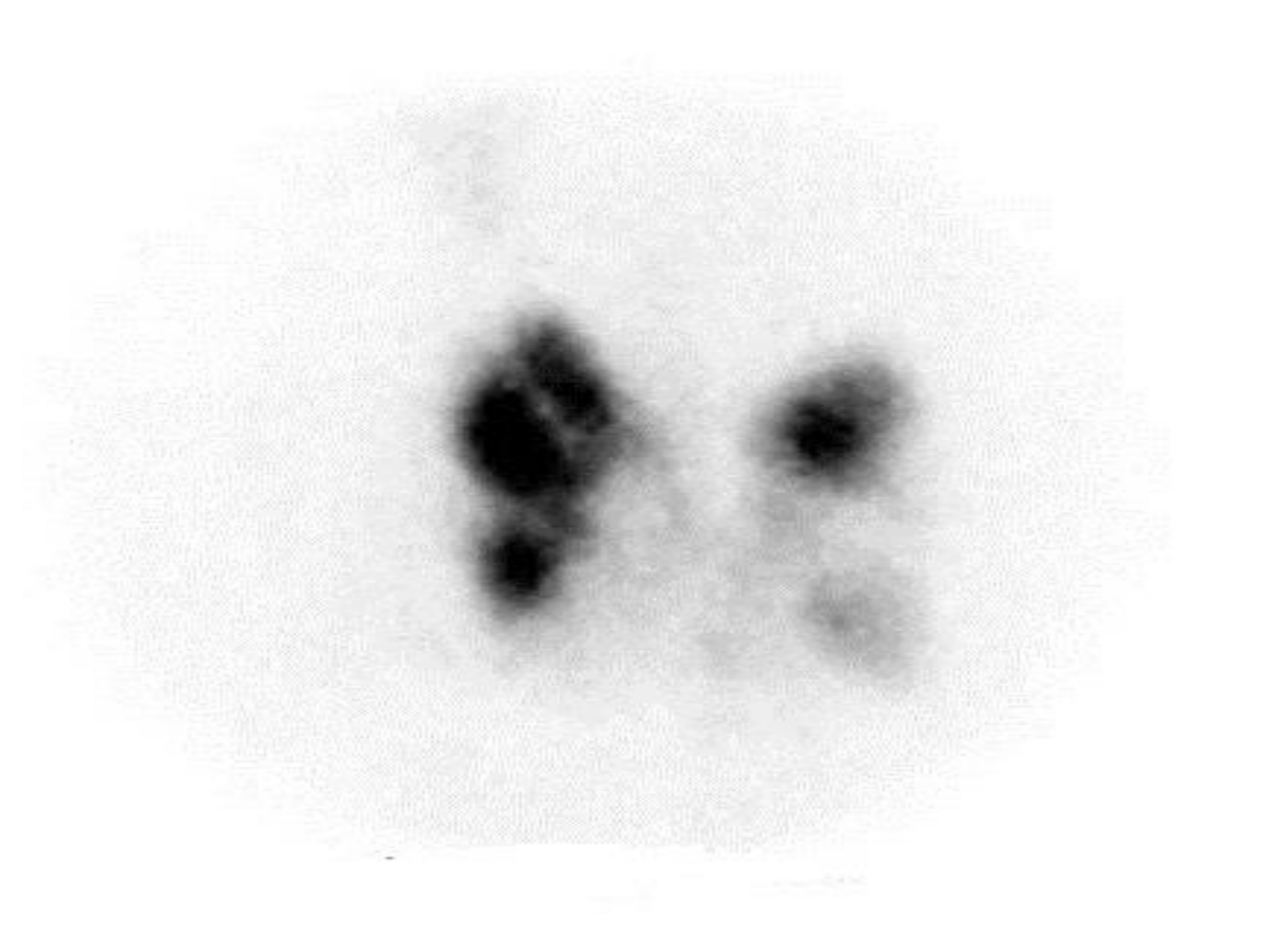


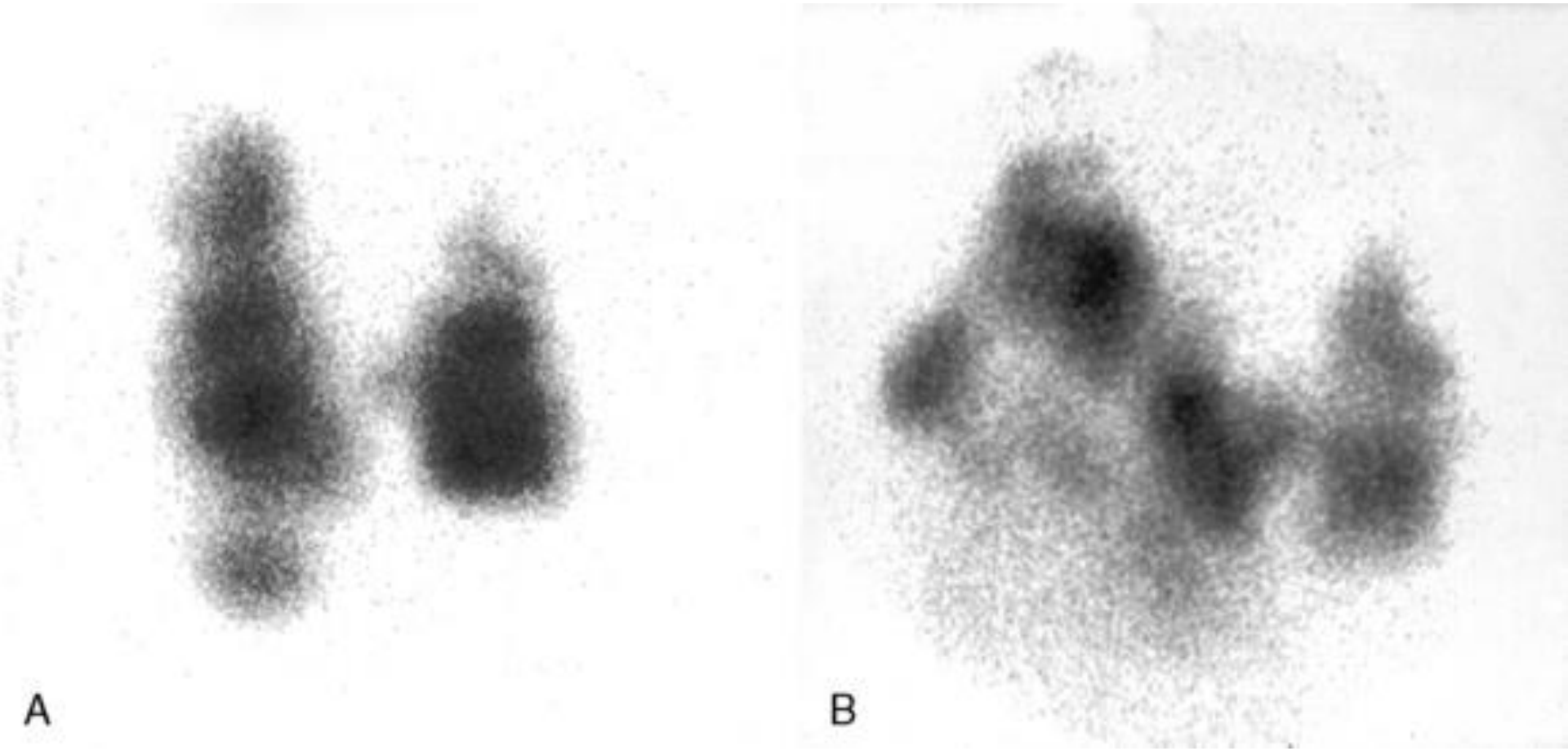


Graves' Disease

- Also known as diffuse toxic goiter
- Diffuse enlargement of thyroid gland
- Homogeneous or diffuse uptake
- No significant focal abnormalities (nodules)
- 24-hour RAIU is elevated, typically above > 30% (usually above 60%)
- Confirmed by TSH Receptor Antibody (TRAb)






A
B

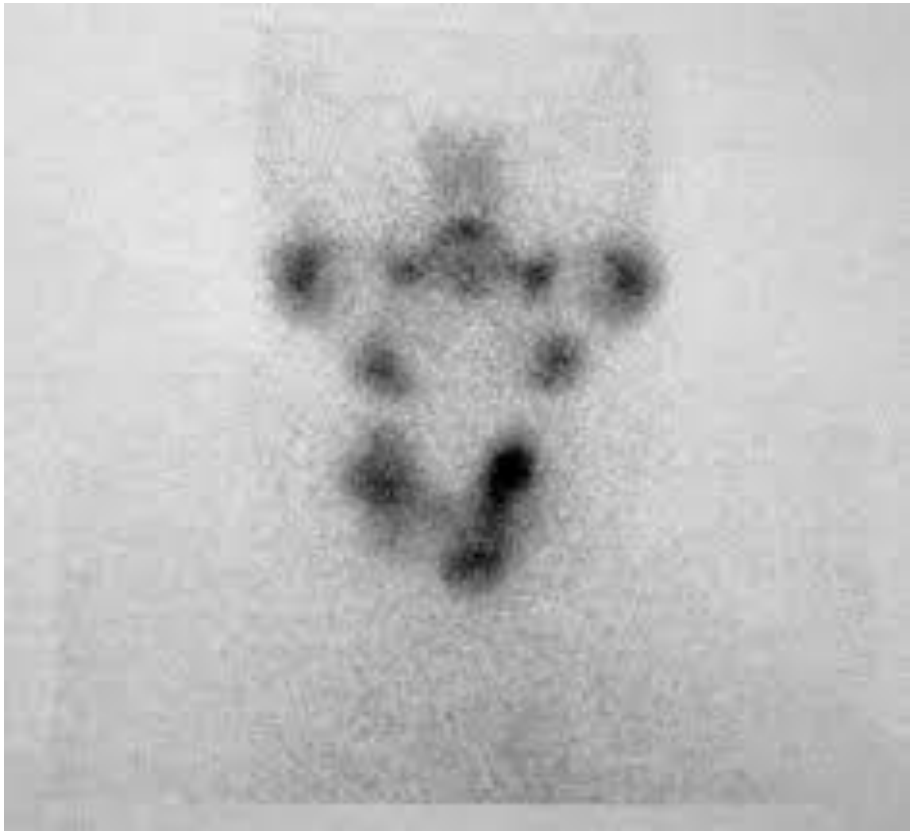
Toxic or Autonomous Multinodular Goiter

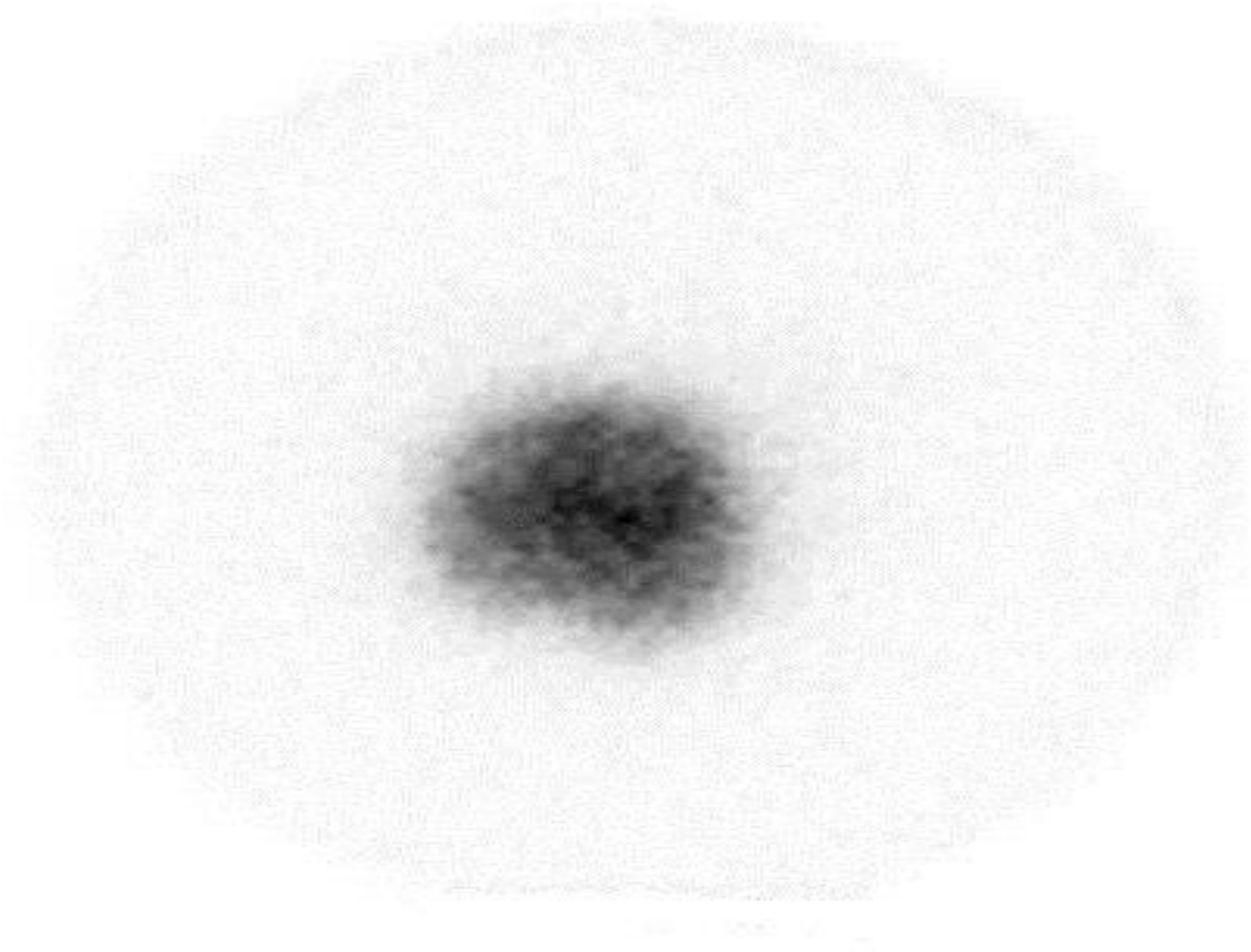
Also known as Plummer disease

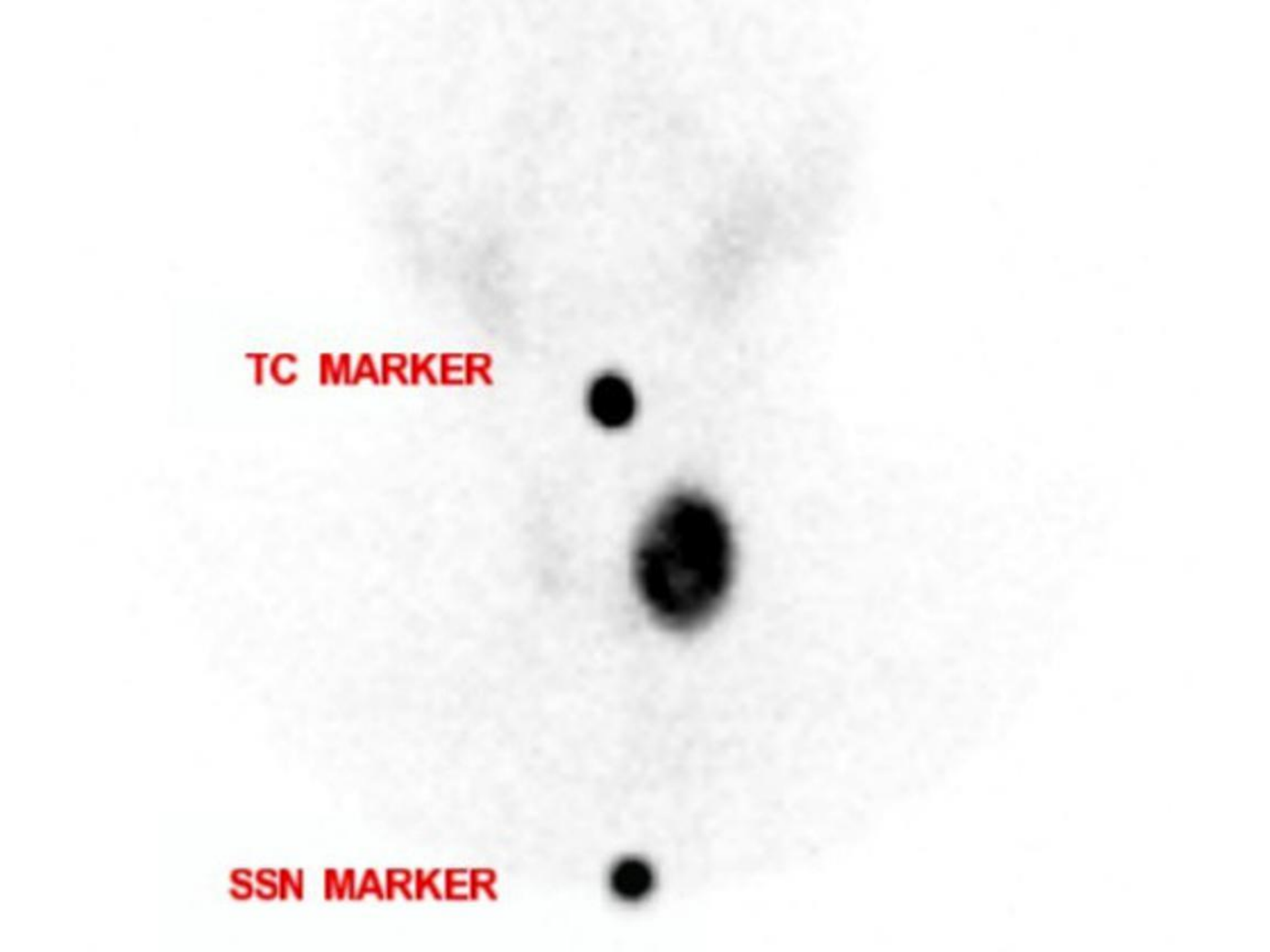
Inhomogeneous or heterogeneous uptake in thyroid gland.

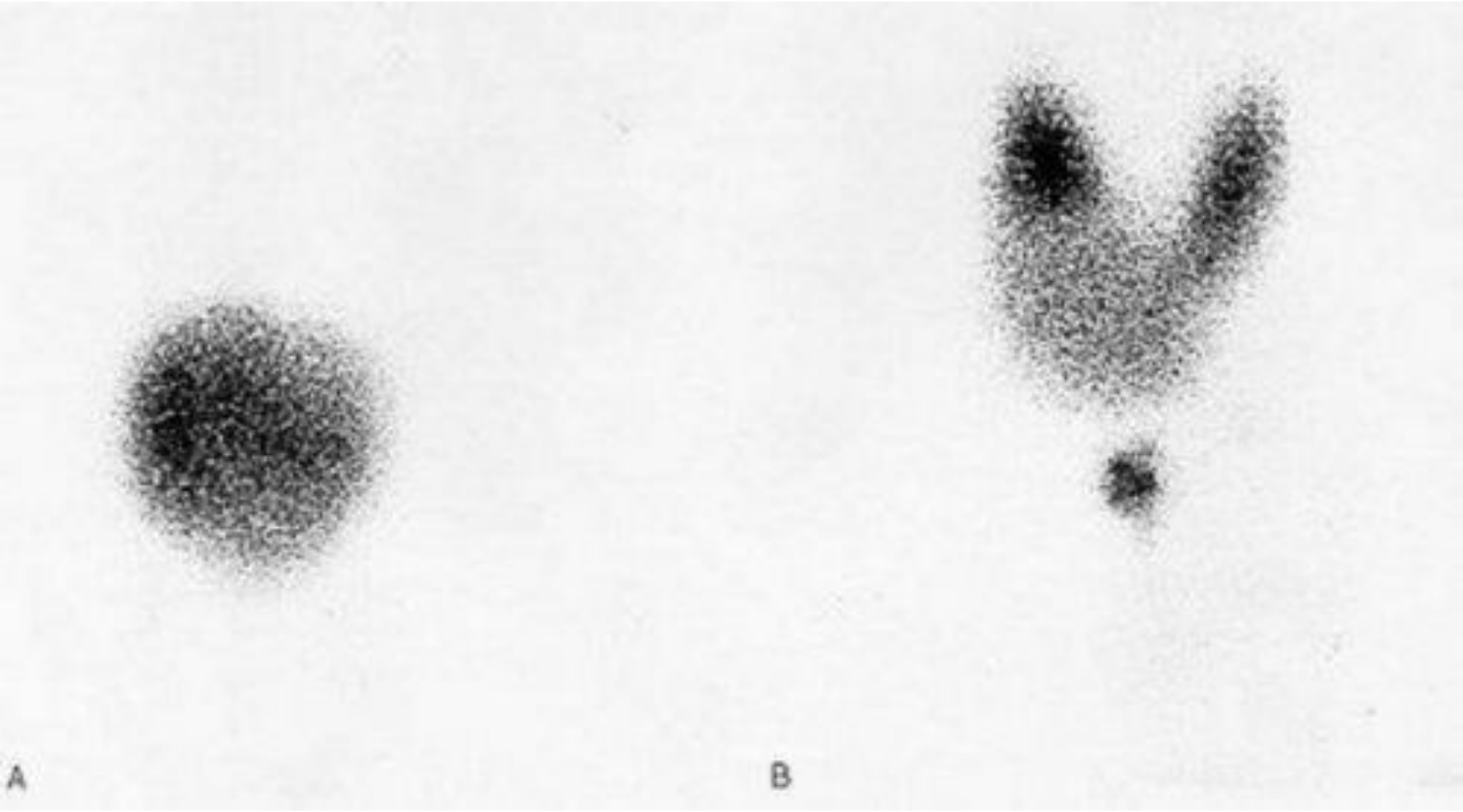
Multiple cold and/or hot nodules in both thyroid lobes.

24-hour RAIU is usually mildly elevated > 30% (usually between 40% and 50%)






TC MARKER
SSN MARKER

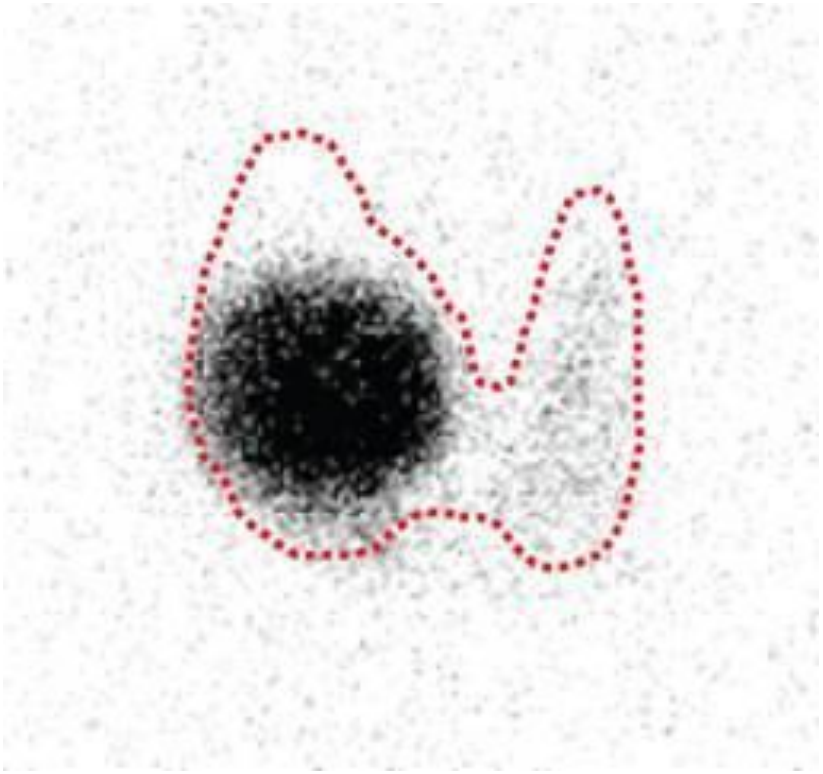

A
B

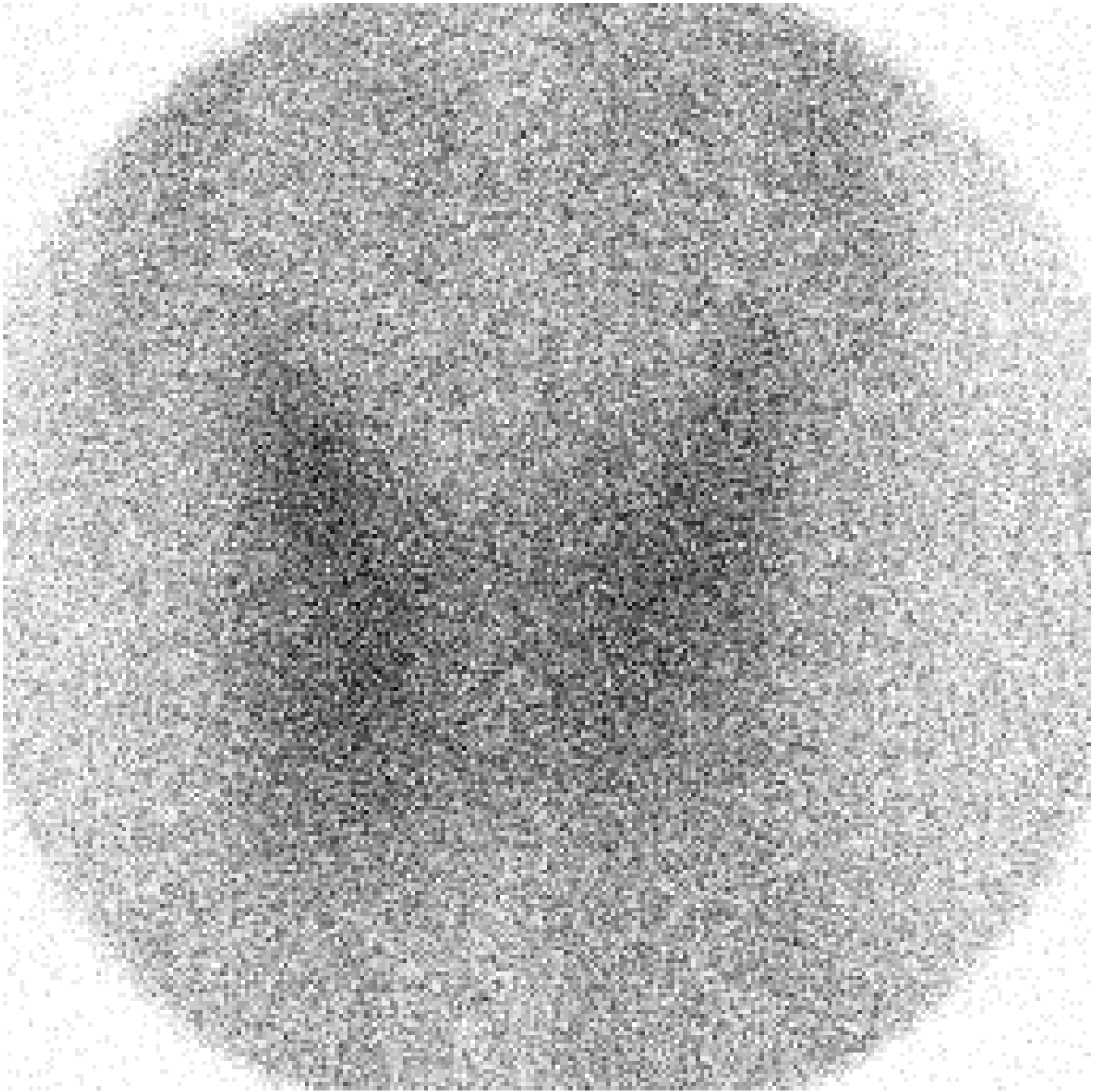
Toxic Adenoma

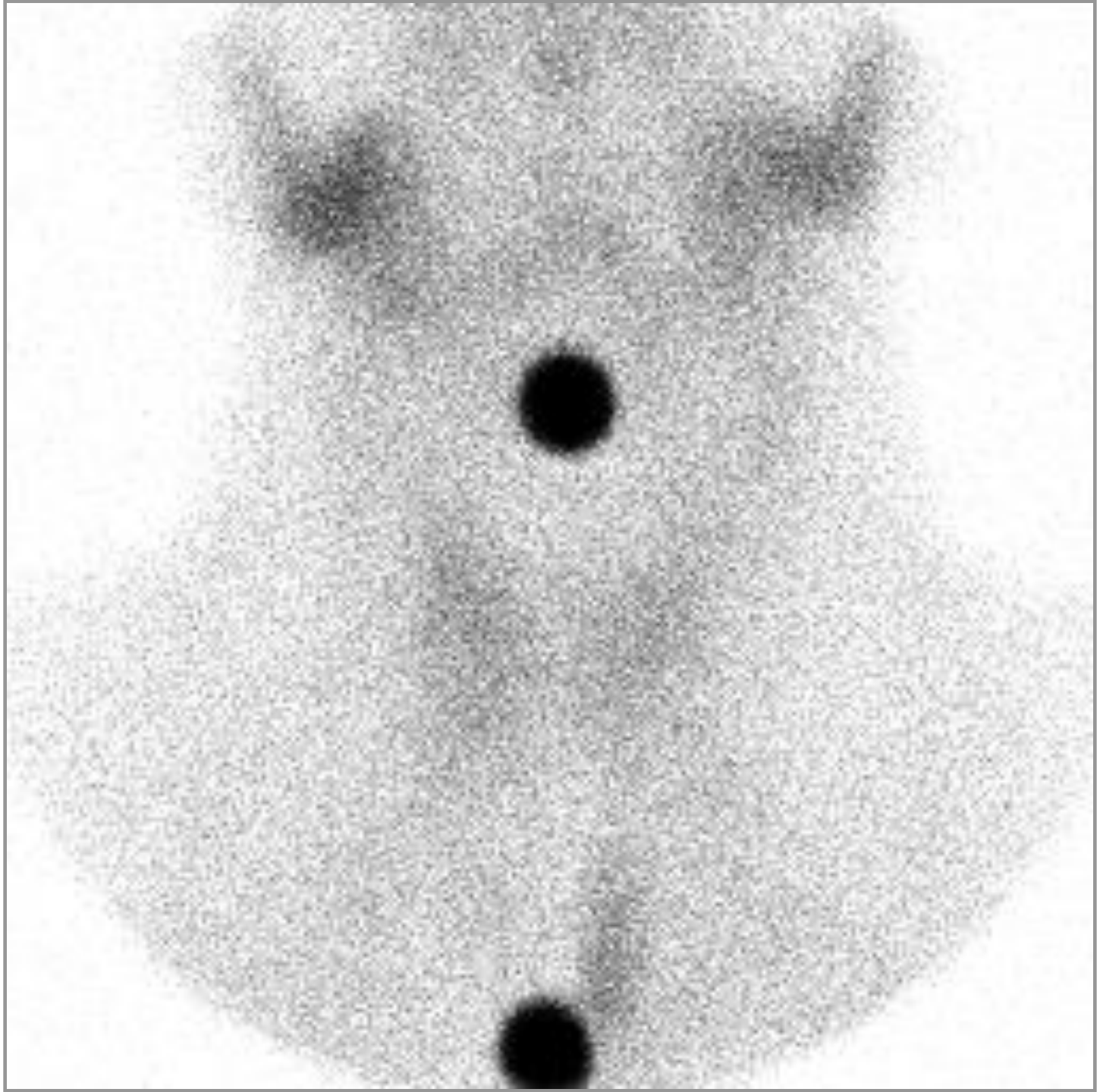
Single hot nodule (independent of TSH or autonomous).

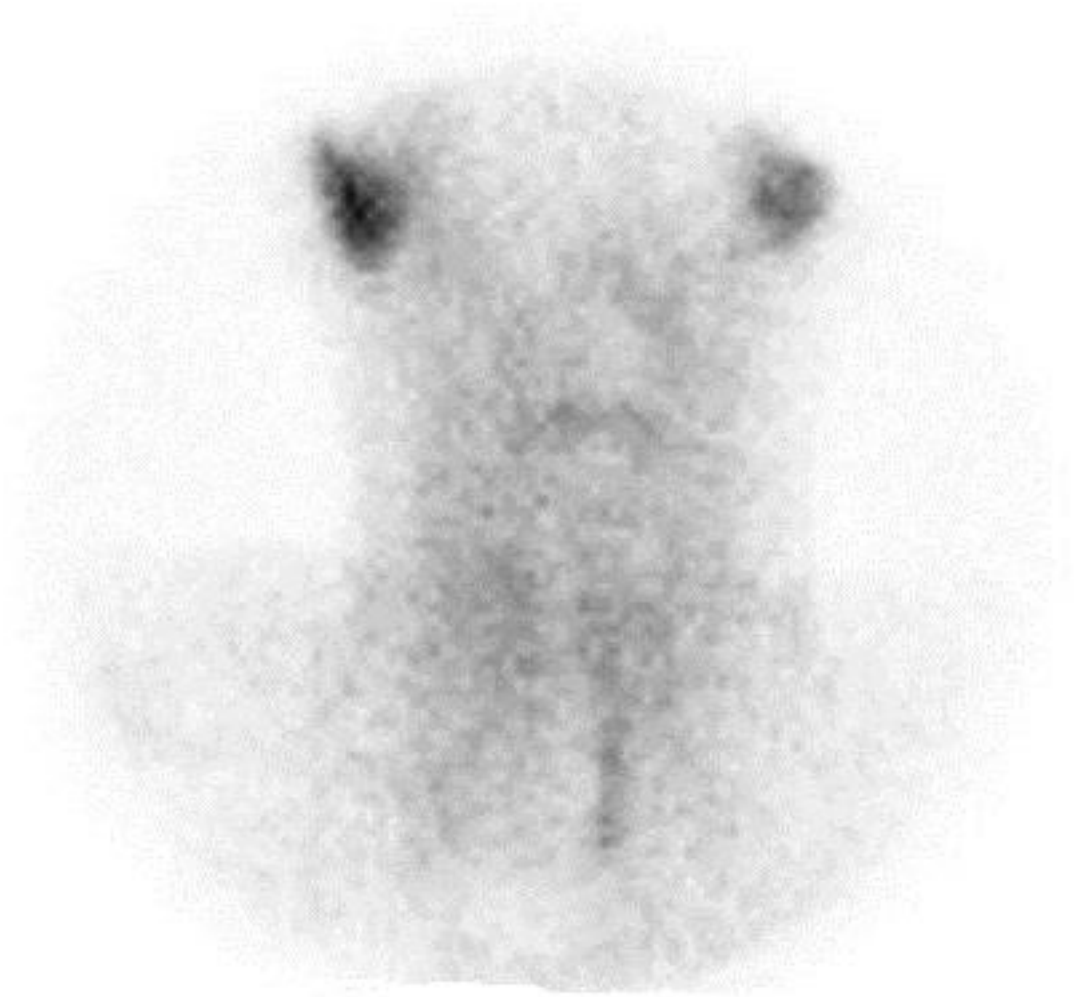
Rest of thyroid gland is poorly visualized due to low TSH level (TSH dependent).

24-hour RAIU is slightly elevated, > 30%.









Subacute thyroiditis

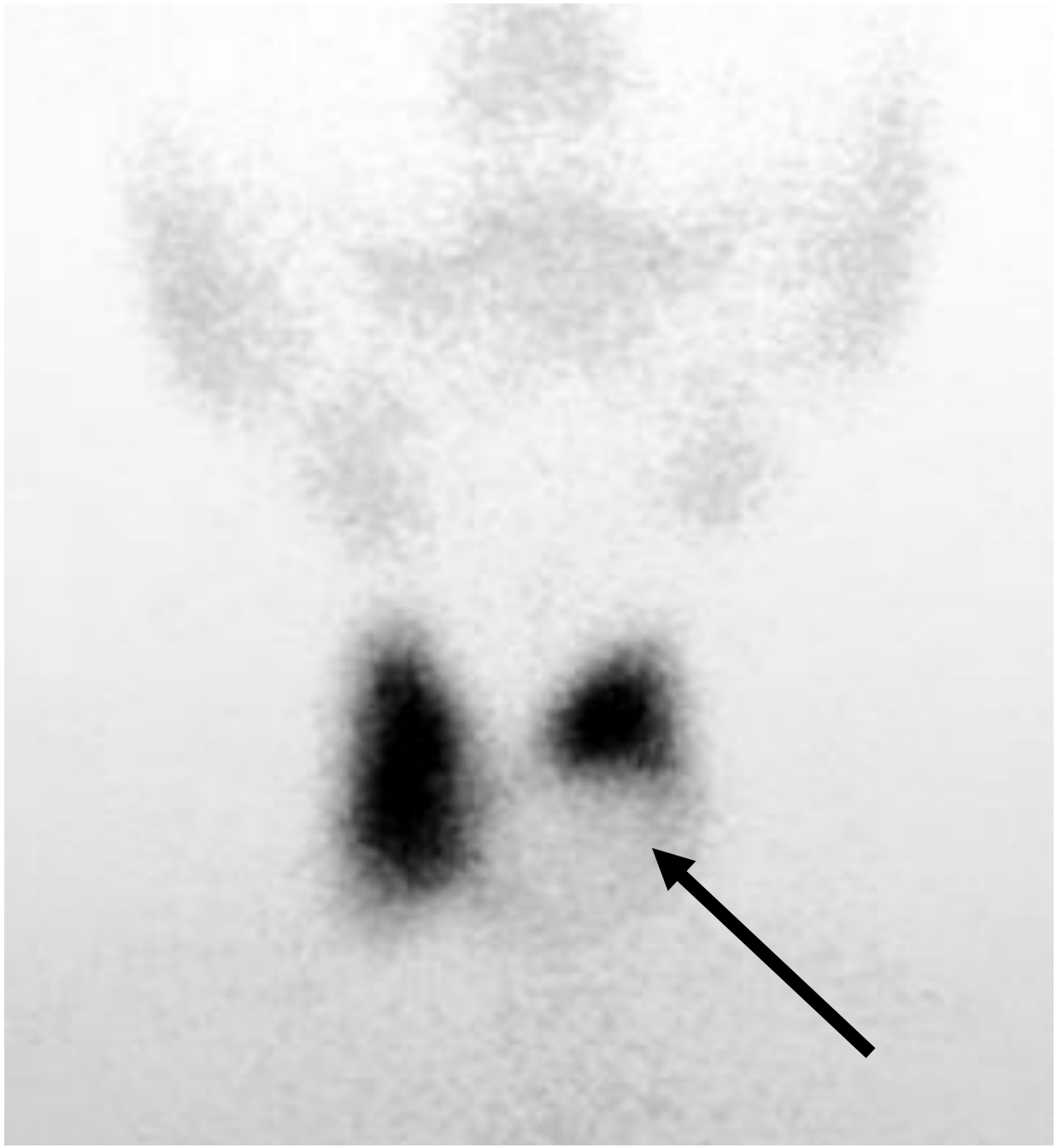
Inflammation of thyroid gland that leads to release of stored thyroid hormone due to follicular cell destruction

Heterogeneous uptake, could be mild or severe

In some cases, thyroid gland is not visualized

No significant focal abnormalities (nodules)

24-hour RAIU is low, usually < 5%.

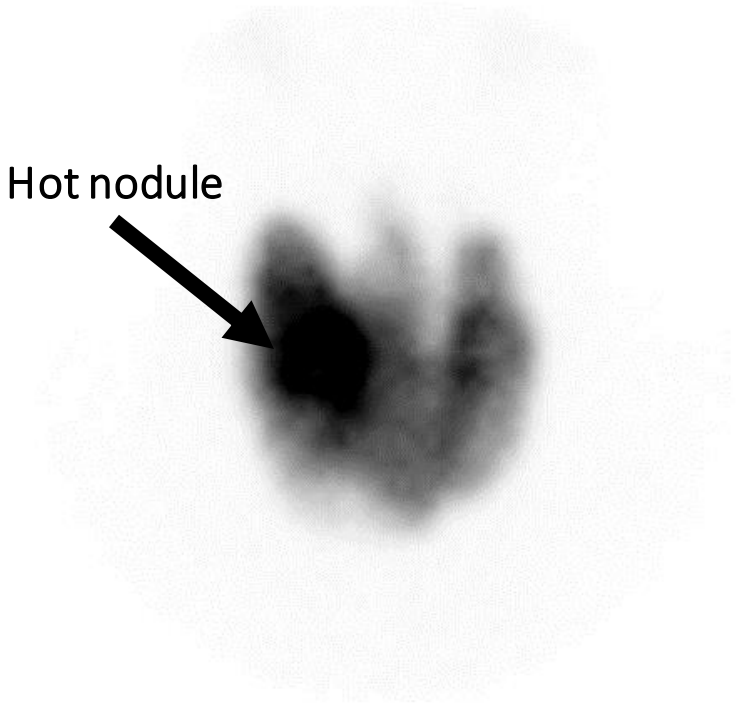


Cold nodules

Focally decreased uptake

15% malignancy risk

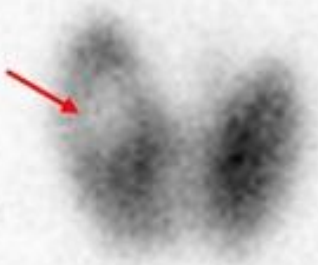
Next step is correlate with ultrasound to see if there is need for FNA or biopsy


Hot nodule

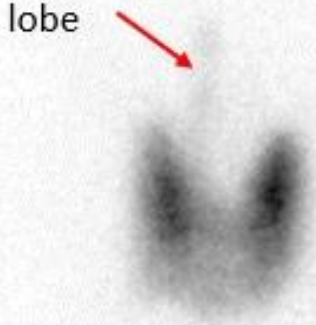
Hot nodules

Focally increased uptake

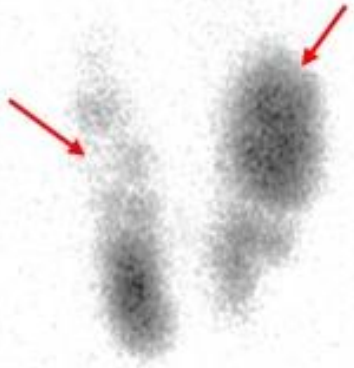
Next step is reassurance



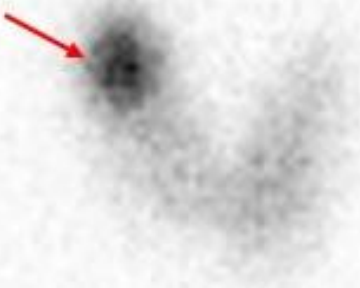
COLD NODULE



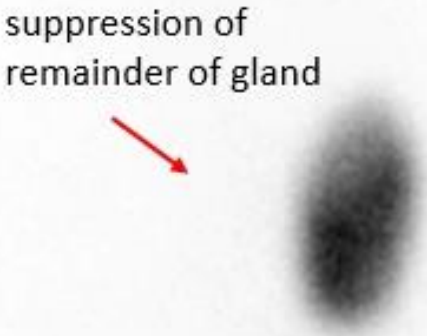
GRAVE DISEASE



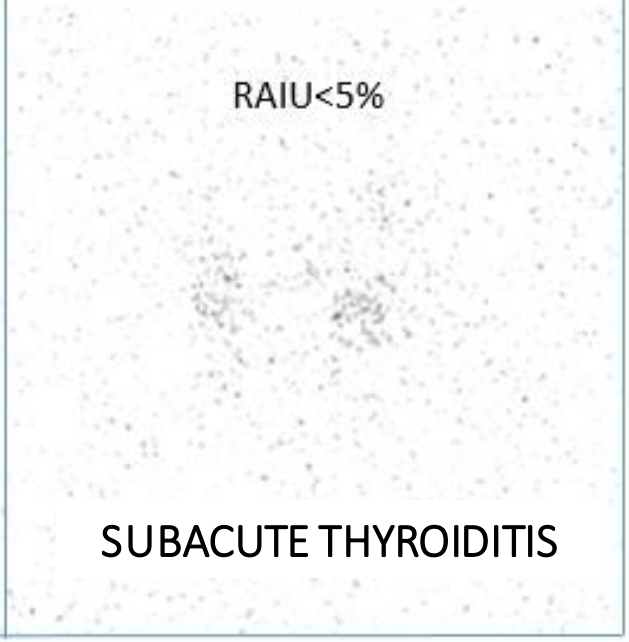
TOXIC MULTINODULAR



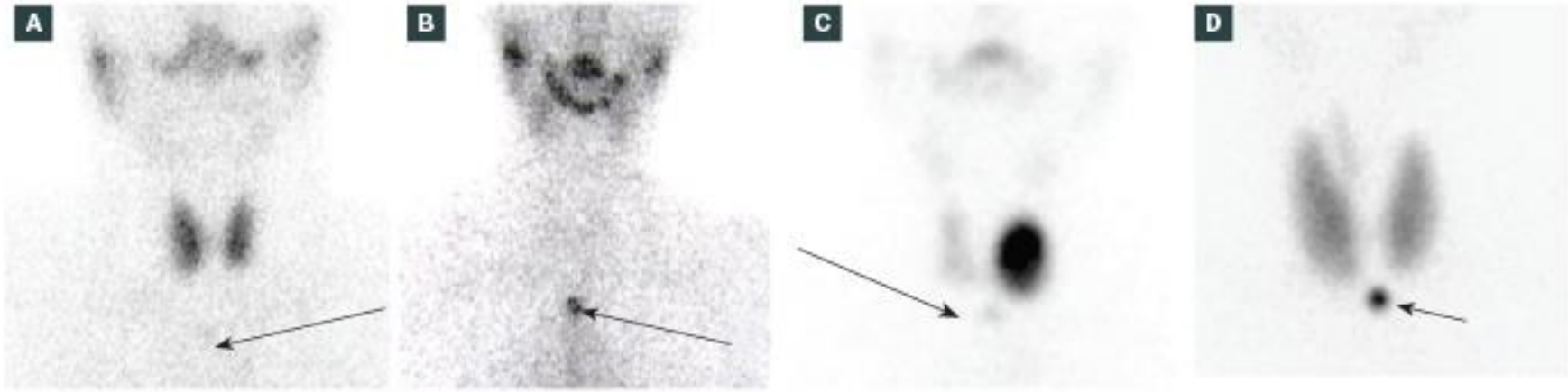
HOT NODULE



TOXIC ADENOMA



SUBACUTE THYROIDITIS



Subacute

Diagnosis	Normal thyroid	Thyroiditis	Left toxic adenoma	Graves' disease
Thyroid uptake	Diffuse, symmetrical	Low or absent	Increased in nodule Contralateral reduced	Diffuse, symmetrical
Salivary gland uptake	Normal	Appears prominent	Appears reduced	Appears reduced

Therapeutic Options

- Radioactive Iodine Treatment
  - As primary or secondary after medications or surgery
- Pharmacologic
  - Thioureas (Anti-Thyroid Drugs)
    - *Propylthiouracil (PTU)*
    - *Methimazole (MZ)*
    - *Carbimazole (CBZ)*
  - Symptomatic control with beta blockers
  - Corticosteroids
  - Stable Iodide (SSKI, etc.)
  - Rituximab
- Surgery

^{131}I Treatment

- Beta-emitting radionuclide
- Energy level 606 keV (beta) and 364 keV (gamma)
- Produced by reactor (fission)
- Half life of 8 days
- Indications
  - Hyperthyroidism
    - *Graves' disease*
    - *Toxic multinodular goiter*
    - *Toxic adenoma*
  - Differentiated thyroid cancer
    - *Papillary thyroid cancer*
    - *Follicular thyroid cancer*

Myocardial Perfusion

Radiopharmaceuticals

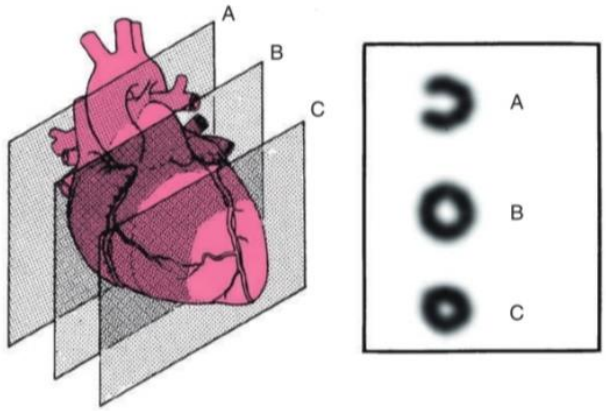
^{99m}Tc-sestamibi

^{99m}Tc-tetrofosmin

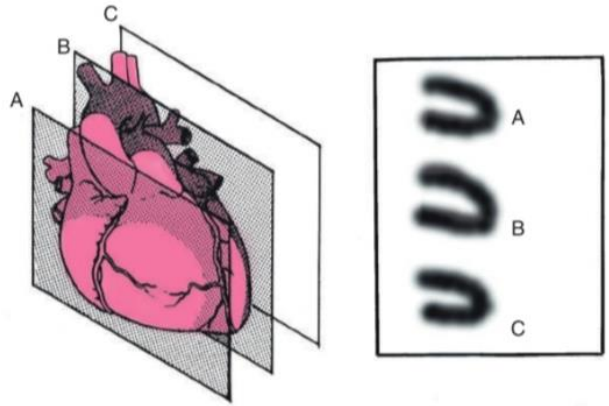
^{201}Thalium

Methods of Inducing Stress

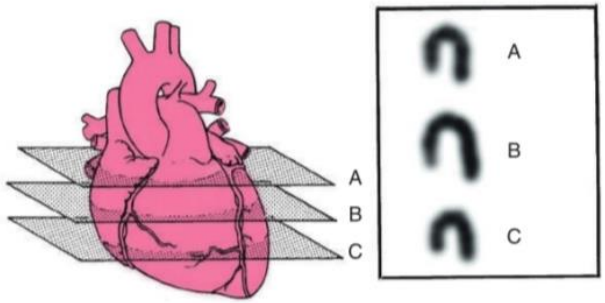
- Pharmacologic
  - Adenosine
  - Dobutamine
  - Dipyridamole
  - Regadenosone
- Exercise
  - Treadmill
  - Bicycle



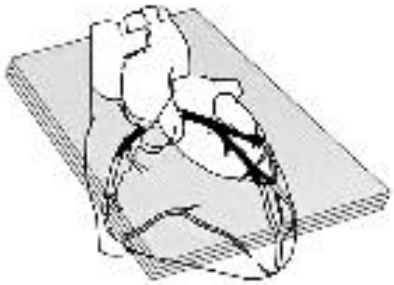
• **Fig. 5.8** Short-Axis Anatomy and Images. Short-axis sections through the left ventricle from the base of the heart to the apex are shown with corresponding single-photon emission computed tomography slices of the myocardium. Note the considerable thinning of the proximal septal wall in plane *A* (the base of the heart) as a result of the membranous septum.



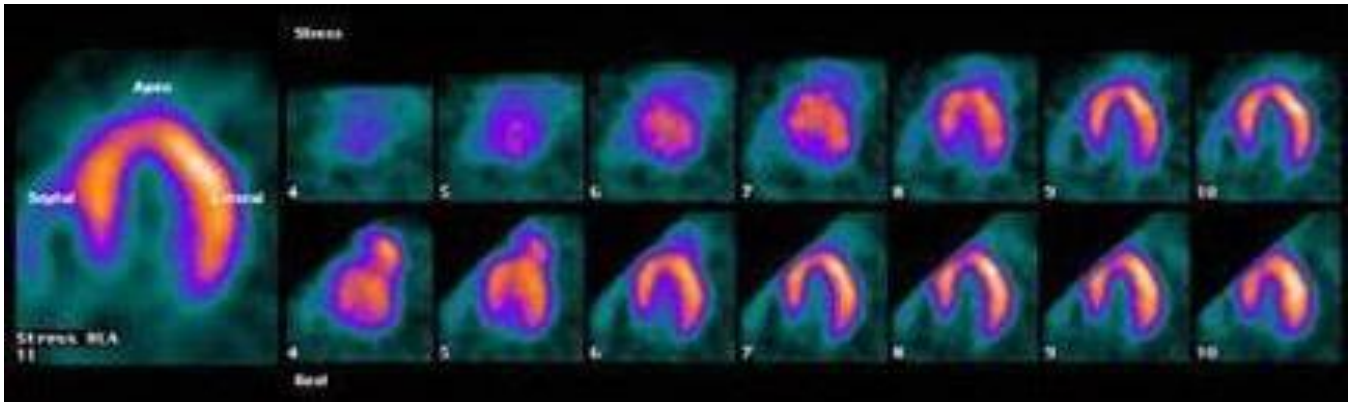
• **Fig. 5.9** Vertical Long-Axis Anatomy and Images. Vertical long-axis sections through the left ventricle from septum to free (lateral) wall are shown with corresponding single-photon emission computed tomography slices of the myocardium.

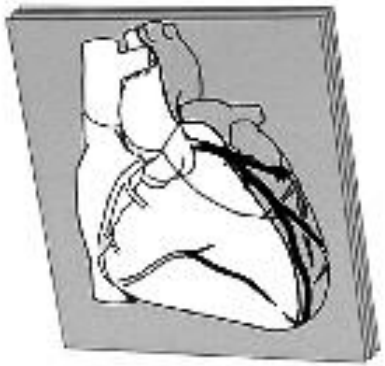


• **Fig. 5.10** Horizontal Long-Axis Anatomy and Images. Horizontal long-axis sections through the left ventricle from the anterior to the inferior wall are shown with corresponding single-photon emission computed tomography slices of the myocardium.



A


Stress
Apex
Septal
Lateral
Stress HLA
Rest



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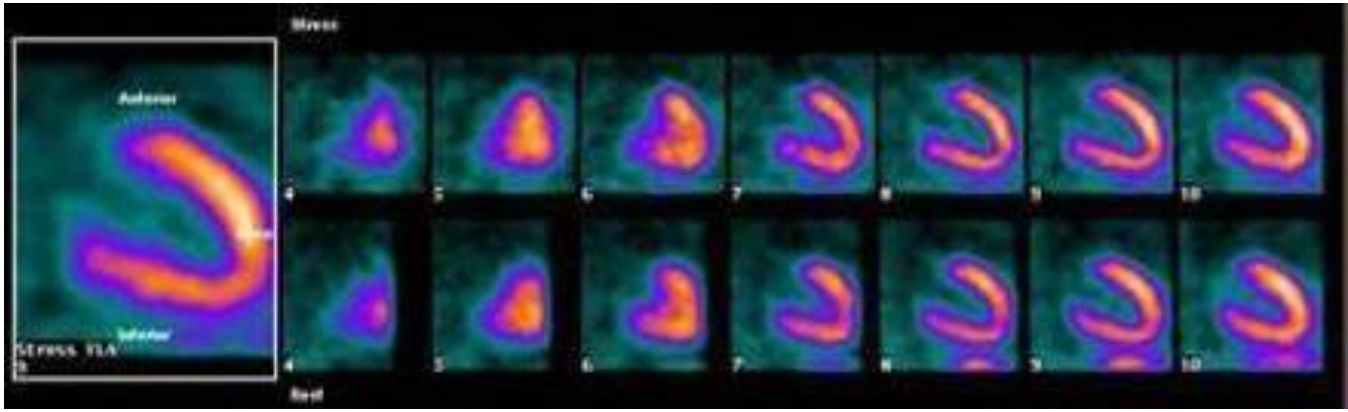
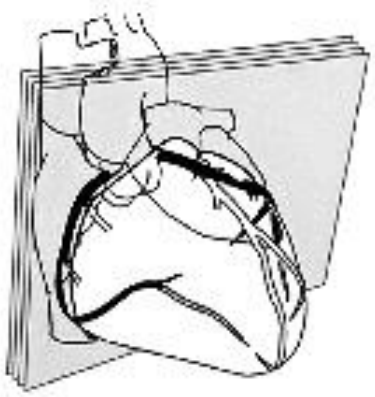
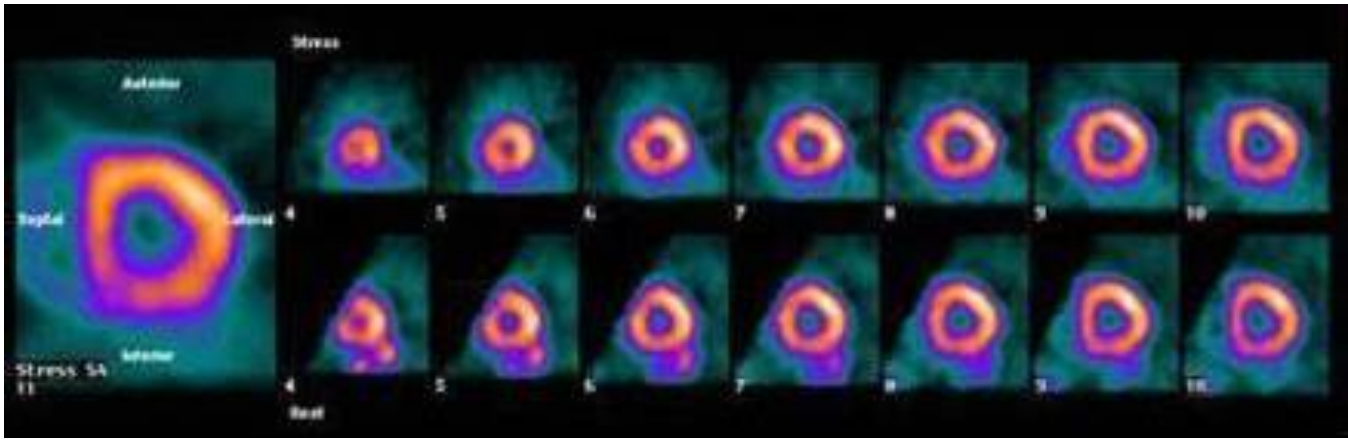
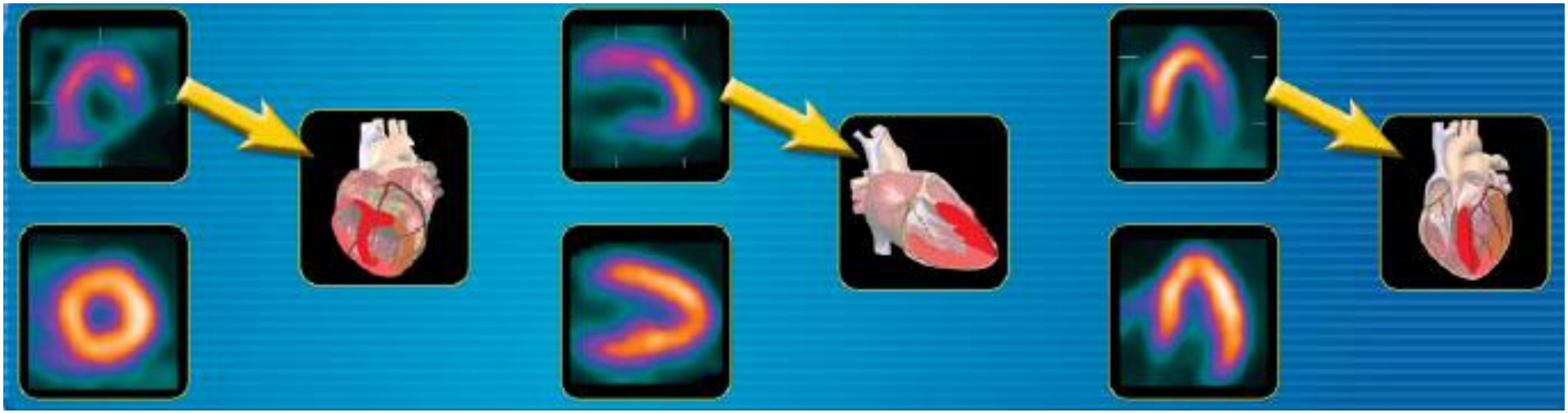
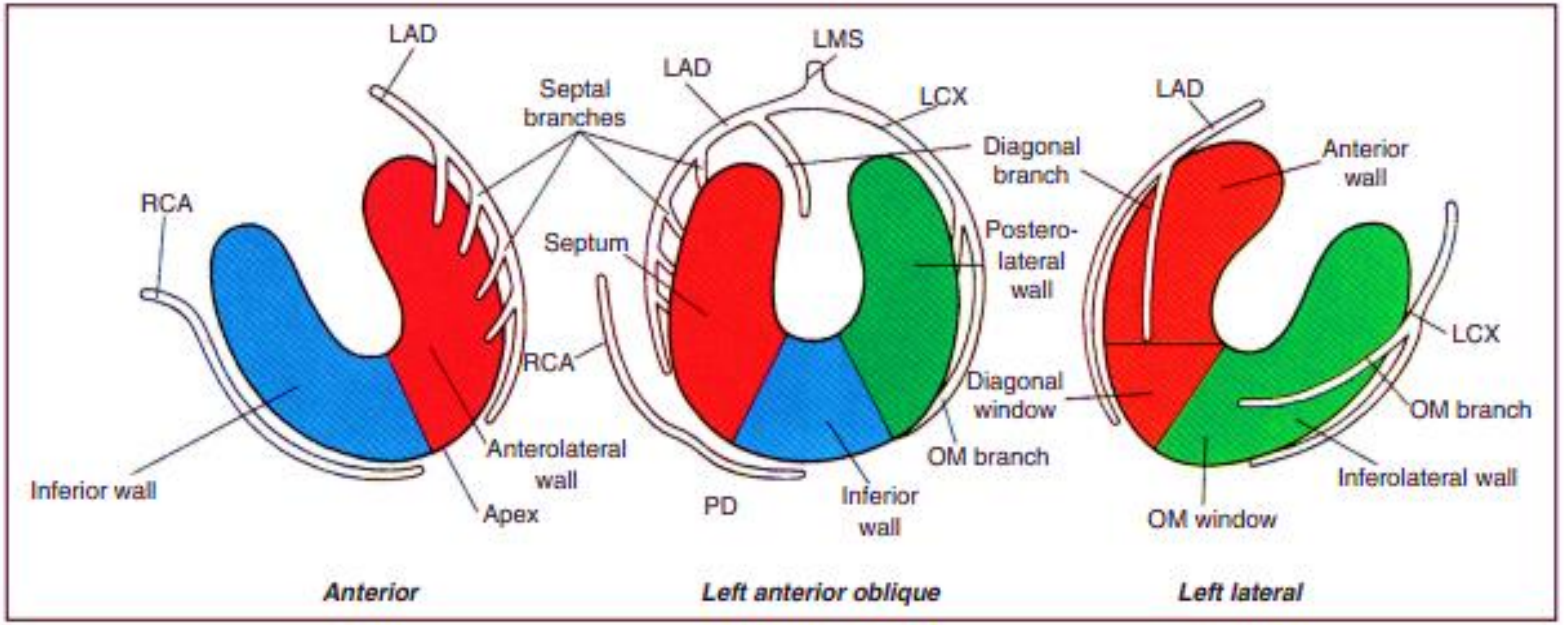

Stress
Anterior
Inferior
Stress VLA
Rest



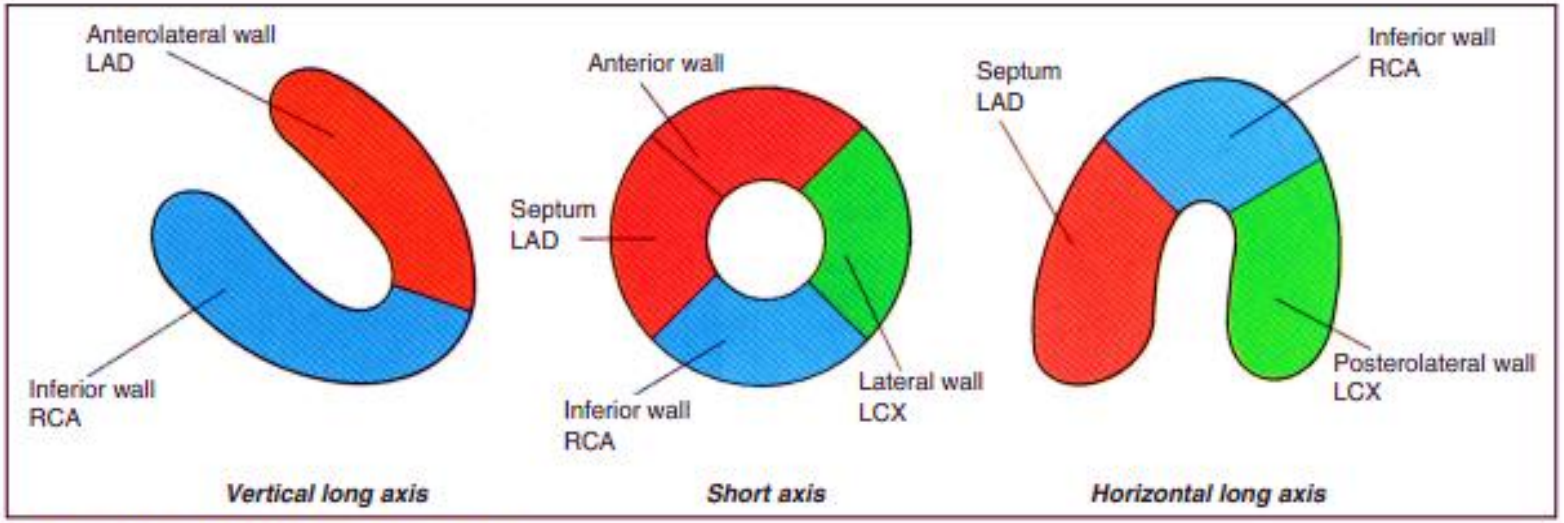
C


Stress
Anterior
Septal
Lateral
Inferior
Stress SA
Rest



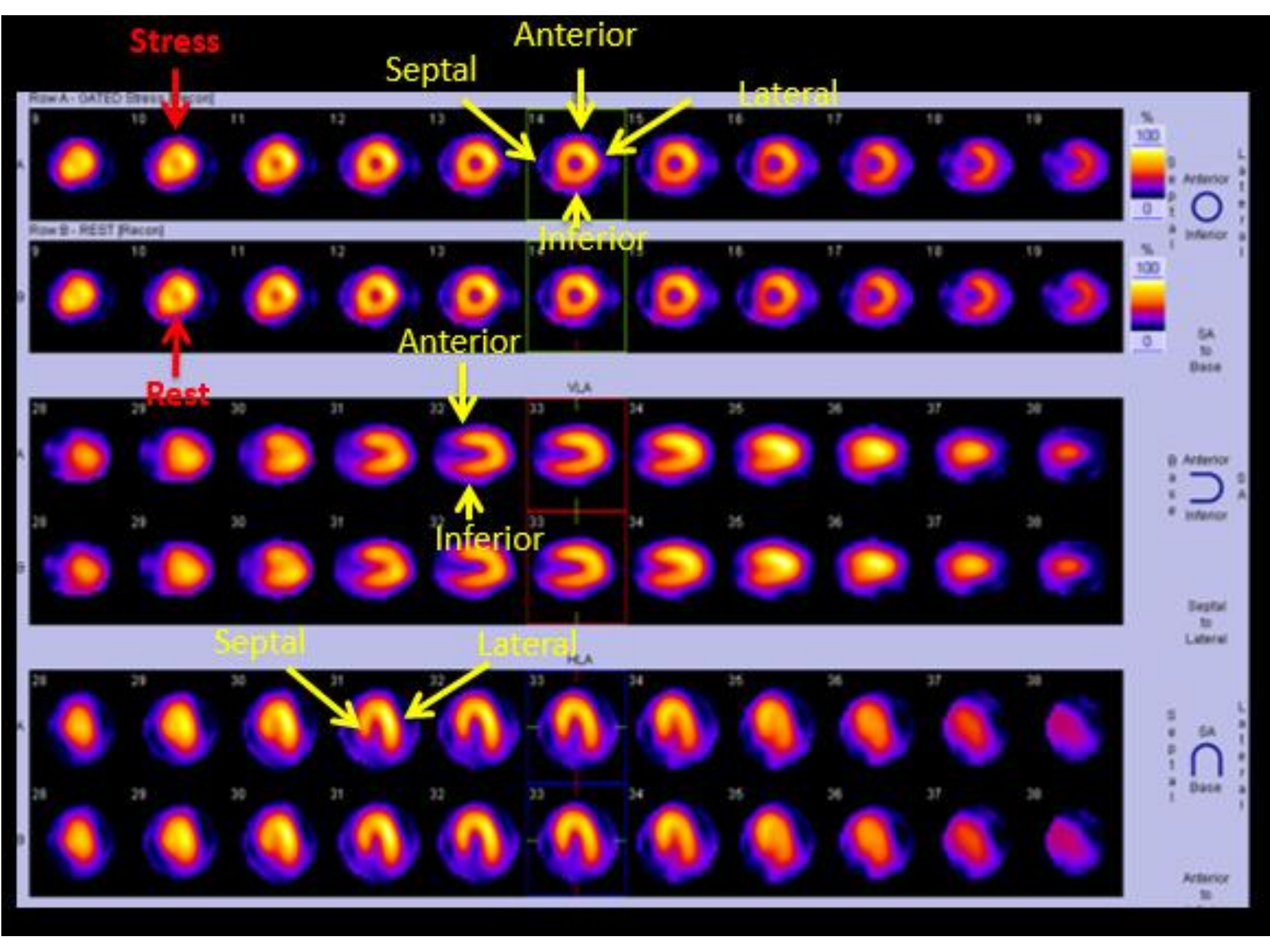


(**A**) *Coronary artery territories on planar views*

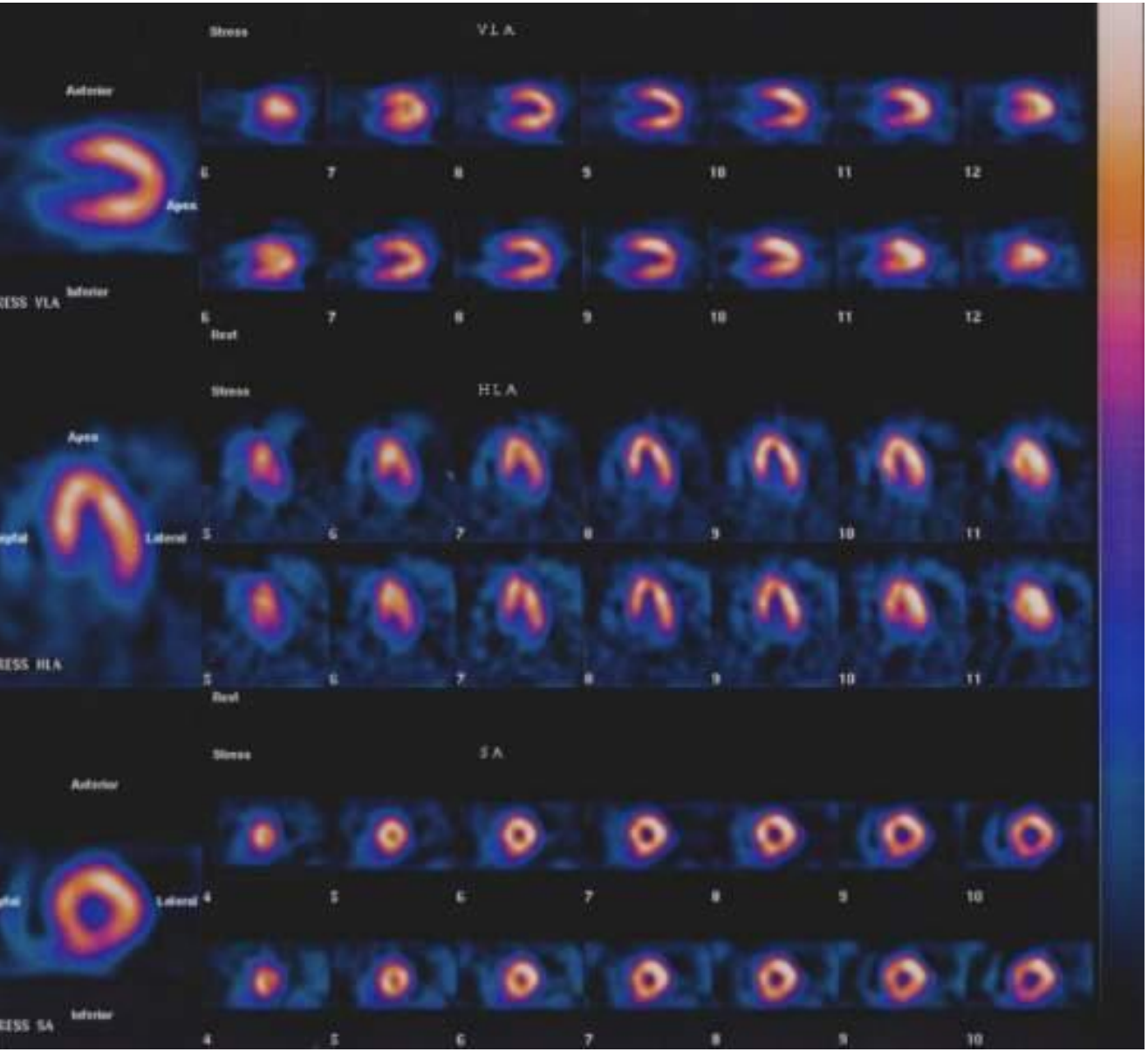


(**B**) *Coronary artery territories on SPECT views*

Figure 6.3 Normal coronary artery territories in the left ventricle corresponding to myocardial SPECT views.

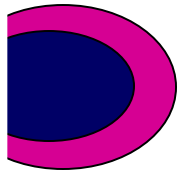

Stress
Anterior
Septal
Lateral
Inferior
Rest
Anterior
Inferior
Septal
Lateral

Normal



Stress

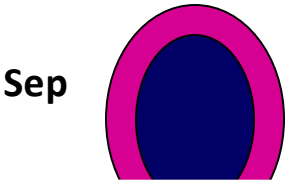
Rest



Septum → Lateral

Stress

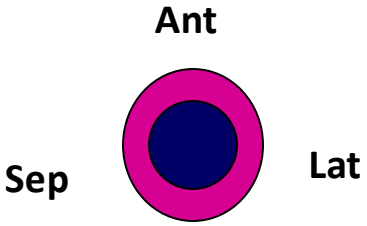
Rest



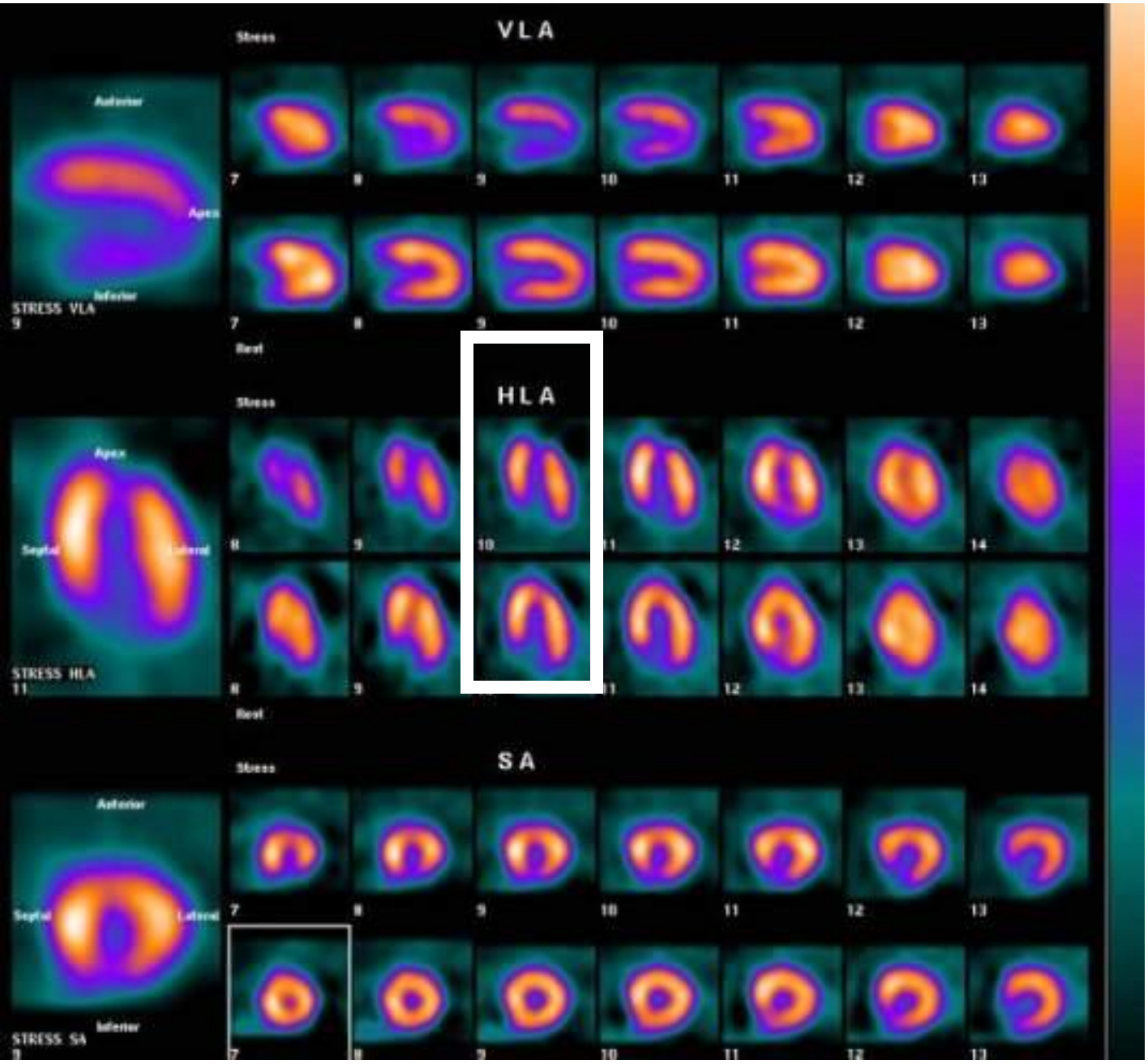
Inferior → Anterior

Stress

Rest



Apex → Base



Ant

Stress

Apex

Rest

Inf

Septum → Lateral

Apex

Stress

Sep

Lat

Rest

Inferior → Anterior

Ant

Stress

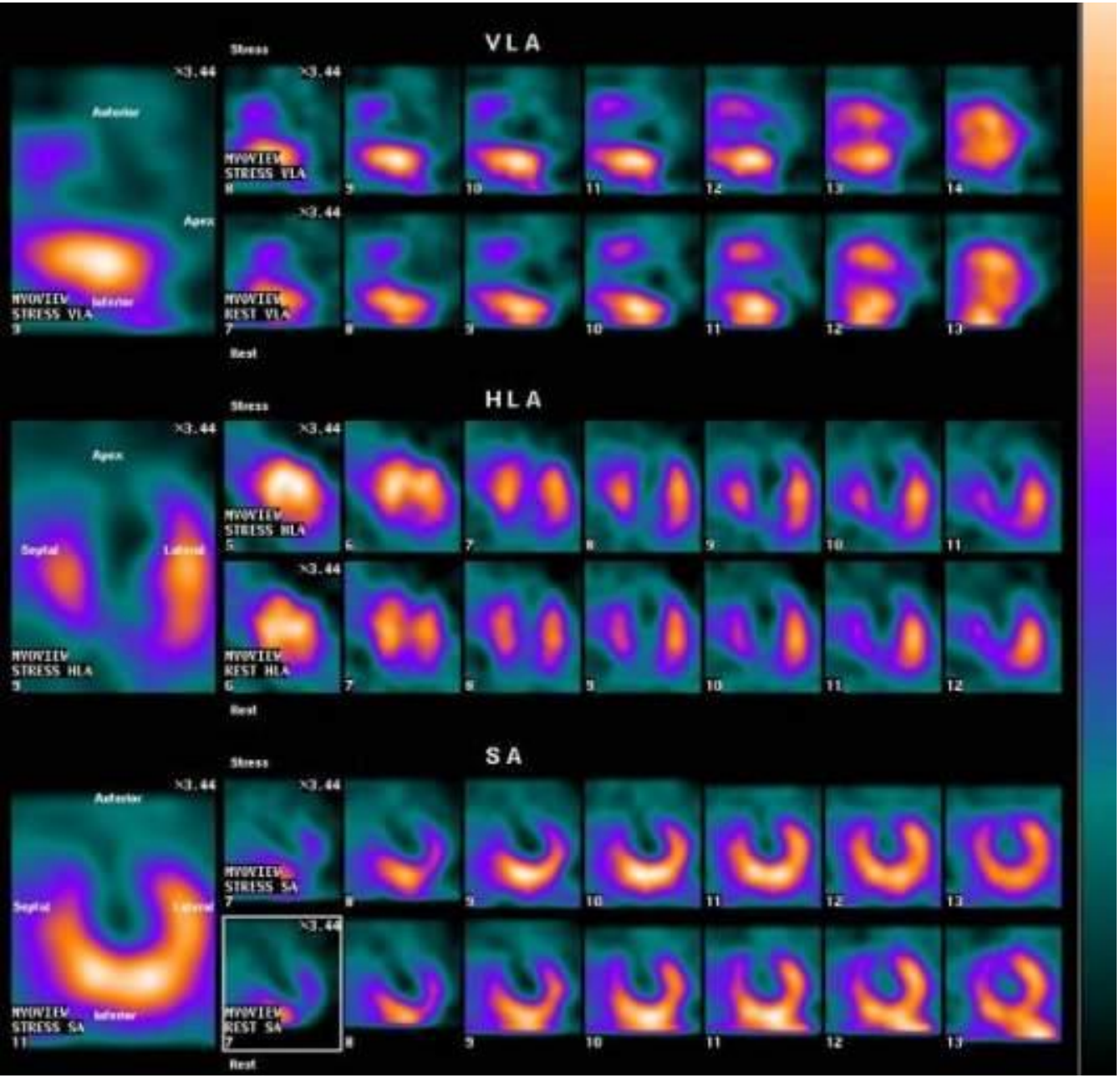
Sep

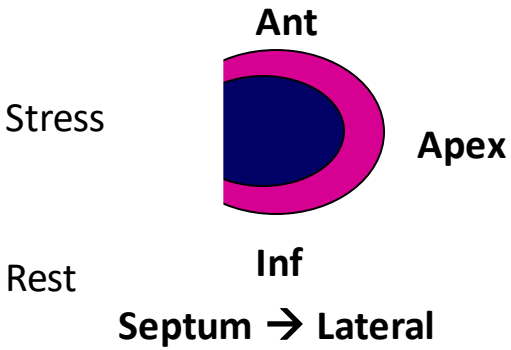
Lat

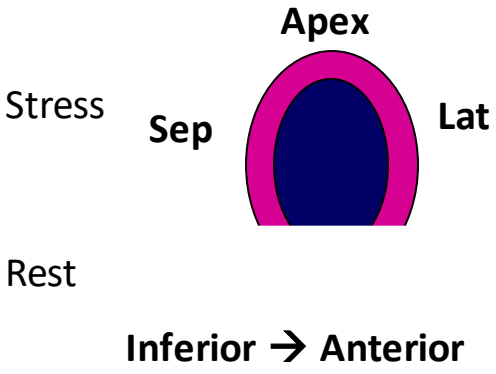
Rest

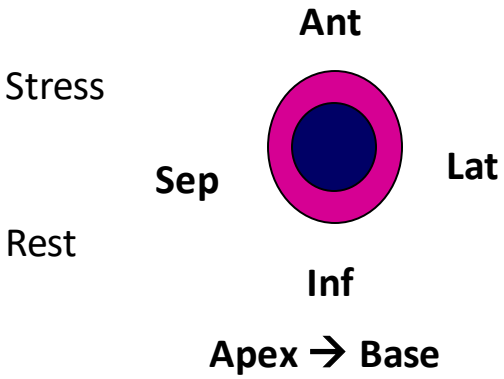
Inf

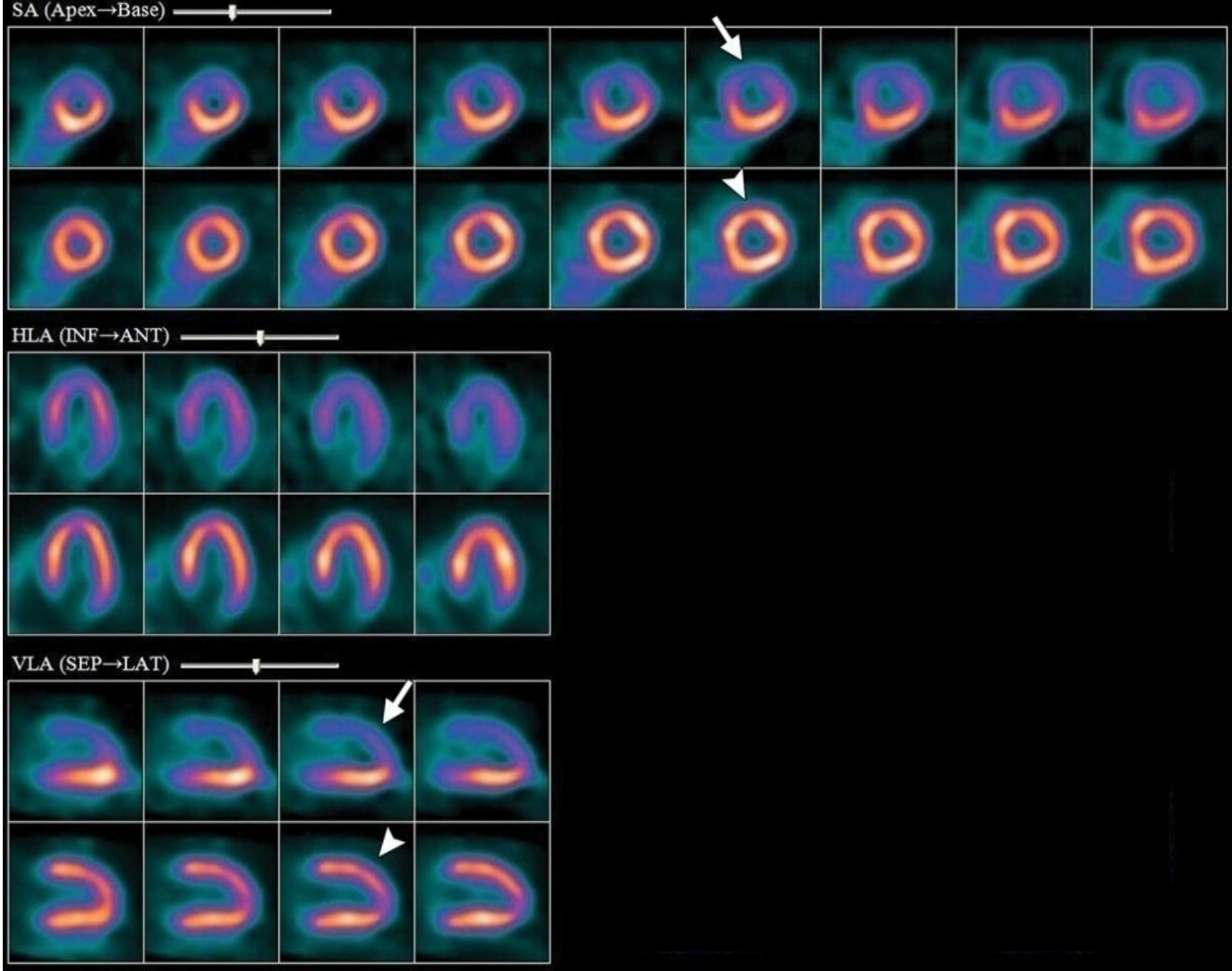
Apex → Base

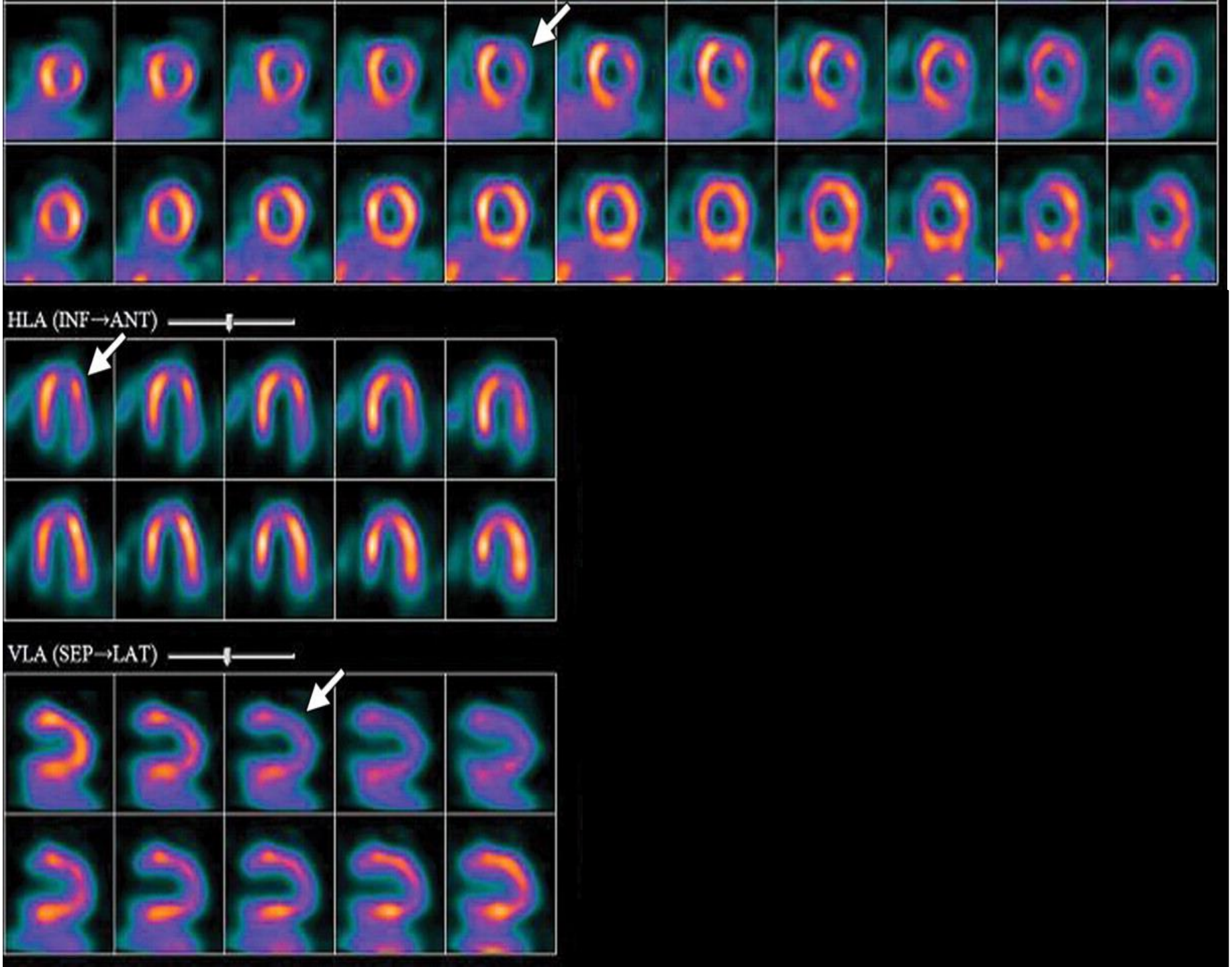

VLA
Stress
Rest
HLA
Stress
Rest
SA
Stress
Rest

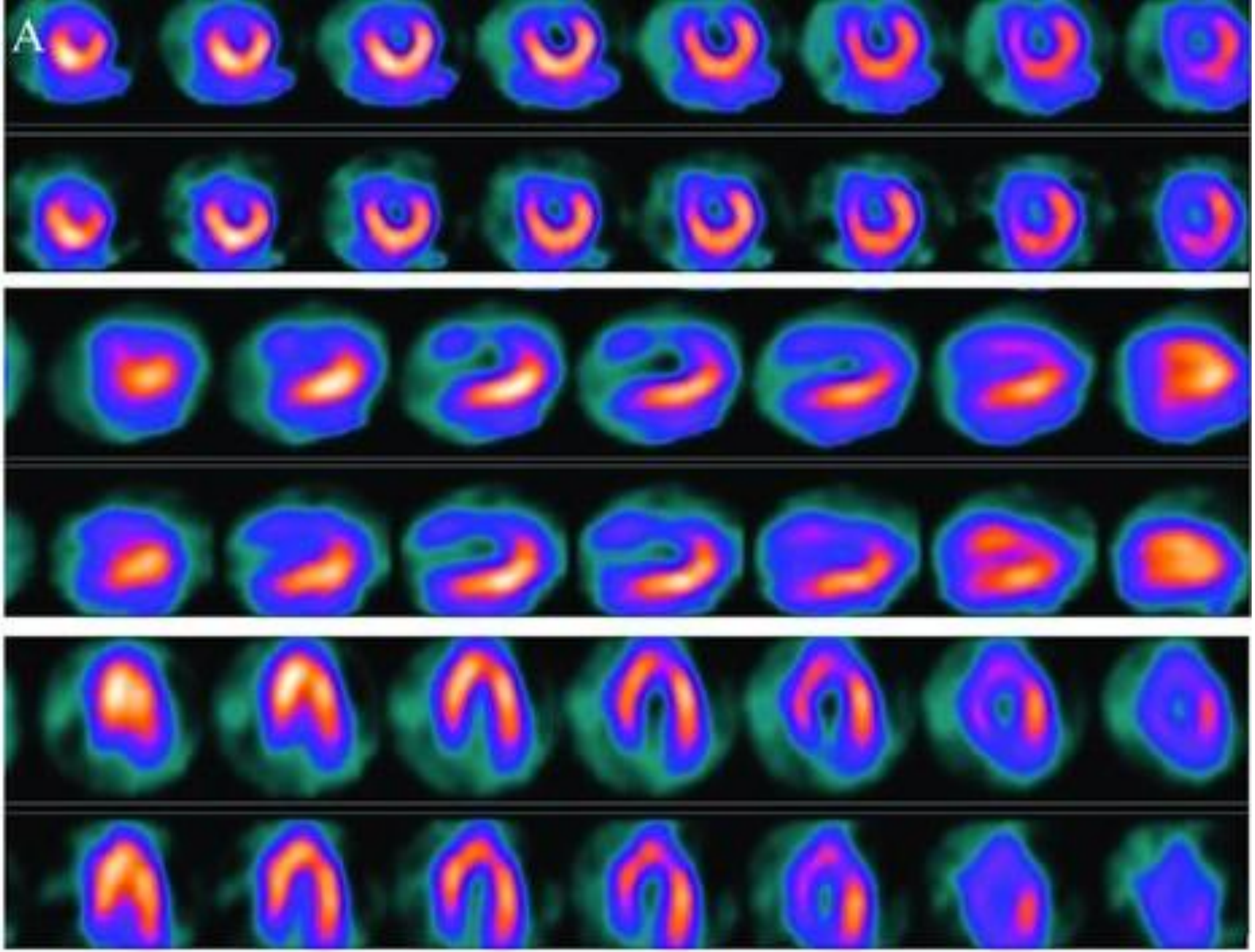

Ant
Stress
Apex
Rest
Inf
Septum → Lateral


Apex
Stress
Sep
Lat
Rest
Inferior → Anterior

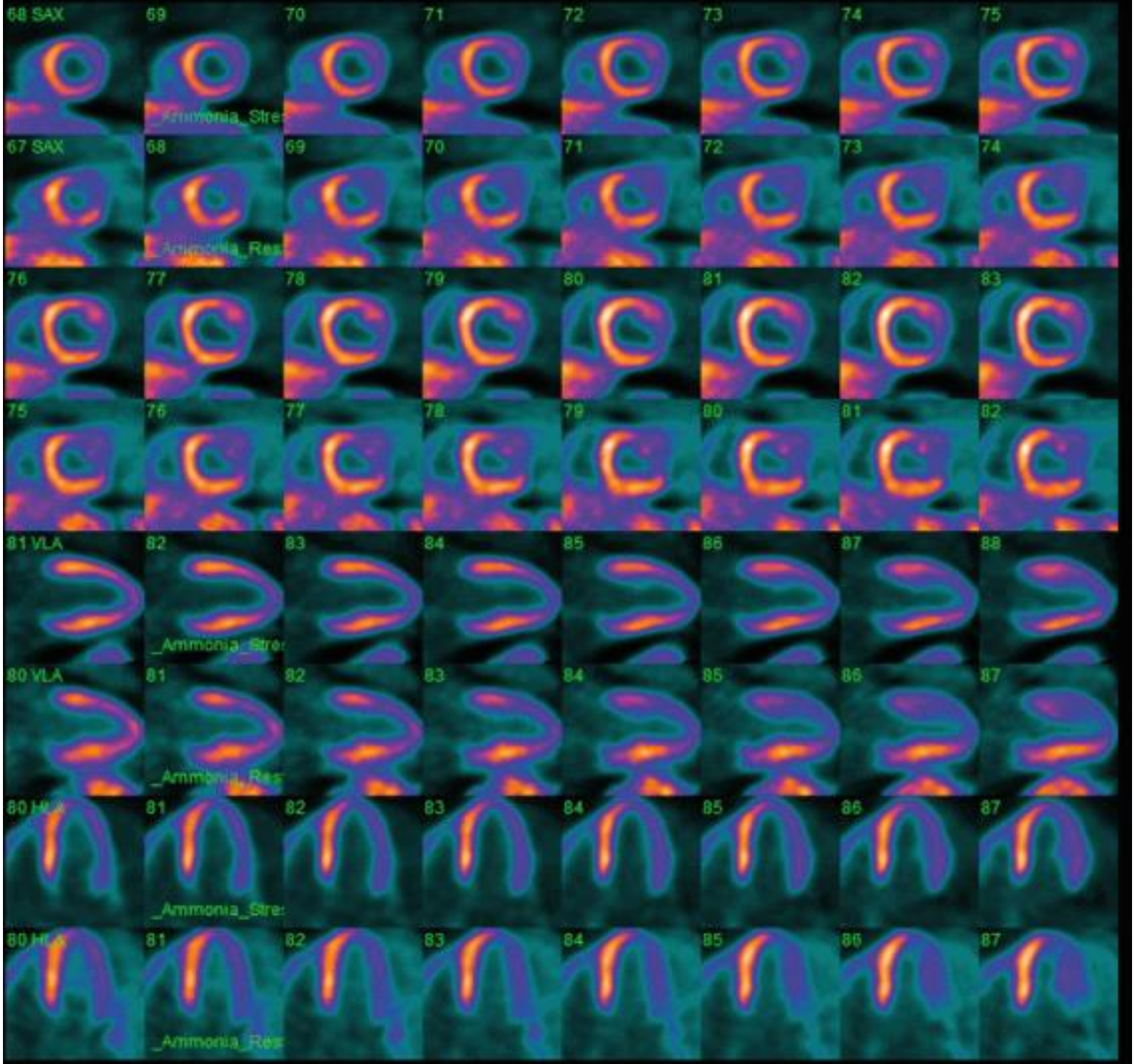

Ant
Stress
Sep
Lat
Rest
Inf
Apex → Base


SA (Apex→Base)
HLA (INF→ANT)
VLA (SEP→LAT)


HLA (INF→ANT)
VLA (SEP→LAT)


A


72.8 SAX
73.8
74.8
75.8
76.8
77.8
78.8
79.8
_Ammonia_Stress_
72.0 SAX
73.0
74.0
75.0
76.0
77.0
78.0
79.0
_Ammonia_Rest_St
80.8
81.8
82.8
83.8
84.8
85.8
86.8
87.8
80.0
81.0
82.0
83.0
84.0
85.0
86.0
87.0
80.2 VLA
81.2
82.2
83.2
84.2
85.2
86.2
87.2
_Ammonia_Stress_
80.4 VLA
81.4
82.4
83.4
84.4
85.4
86.4
87.4
_Ammonia_Rest_St
80.1 HLA
81.1
82.1
83.1
84.1
85.1
86.1
87.1
_Ammonia_Stress_
80.2 HLA
81.2
82.2
83.2
84.2
85.2
86.2
87.2
_Ammonia_Rest_St


68 SAX
69
70
71
72
73
74
75
67 SAX
68
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79
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81
82
81 VLA
82
83
84
85
86
87
88
80 VLA
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86
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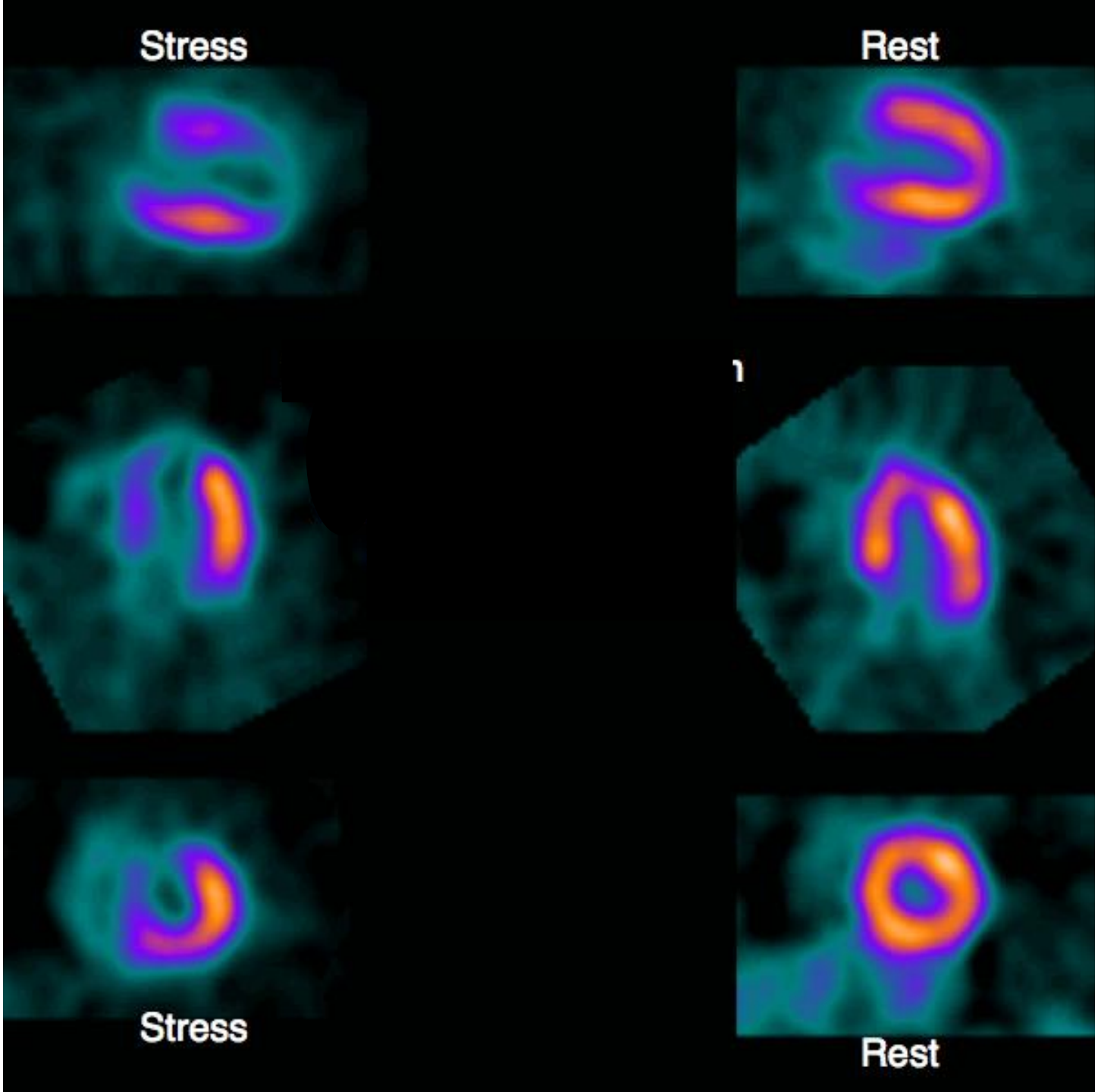
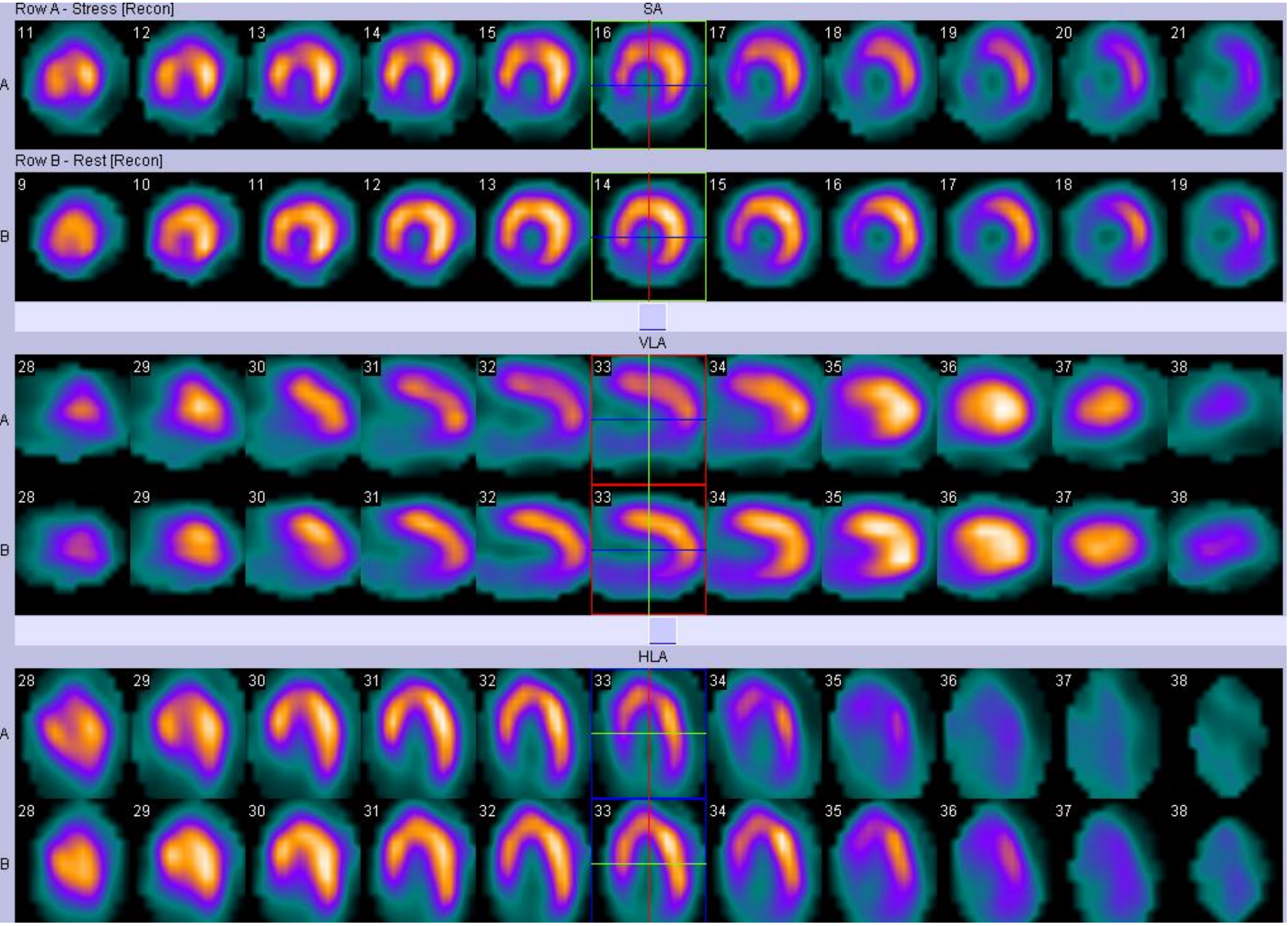
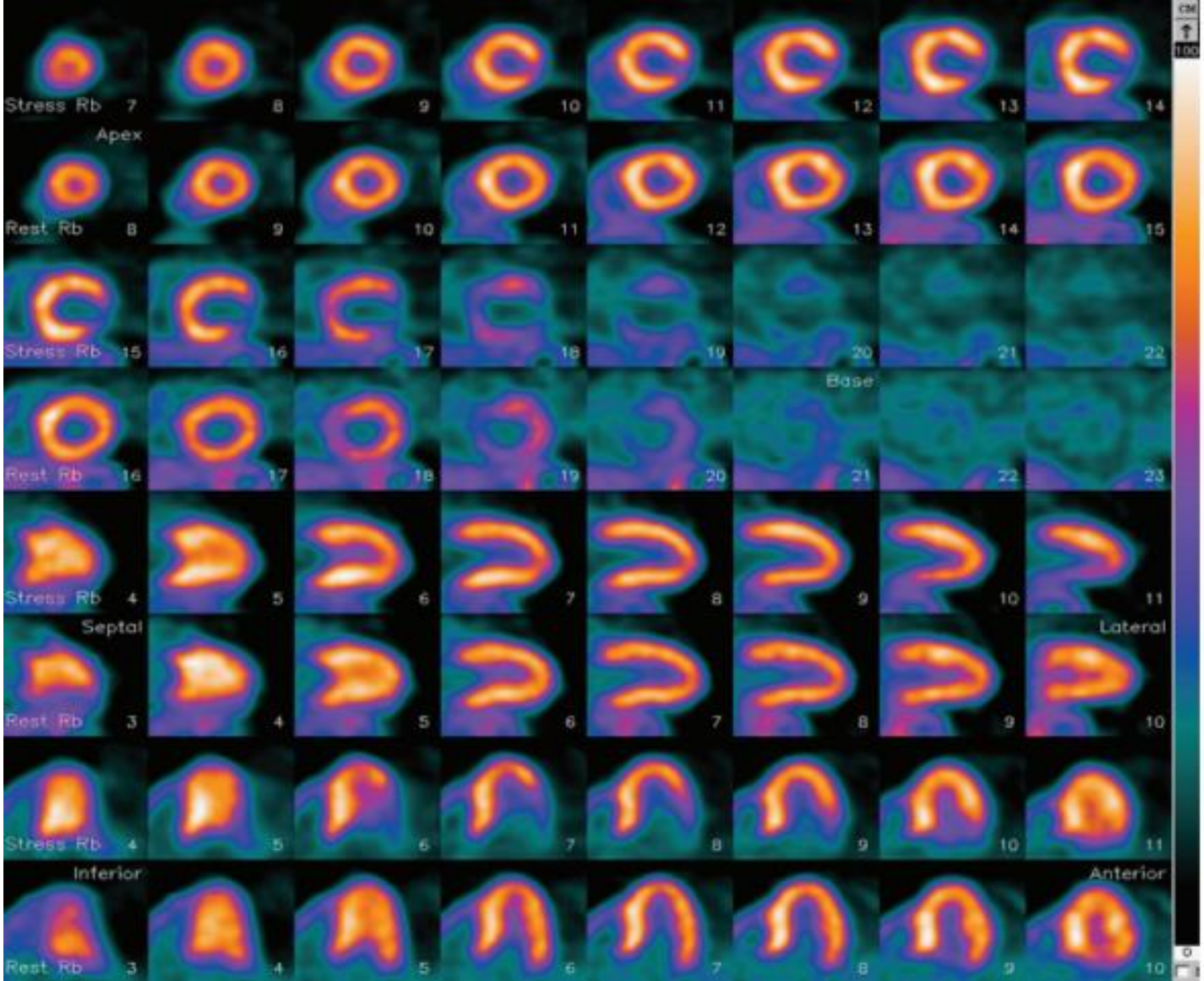
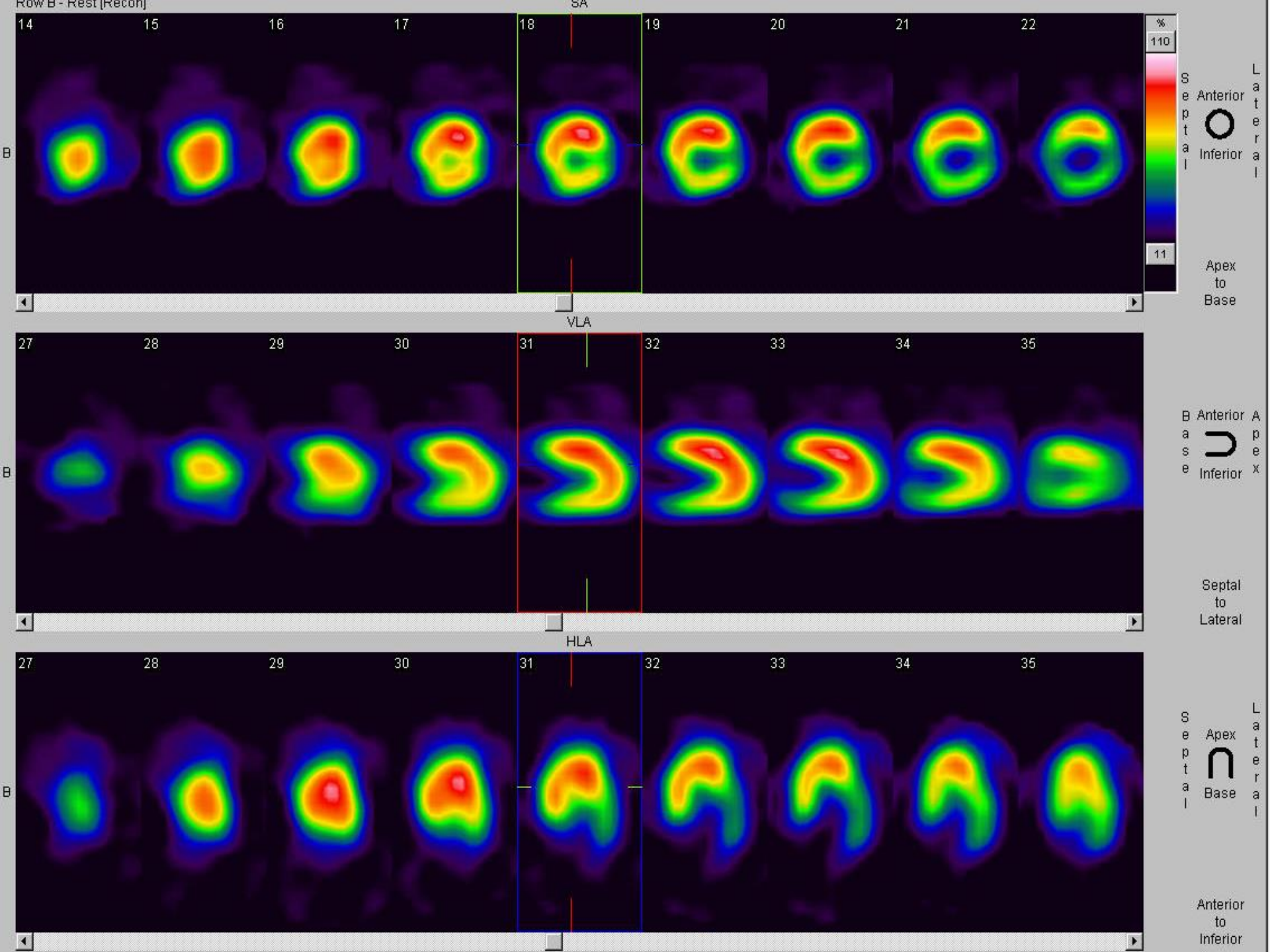

Stress
Rest
Stress
Rest


Row A - Stress [Recon]
SA
11 12 13 14 15 16 17 18 19 20 21
A
Row B - Rest [Recon]
9 10 11 12 13 14 15 16 17 18 19
B
VLA
28 29 30 31 32 33 34 35 36 37 38
A
28 29 30 31 32 33 34 35 36 37 38
B
HLA
28 29 30 31 32 33 34 35 36 37 38
A
28 29 30 31 32 33 34 35 36 37 38
B


Stress Rb 7
8
9
10
11
12
13
14
Apex
Rest Rb 8
9
10
11
12
13
14
15
Stress Rb 15
16
17
18
19
20
21
22
Rest Rb 16
17
18
19
20
21
Base
22
23
Stress Rb 4
5
6
7
8
9
10
11
Septal
Lateral
Rest Rb 3
4
5
6
7
8
9
10
Stress Rb 4
5
6
7
8
9
10
11
Inferior
Anterior
Rest Rb 3
4
5
6
7
8
9
10
100
0


Row B - Rest [Recon]
SA
14
15
16
17
18
19
20
21
22
%
110
11
B
Septal
Anterior
Inferior
Lateral
Apex
to
Base
VLA
27
28
29
30
31
32
33
34
35
B
Base
Anterior
Inferior
Apex
Septal
to
Lateral
HLA
27
28
29
30
31
32
33
34
35
B
Septal
Apex
Base
Lateral
Anterior
to
Inferior

Lung Scintigraphy

Radiopharmaceuticals

- Radiopharmaceuticals
  - Perfusion
    - *^{99m}Tc-MAA (macroaggregated albumin)*
  - Ventilation
    - *^{99m}Tc-DTPA*
    - *Sulfur colloid aerosols*

Indications

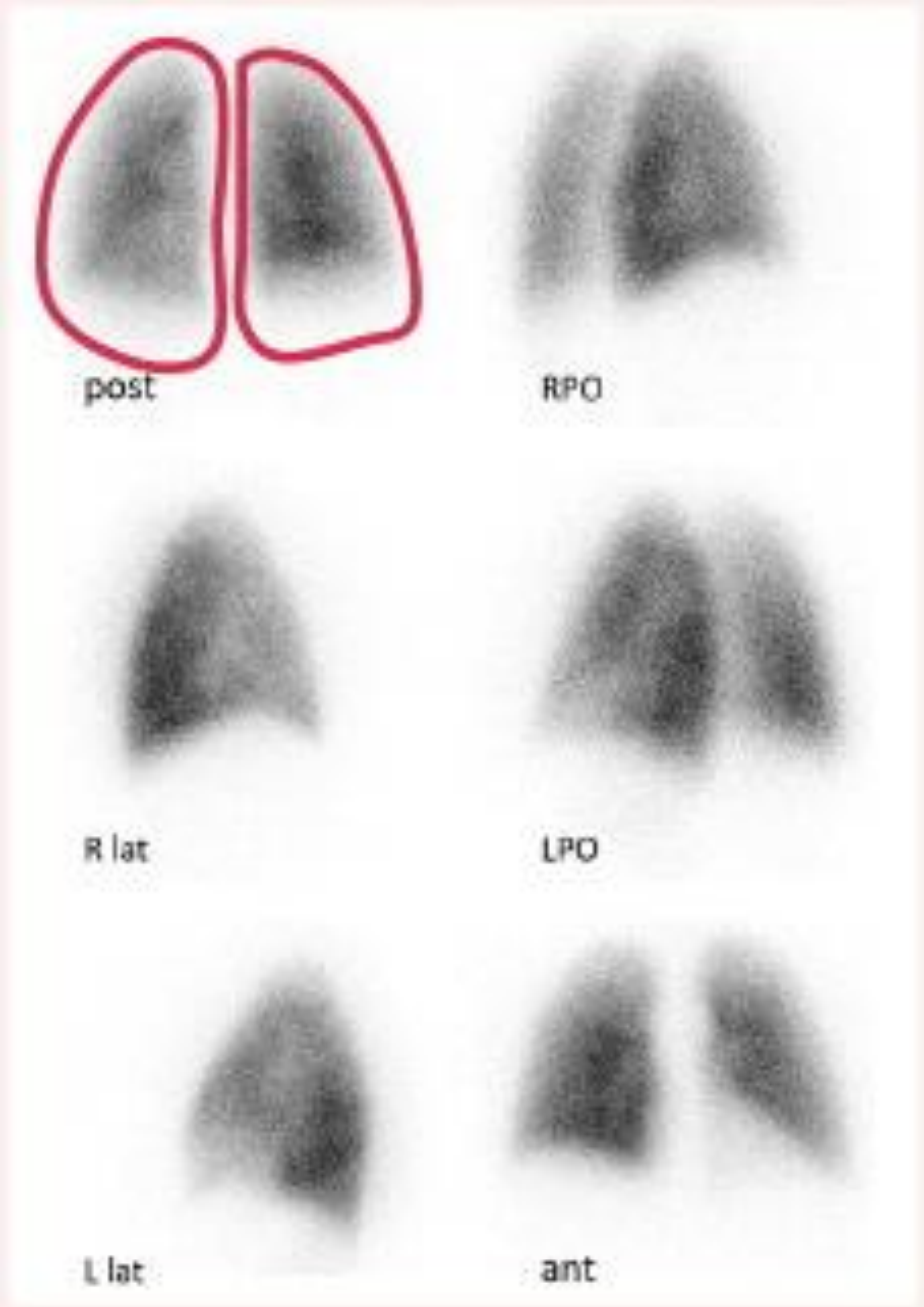
Pulmonary embolism

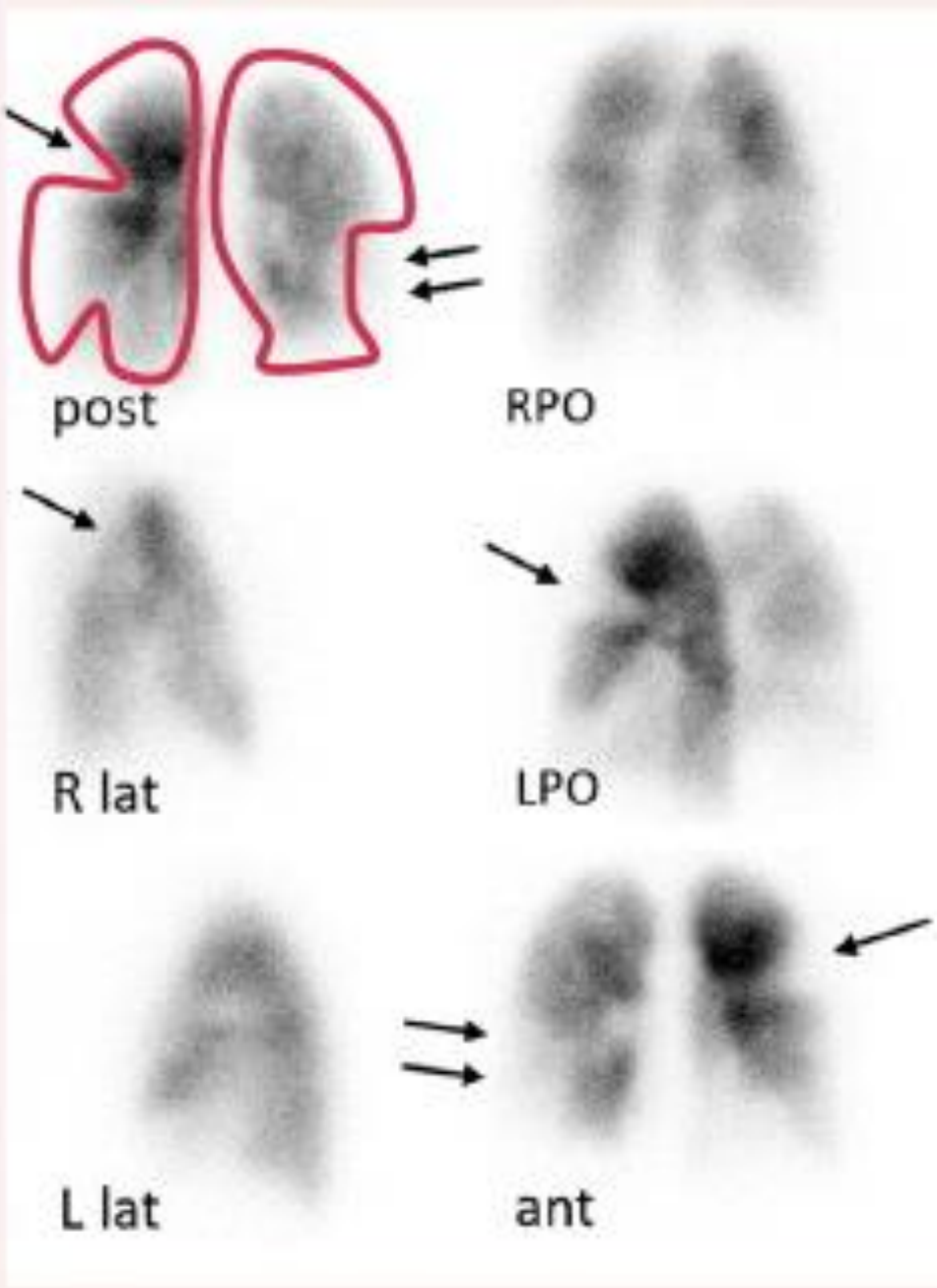
- CTPA is the gold standard for diagnosis
- V/Q scans are typically used when a patient has contrast allergy, chronic kidney disease, or pregnant

Chronic thrombo-embolic pulmonary hypertension (CTEPH)

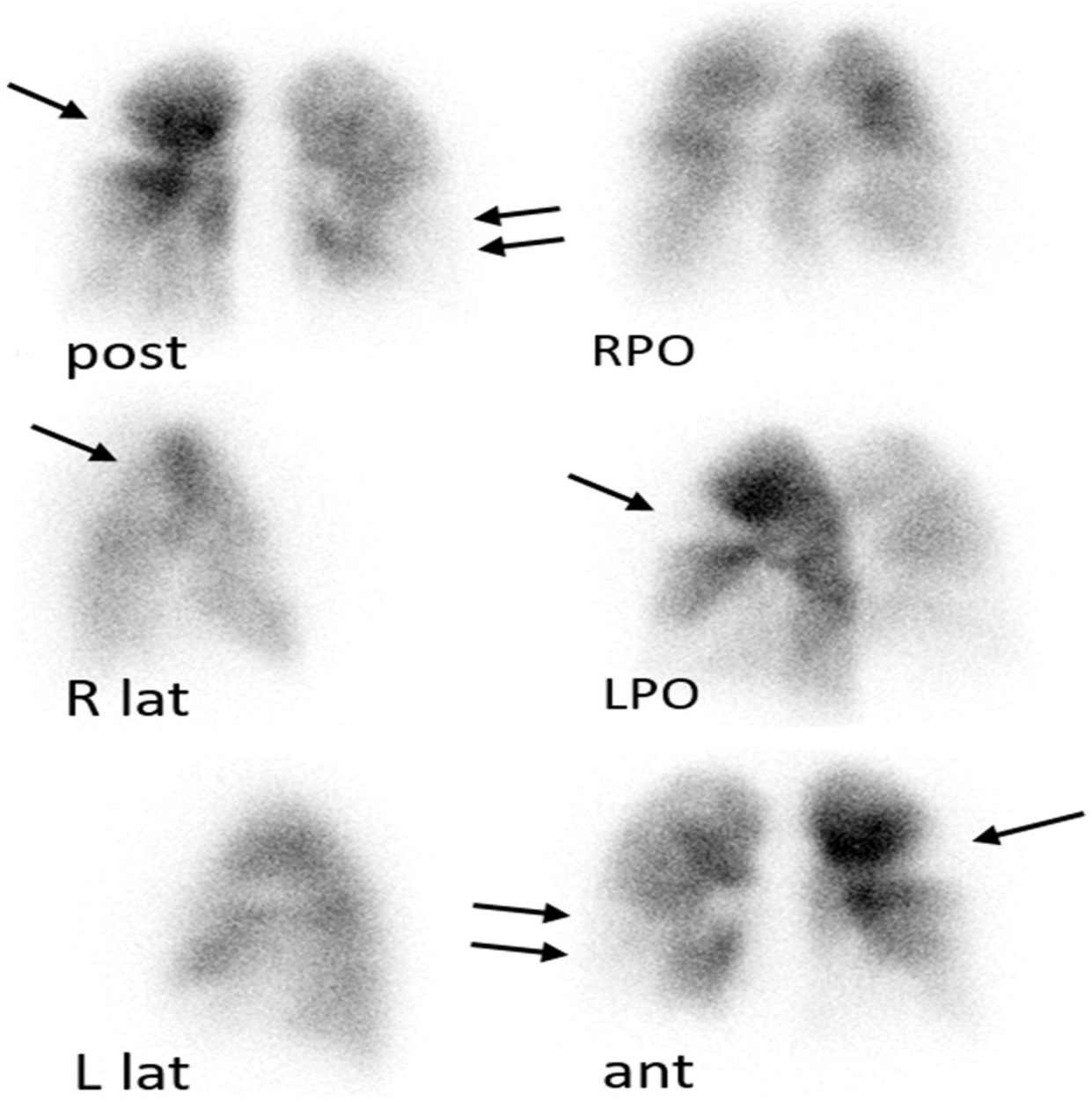
- V/Q has higher sensitivity in the diagnosis of CTEPH than CTPA

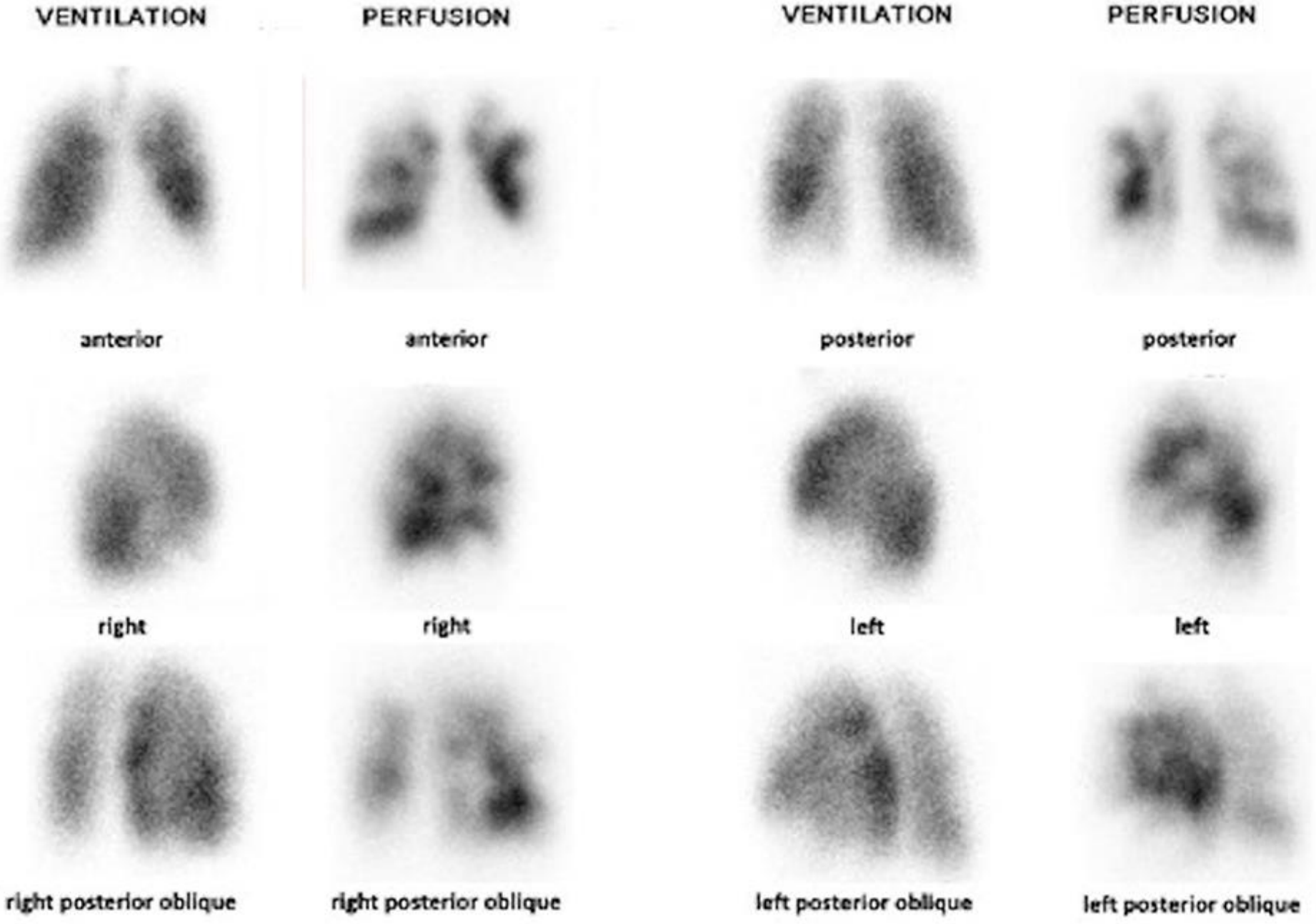
Quantitative function

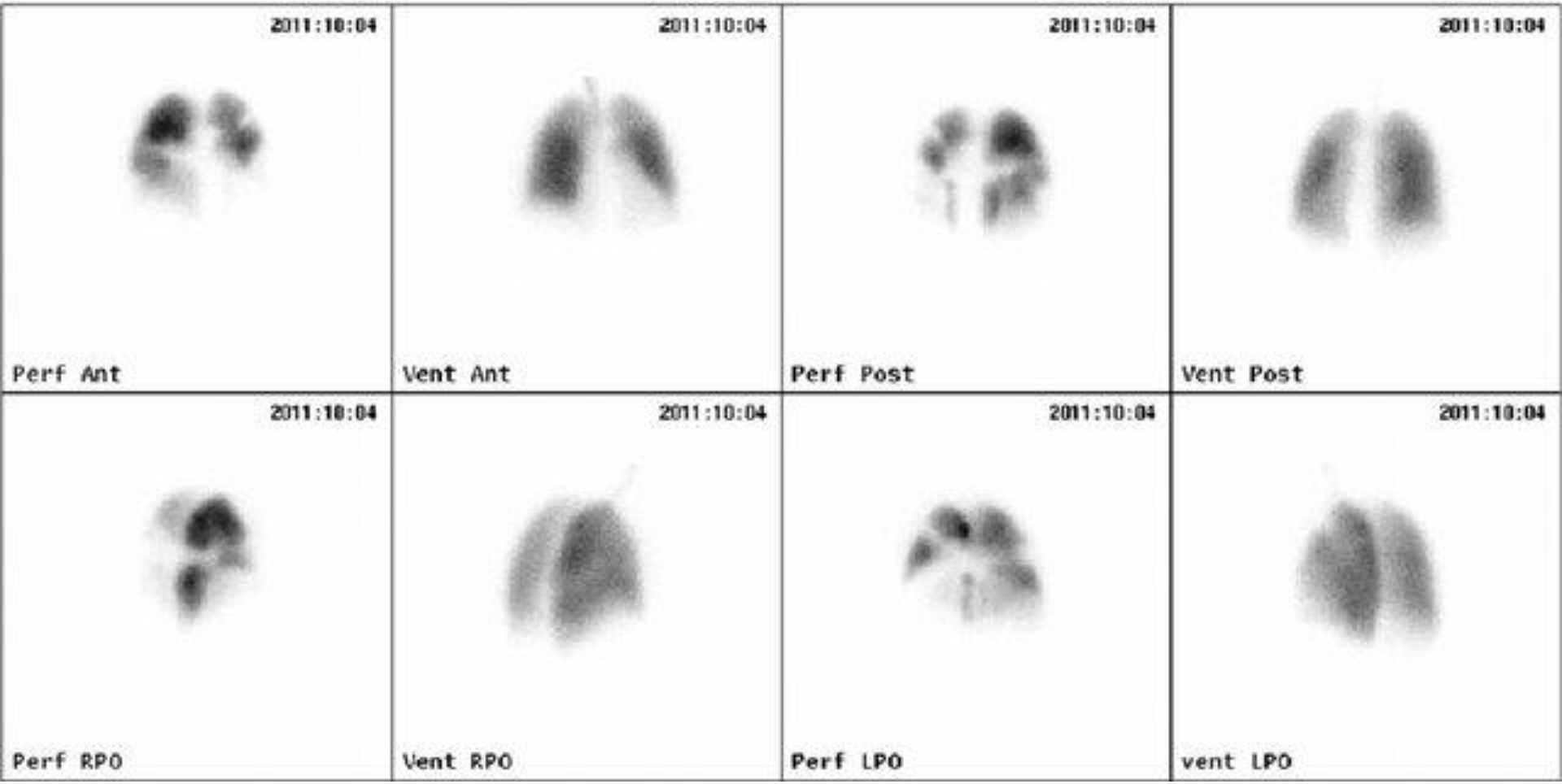

post
RPO
R lat
LPO
L lat
ant

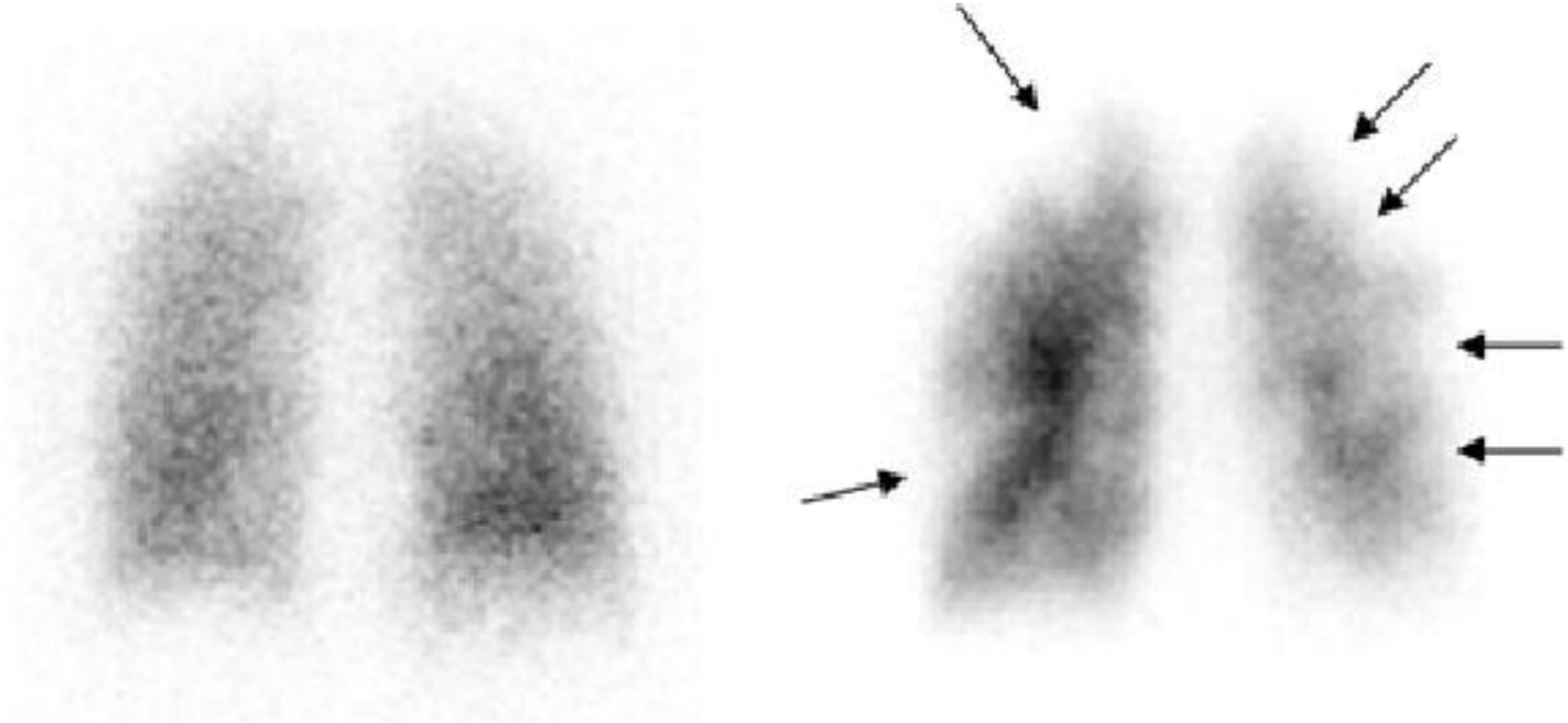

post
RPO
R lat
LPO
L lat
ant

Perfusion



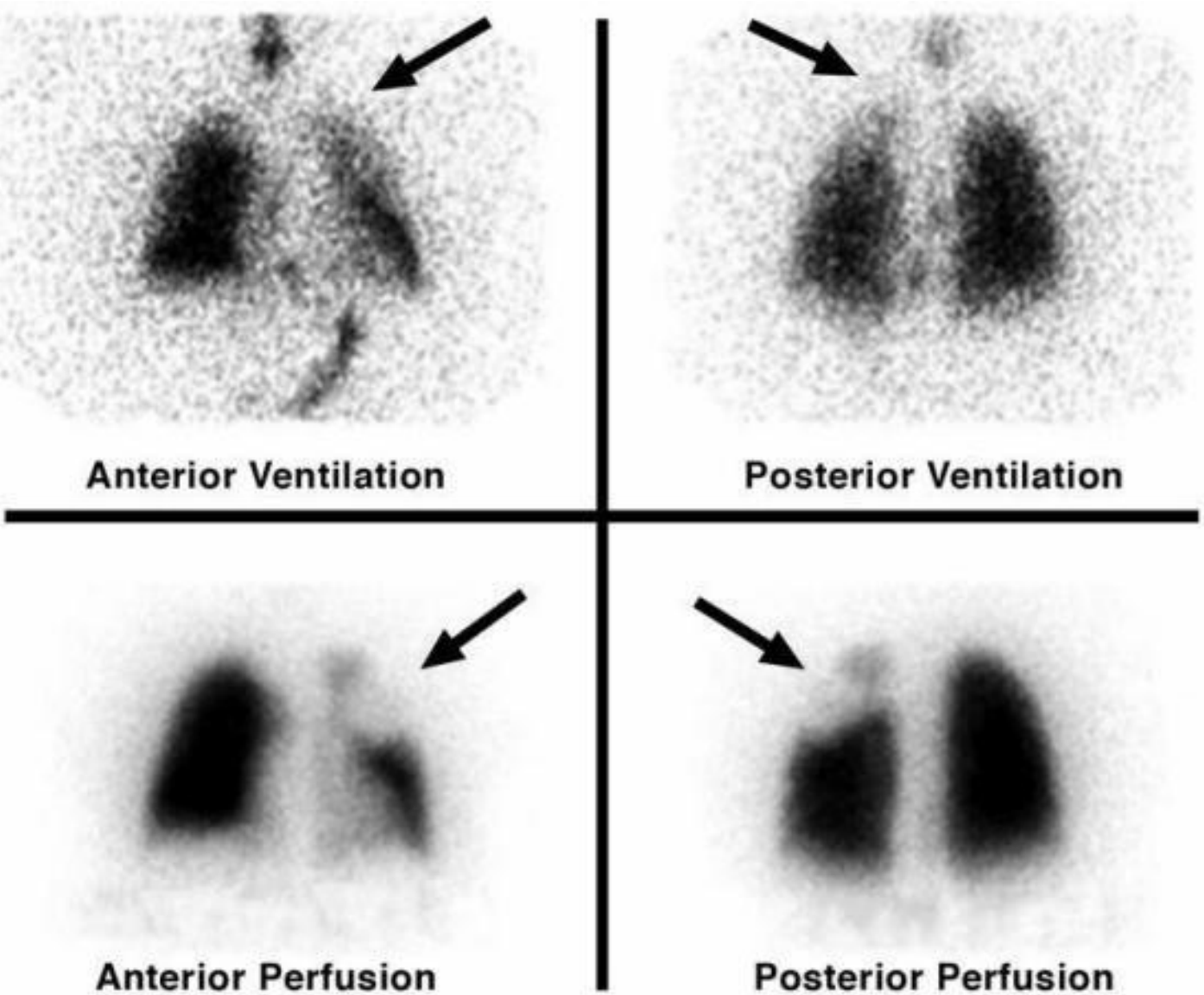

VENTILATION
PERFUSION
VENTILATION
PERFUSION
anterior
anterior
posterior
posterior
right
right
left
left
right posterior oblique
right posterior oblique
left posterior oblique
left posterior oblique


2011:10:04
Perf Ant
2011:10:04
Vent Ant
2011:10:04
Perf Post
2011:10:04
Vent Post
2011:10:04
Perf RPO
2011:10:04
Vent RPO
2011:10:04
Perf LPO
2011:10:04
vent LPO



Ventilation

Perfusion


Anterior Ventilation
Posterior Ventilation
Anterior Perfusion
Posterior Perfusion

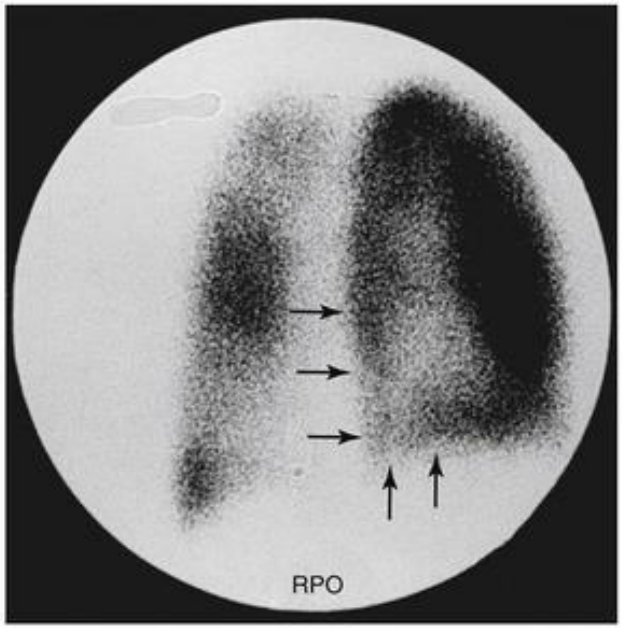
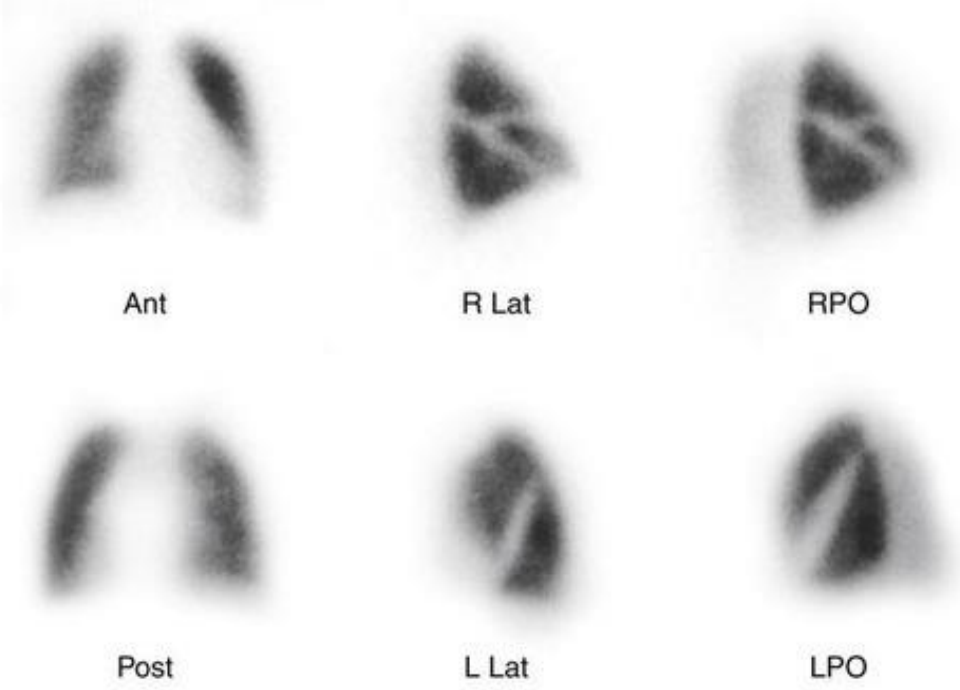


FIGURE 6-13 **Stripe sign.** Single view from a perfusion lung scan in a patien...



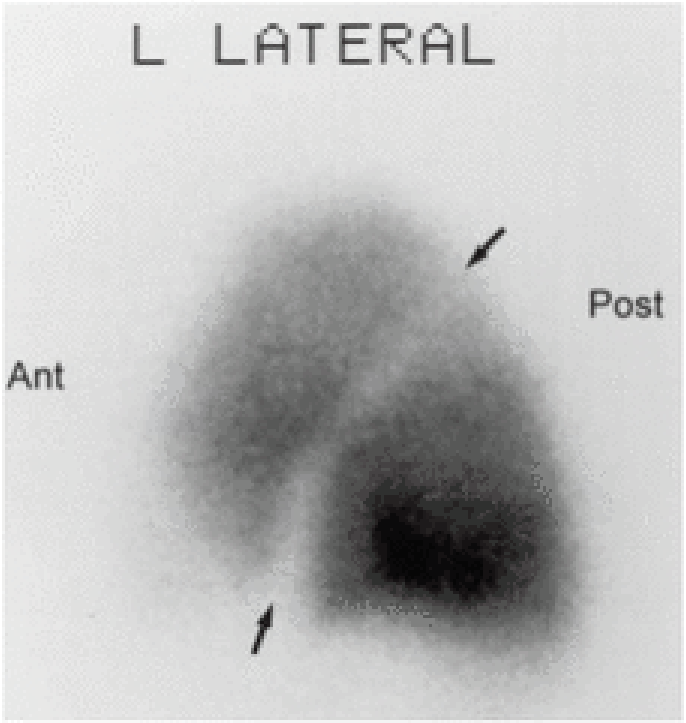
The Fissure Sign[1]

APPEARANCE

The linear area of reduced or absent radionuclide uptake along the distribution of the major and/or minor fissure on a lung perfusion scan is referred to as the fissure sign (Figure).

EXPLANATION

Many conditions can cause the fissure sign, but peripheral lung hypoperfusion adjacent to the fissures is the common explanation (1,2).



Bone Scintigraphy

^{99m}Tc-MDP

Basics

Radiopharmaceutical

^{99m}Tc Methylene Diphosphonate (MDP) IV

Which tumors do we get bone scans for?

Breast, prostate, most others use PET scan

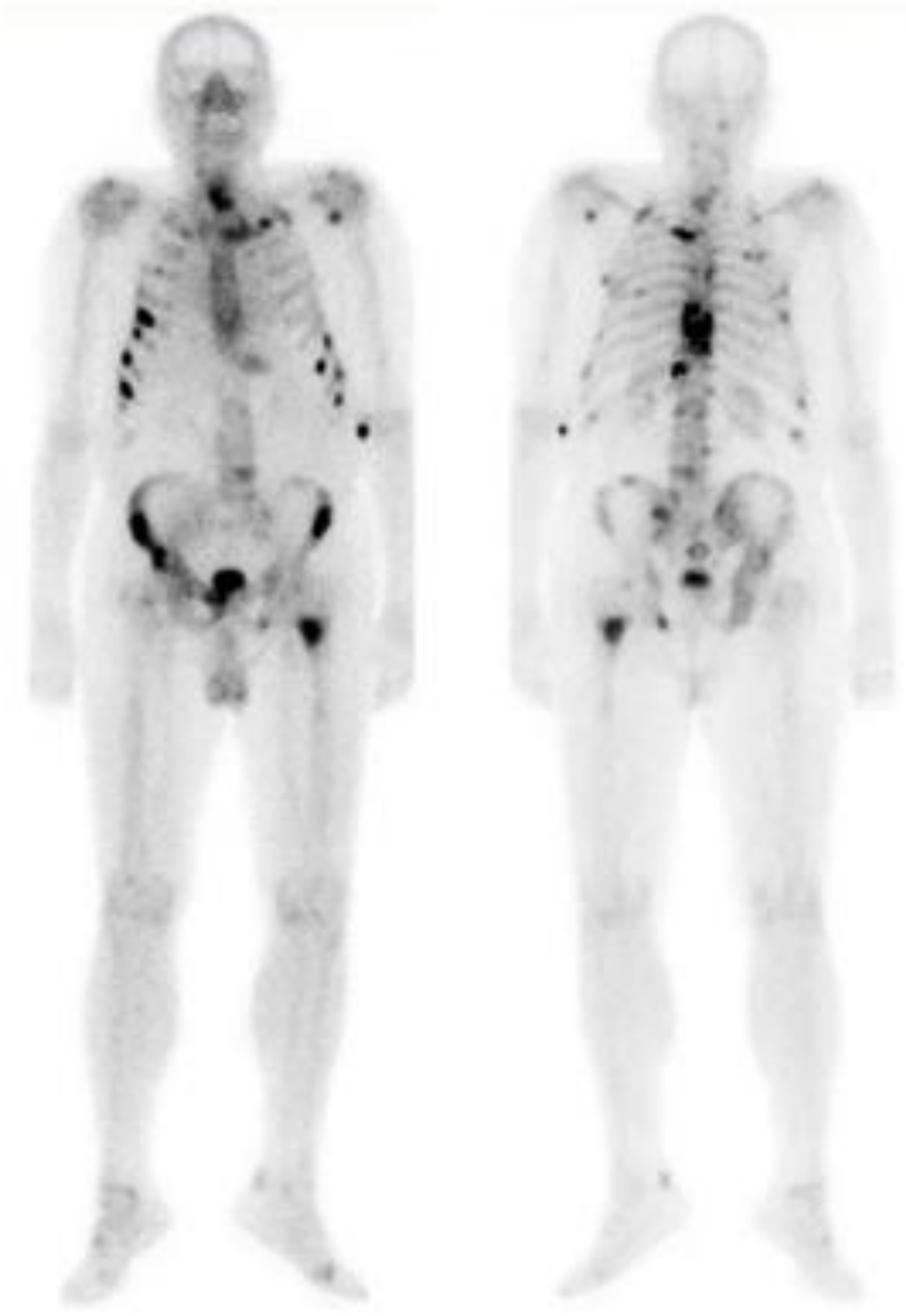
Breast cancer often sends solitary metastases to the sternum

Prostate cancer metastases often start in the spine

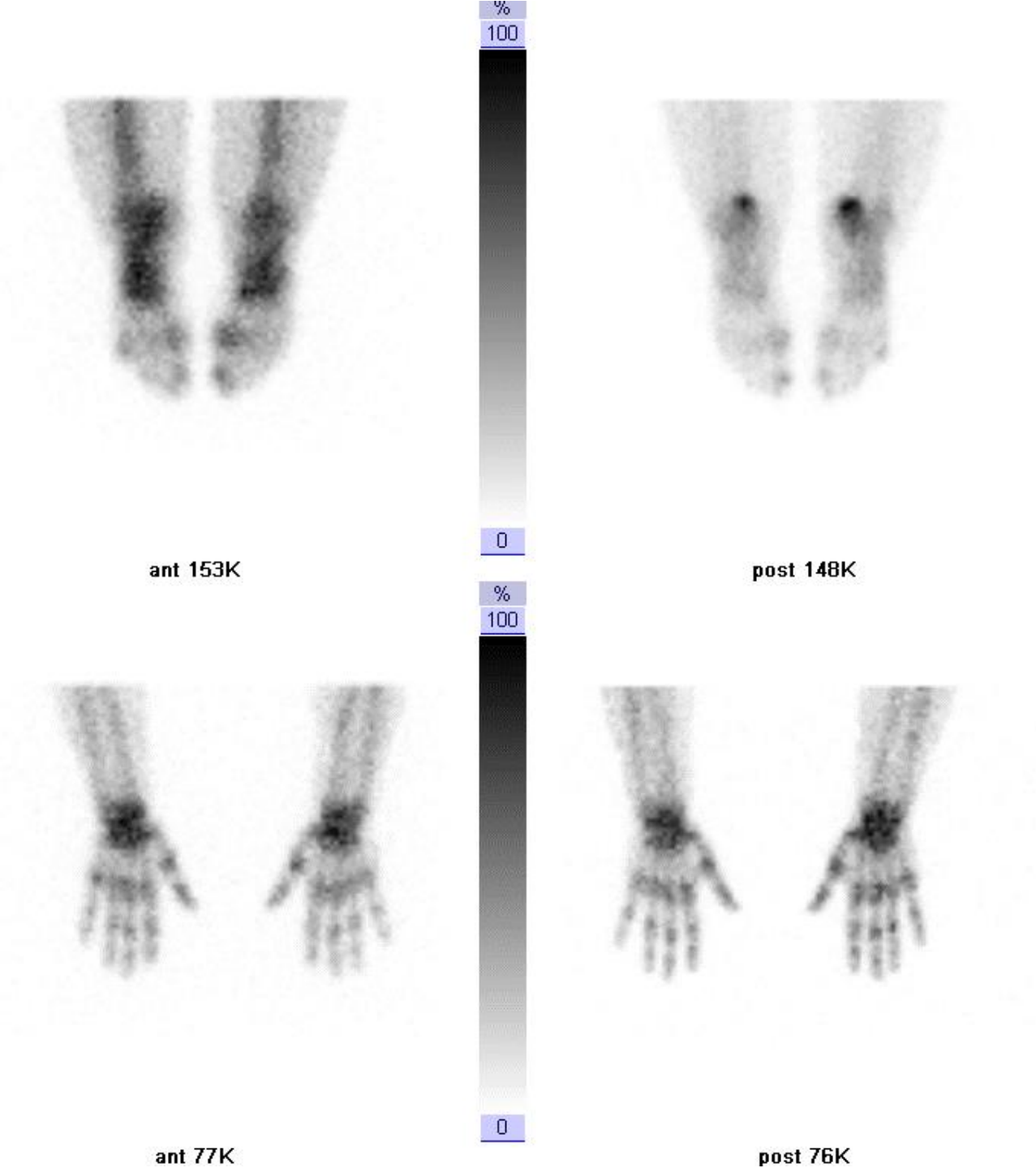
Primary bone response to some tumors

Predominantly osteoblastic
Prostate
Carcinoid
Gastrinoma
Small cell lung cancer
Hodgkin's disease
Medulloblastoma
Predominantly osteolytic
Renal cell cancer
Melanoma
Squamous cell cancers of the aerodigestive tract
Multiple myeloma
Non-small cell lung cancer
Thyroid cancer
Non Hodgkins lymphoma
Mixed osteoblastic and osteolytic
Breast cancer
Gastrointestinal cancers
Squamous cancers at most primary sites

71-year-old male recently diagnosed with prostate cancer was referred to nuclear medicine to rule out bony metastases

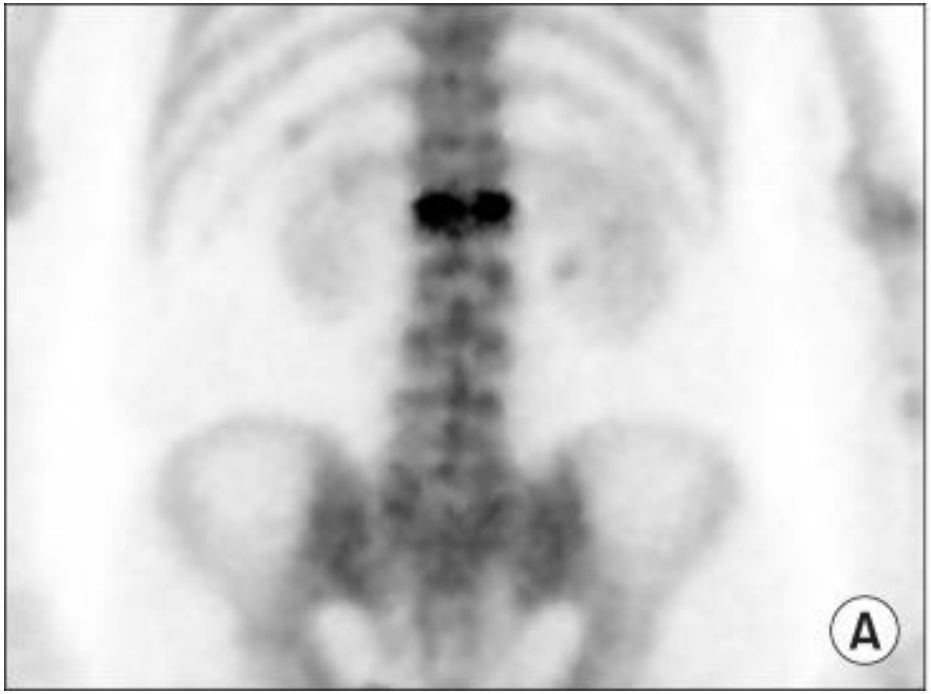


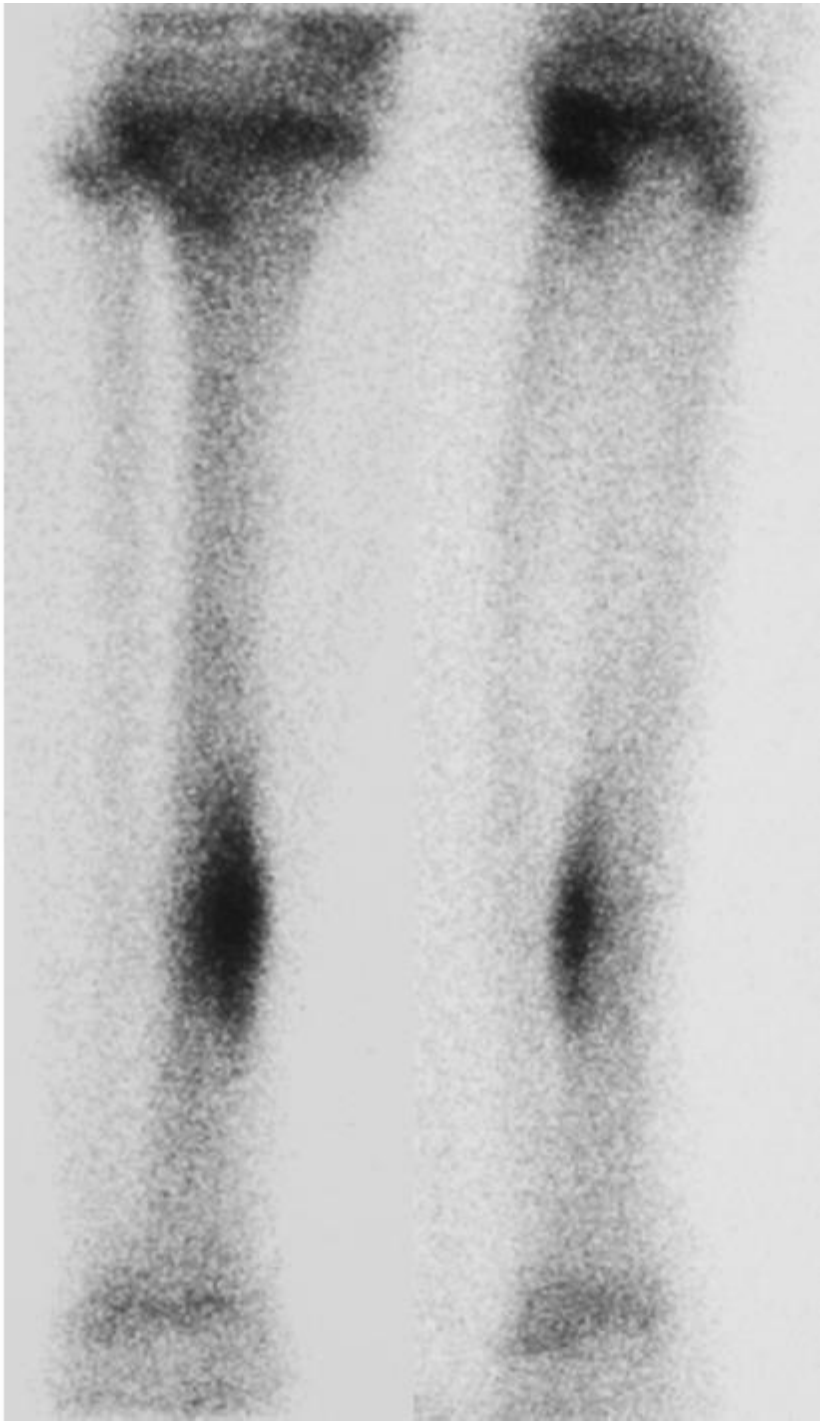
68-year-old male recently diagnosed with prostate cancer was referred to nuclear medicine to rule out bony metastases



41-year-old female was referred to nuclear medicine to evaluate bilateral joint pain and morning stiffness

79-year-old female with back pain and vertebral loss of height on CT





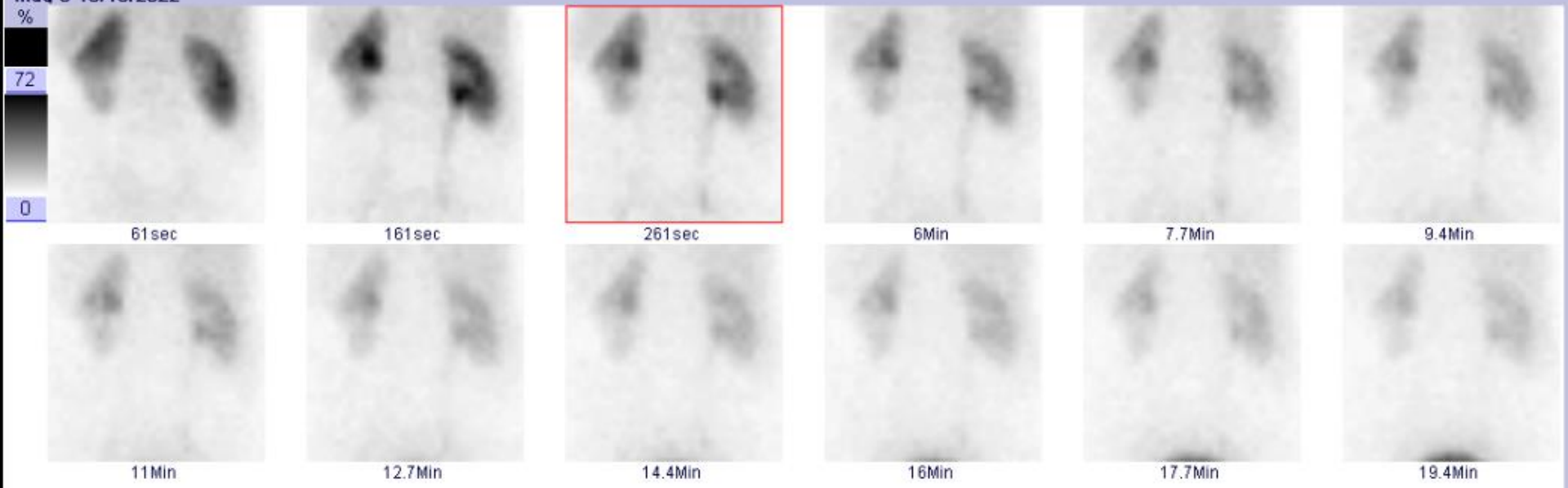
26-year-old female who recently started having to walk 15 km twice a day to get to and from work is now complaining from bilateral shin pain not responding to analgesia.

Renal Scans

Diuretic Renography

- Radiopharmaceuticals
  - ^{99m}Tc MAG3
  - ^{99m}Tc DTPA
- Pharmacologic protocols: diuretics (e.g. furosemide)
- Indications
  - Obstructive vs nonobstructive hydronephrosis
  - Stent function
  - Renal artery stenosis / thrombosis

mag 3 10/18/2022



Phase 2

Kidney

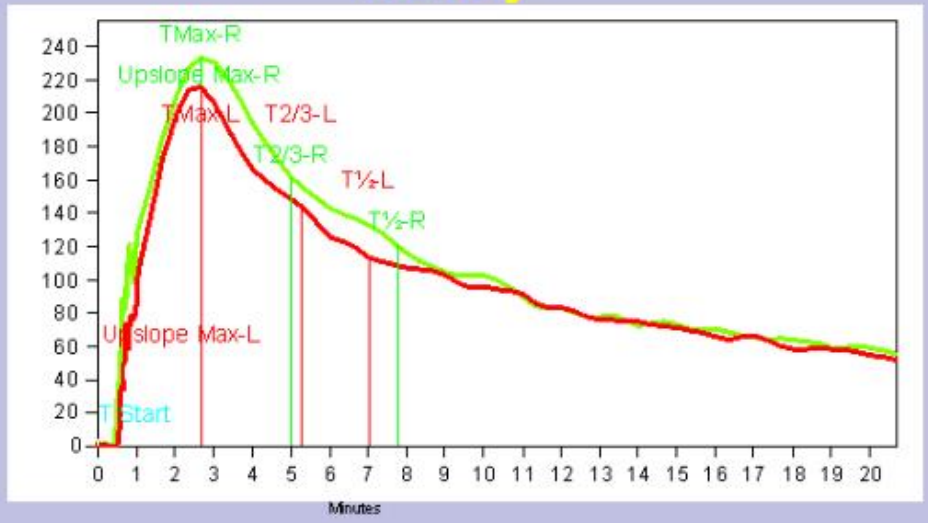
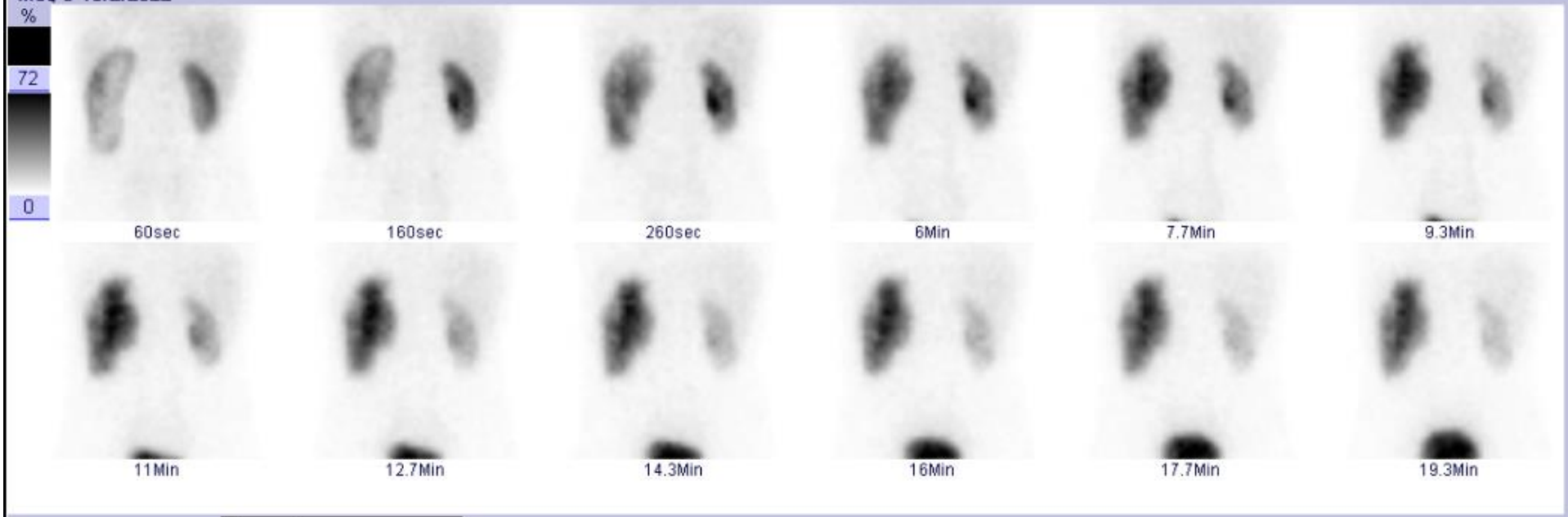


Table of Result Summary

Parameters	Left	Right	Total
Split Function (%)	47.4	52.6	
Kidney Counts (cpm)	8383.3	9315.8	17699
Renal Retention	0.246	0.244	
Time of Max (min)	2.685	2.685	
Time of ½ Max (min)	6.986	7.783	
Time from Max to ½ Max (min)	4.300	5.098	
Time of 2/3 Max (min)	5.254	5.021	
Time from Max to 2/3 Max (min)	2.569	2.335	
Upslope Time Interval (min)	0.501	2.685	
Max Counts (cps)	219.1	239.7	458.8
Slope from Max to ½ Max (cps^2)	0.387	0.377	
Upslope (cps^2)	0.019	0.612	

mag 3 10/2/2022



Phase 2

Kidney

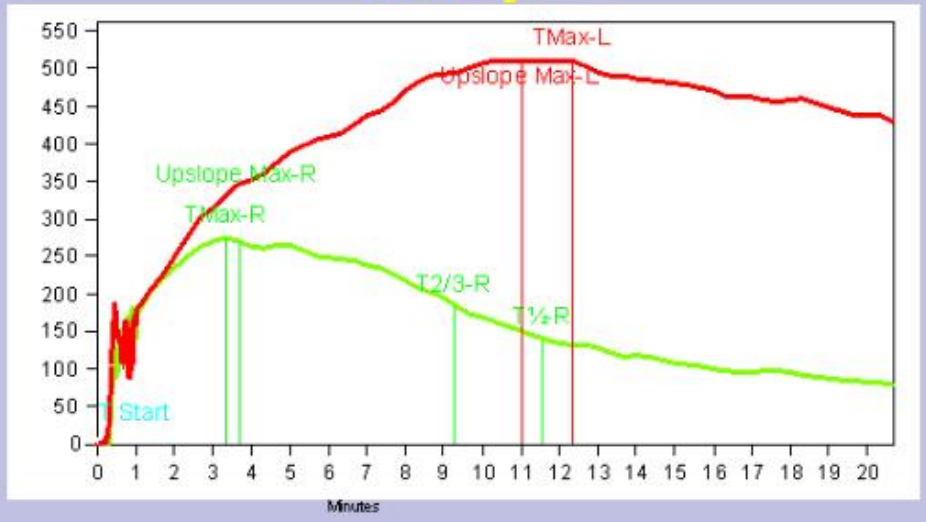


Table of Result Summary

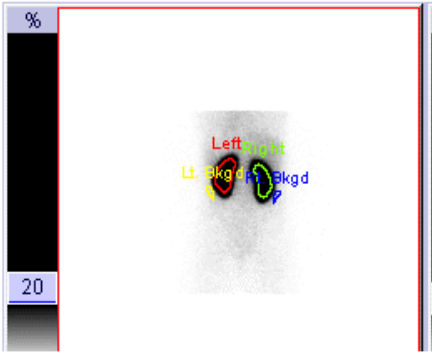
Parameters	Left	Right	Total
Split Function (%)	49.9	50.1	
Kidney Counts (cpm)	12038	12065	24103
Renal Retention	0.846	0.293	
Time of Max (min)	12.3	3.336	
Time of ½ Max (min)		11.6	
Time from Max to ½ Max (min)		8.218	
Time of 2/3 Max (min)		9.239	
Time from Max to 2/3 Max (min)		5.903	
Upslope Time Interval (min)	11.0	3.669	
Max Counts (cps)	521.4	277.5	798.9
Slope from Max to ½ Max (cps^2)		0.290	
Upslope (cps^2)	1.107	1.784	

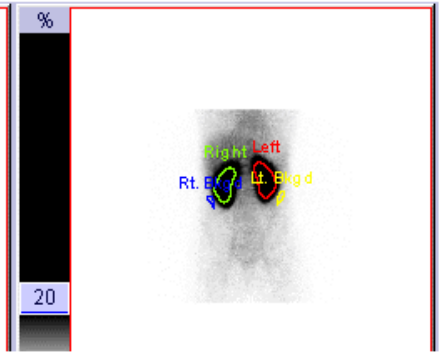
DMSA

- Radiopharmaceutical
  - ^{99m}Tc dimercaptosuccinic acid (DMSA)
- Indications
  - Relative function
  - Scarring
  - Pre nephrectomy assessment

Anterior 404K

Posterior 407K





RAO 352K

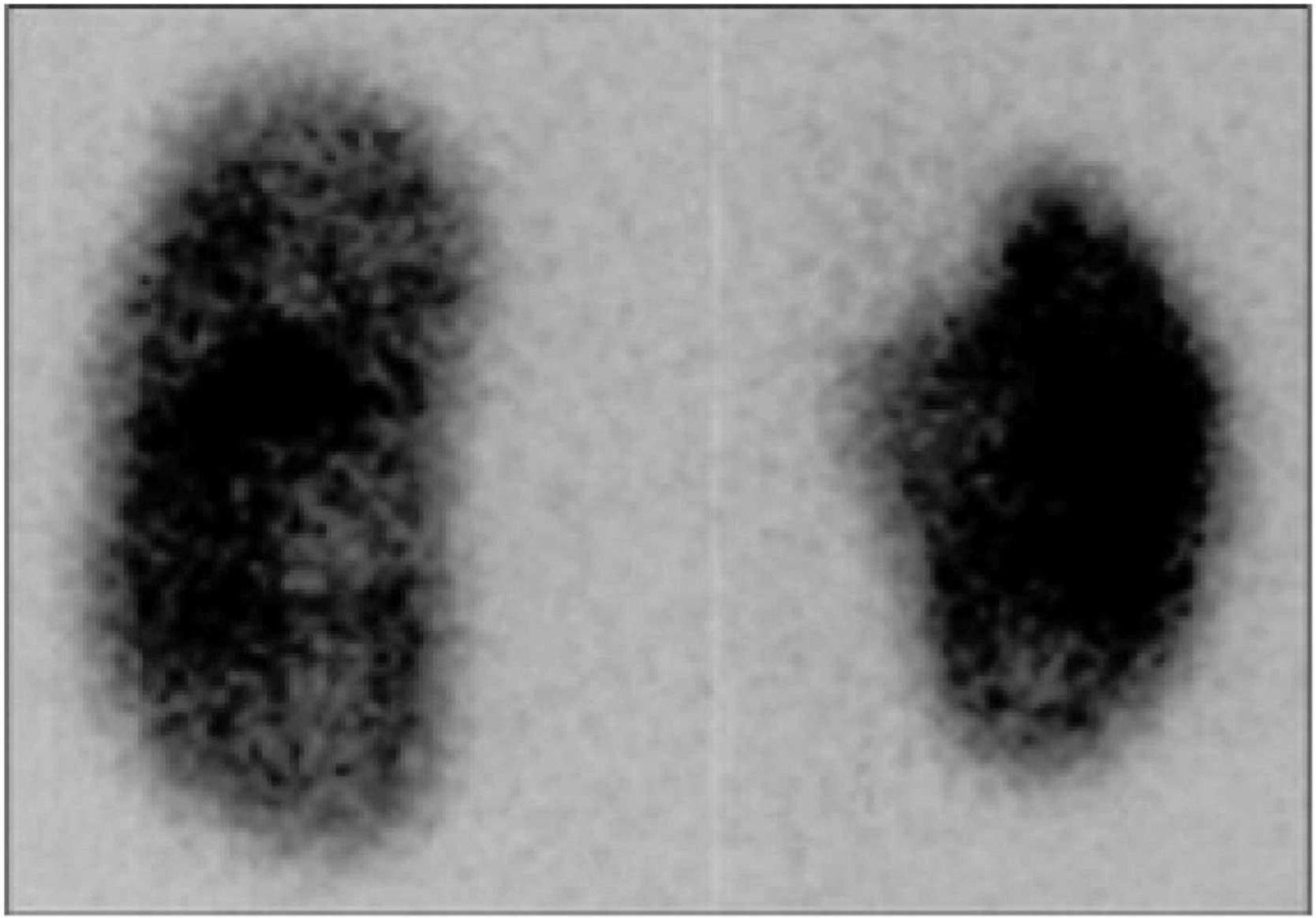
LPO 426K

(% Ratios)	Left	Right
	50.26	49.74
Total	50.26	49.74

RPO 391K

LAO 384K

All Images



HIDA Scan

Uses ^{99m}Tc-mebrofenin or disofenin

Indications

- Acute cholecystitis
- Chronic acalculous cholecystitis
- Sphincter of Oddi dysfunction
- Biliary leak
- Biliary atresia
- Biliary stent patency

PET Imaging

Positron Emitting Tomography

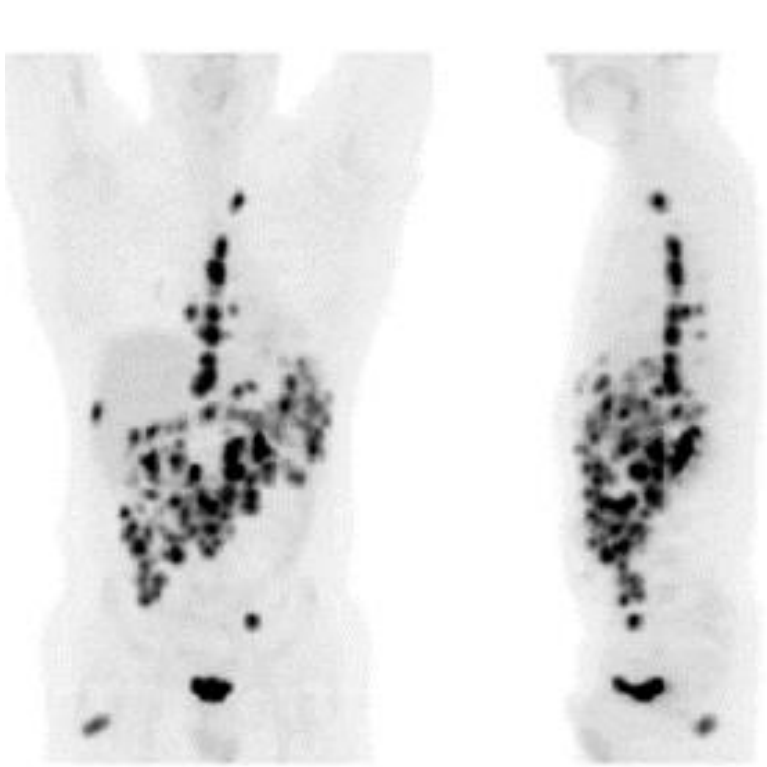
Radioactive fluorine is the most widely used (^{18}F-FDG)

Also uses ^{11}C, ^{15}O, ^{13}N, ^{68}Ga

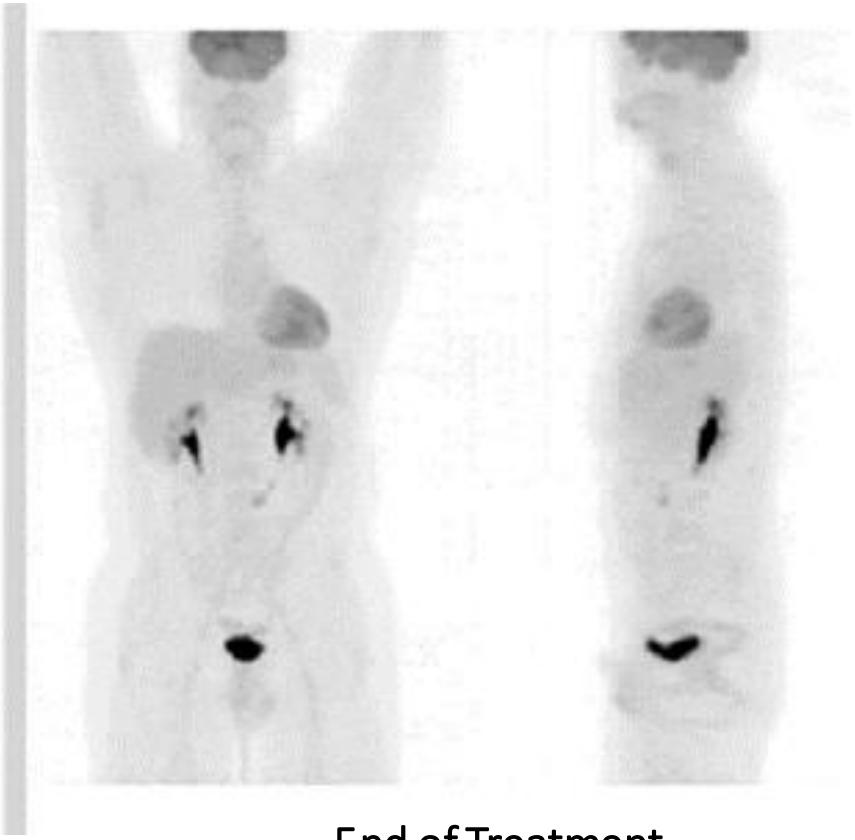
Indications

- Staging
- Response assessment
- Interim evaluation of treatment (lymphoma)
- Evaluation of suspected disease recurrence, relapse and/or residual disease
- Evaluation of indeterminate lesion
- Myocardial viability
- Localizing seizure foci

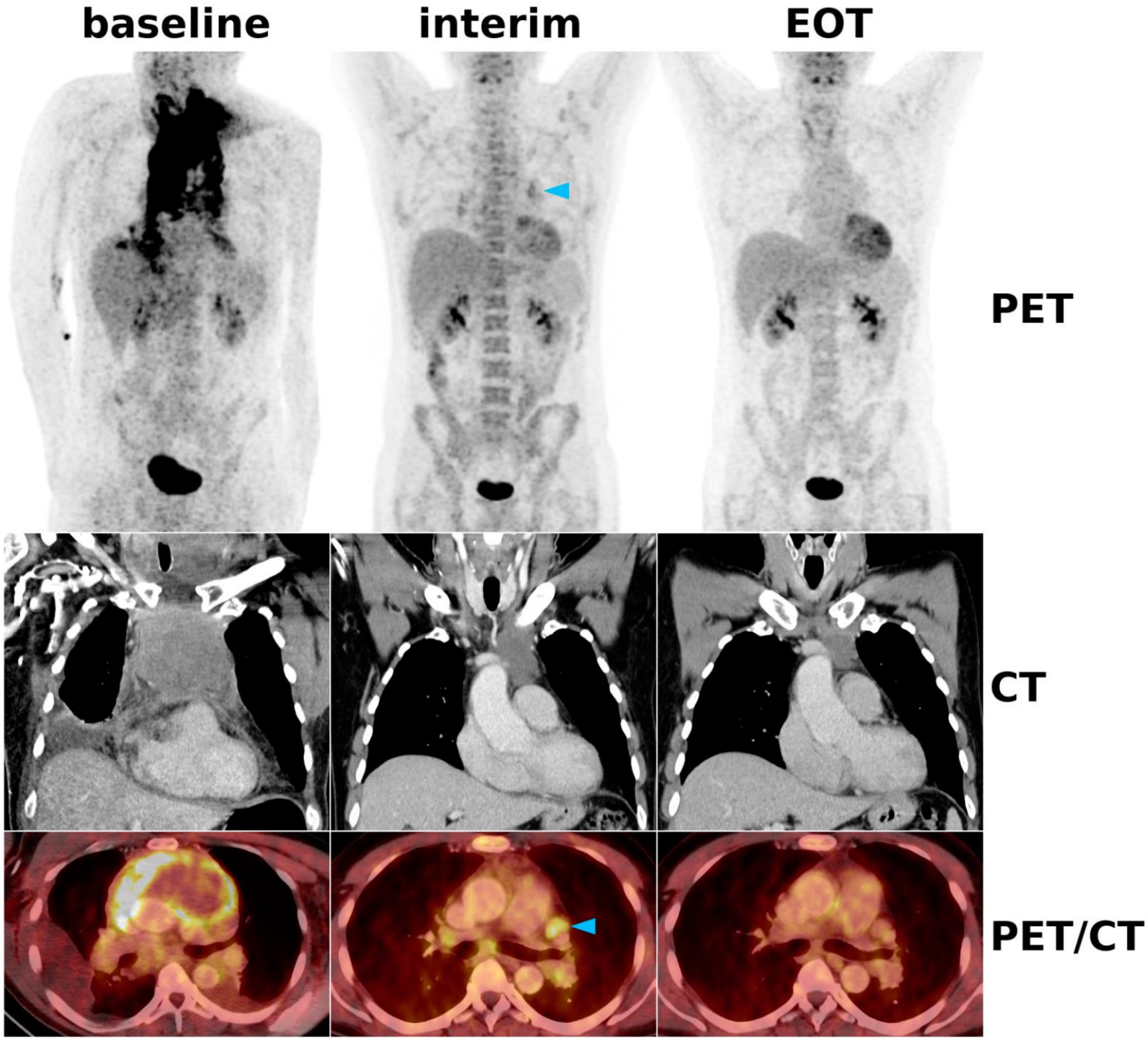
Complete Metabolic Response



Baseline



End of Treatment


baseline
interim
EOT
PET
CT
PET/CT