방사선사를 위한 임상 핵의학

임상강사 강서영
서울대병원 핵의학과

SNUH 서울대학교병원
SEOUL NATIONAL UNIVERSITY HOSPITAL

임상 핵의학

I. 신경계
brain SPECT
Cisternography
Shunt Function Test

II. 심혈관계 및 기타 순환계
Myocardial SPECT
GBP (Gated Blood Pool) Scan
Heart Single Pass (First Pass)

III. 내분비계
Thyroid scan & uptake
$KCLO_4$ discharge test
Parathyroid Scan

IV. 근골격계
Bone scan / Bone SPECT

V. 소화기계
Salivary Scan
GET (Gastric Emptying Time)
Hepatobiliary Scan
Spleen Scan
Meckel's diverticulum Scan
G-I Bleeding Scan

VI. 비뇨생식기계
Renal scan
DMSA scan
Testicular Scan
VCU Scan

VII. 호흡기계
Lung Perfusion & Ventilation Scan

VIII. 종양계
I-123 MIBG
I-131 & I-123 whole body scan
Octreotide Scan
FDG PET/CT
Non-FDG PET/CT

IX. 기타검사
Lymphoscintigraphy
Raynaud's Scam

X. 방사성동위원소 치료
I-131 therapy
Ra-223 therapy
Y-90 therapy

목차

Part I. Gamma Imaging

- 신경계
- 심혈관계
- 근골격계
- 소화기 및 간담도계

Part II. PET Imaging

- FDG PET
- Non-FDG PET

Part III. Therapy

- I-131
- Ra-223 (Xofigo)
- Y-90 therapy

Part I. Gamma Imaging

- Gamma Scintigraphy
- SPECT
- SPECT/CT

신경계 검사 - Brain SPECT

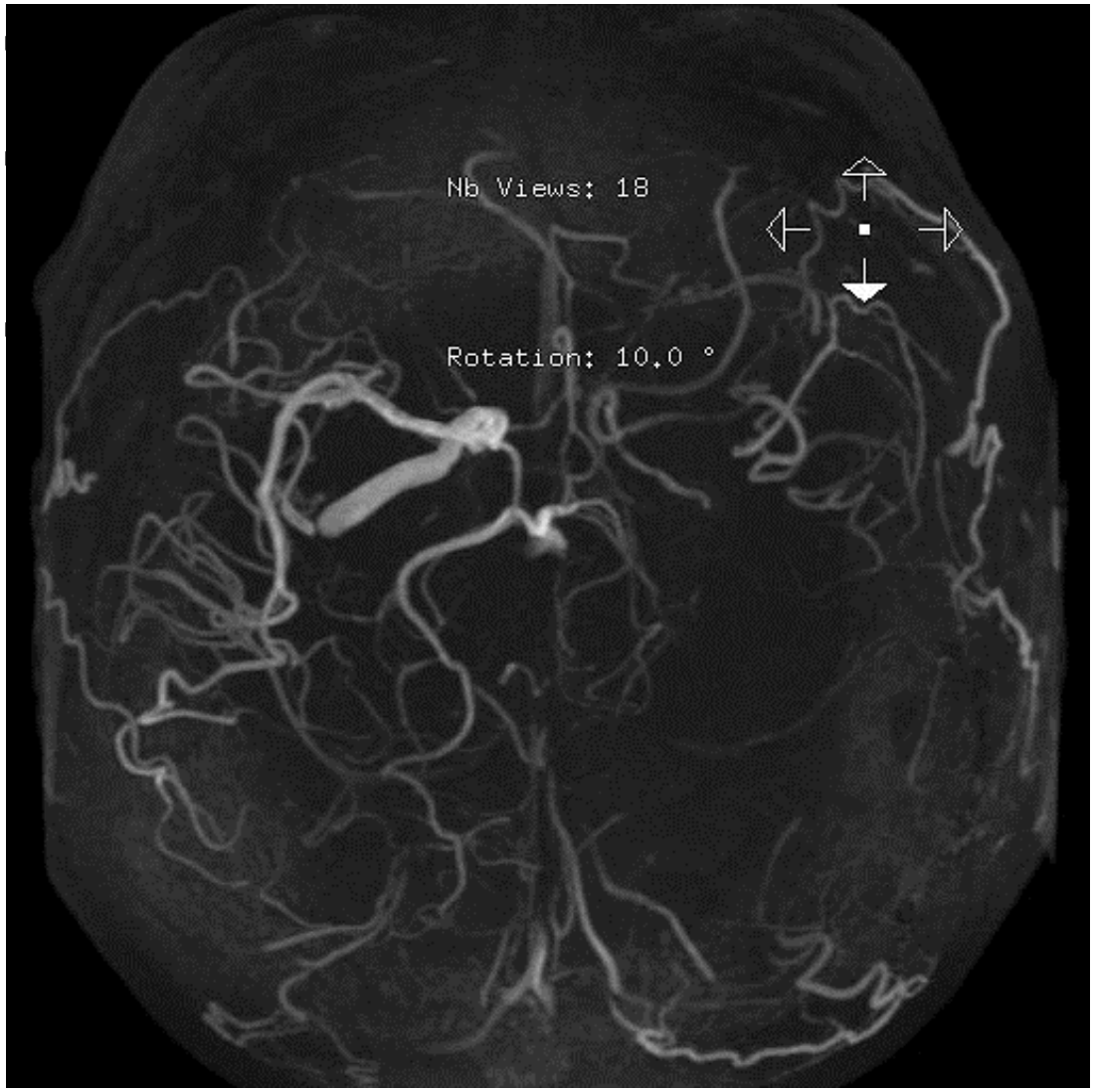
- Indication
  - 뇌혈관 질환의 진단 및 치료 반응 평가
  - 간질 병소의 위치 확인

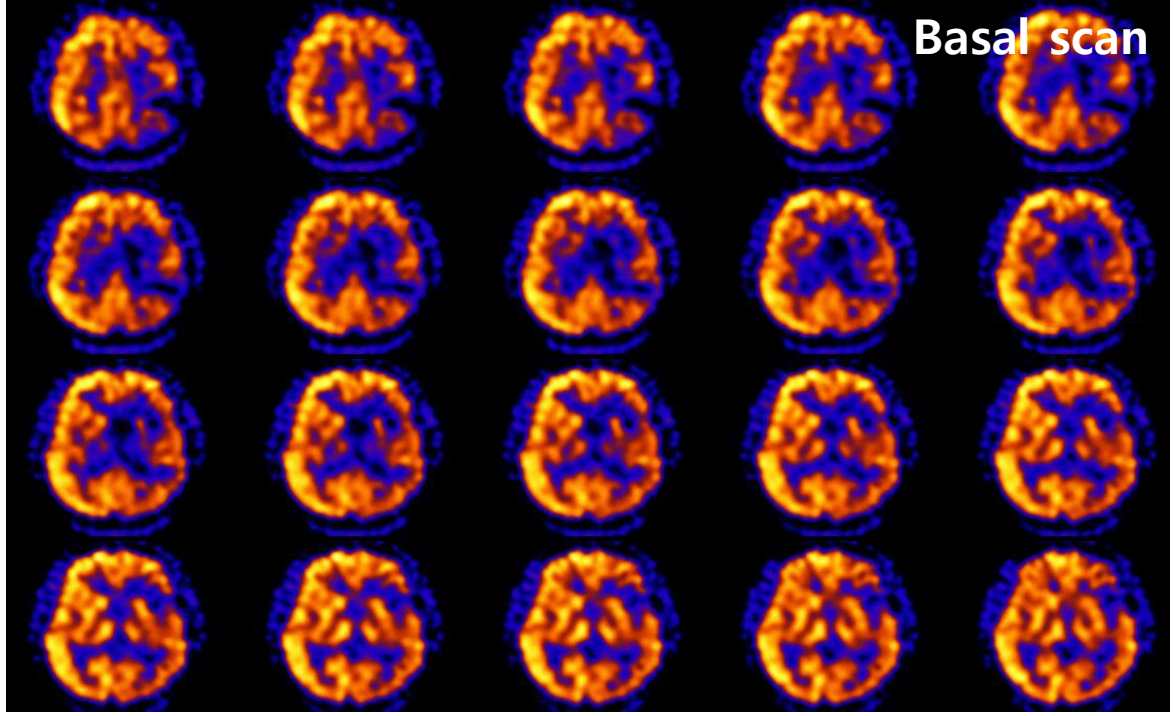
- Patient Preparation
  - 뇌혈류 분포에 영향을 줄 수 있는 카페인, 술 또는 기타 약물 중단
  - 은은한 조명과 조용한 분위기 조성
  - 환자가 눈을 뜬 상태로 검사를 진행하며 말을 하거나 움직이지 않도록 함.

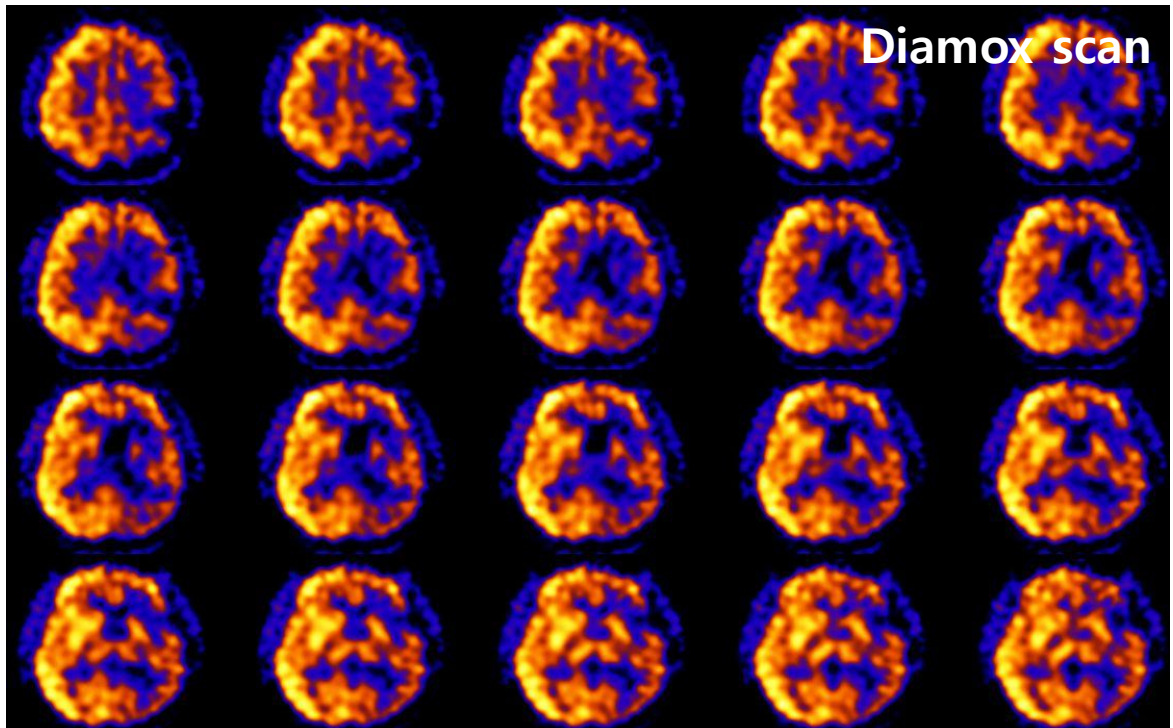
- Radiopharmaceutical
  - ^{99m}Tc-HMPAO
    : 성인(70kg) : 20 mCi for basal SPECT, 40mCi for diamox SPECT
  - ^{99m}Tc-ECD
    : 성인(70kg) : 30 mCi for basal SPECT

- 정상인의 뇌혈류 SPECT 영상에서 방사능의 분포는 좌우대칭!
- 방사능은 소뇌(cerebellum) 그리고, 기저핵(basal ganglia)과 시상(thalamus)에서도 비교적 높은 섭취!

임상 증례





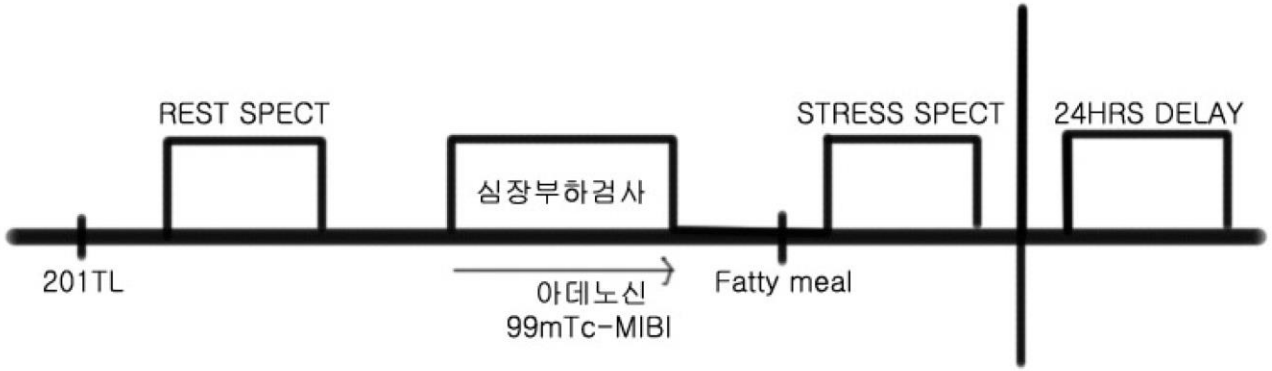


심혈관계 검사 – Myocardial SPECT

- Indication
  - 관상동맥질환
  - 위험군의 수술 전, 위험도 평가

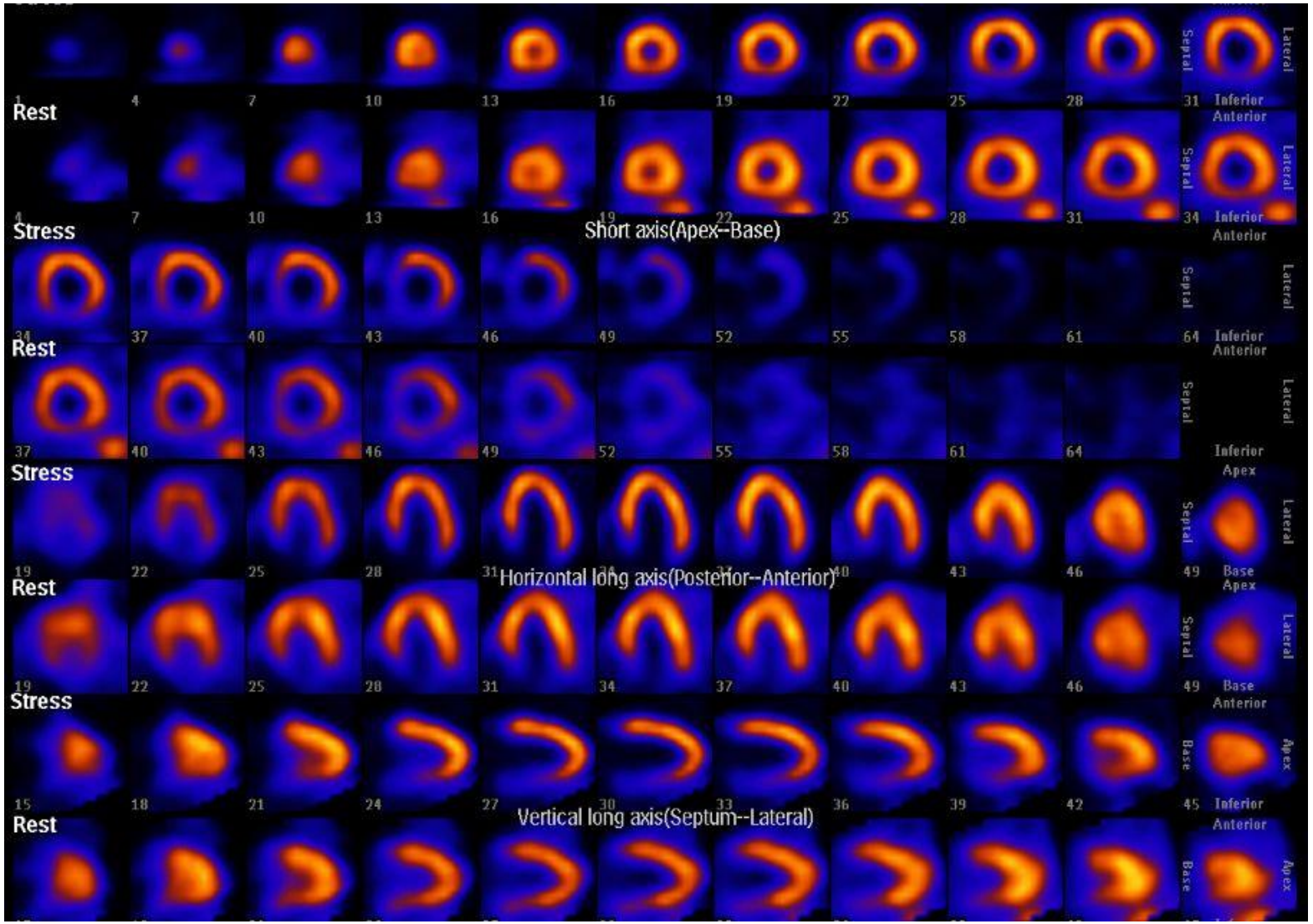
- Patient Preparation
  - 촬영 4-6시간 전, 금식
  - 흡연 및 카페인이 함유된 음식 또는 약물 제한
  - 기타 약제

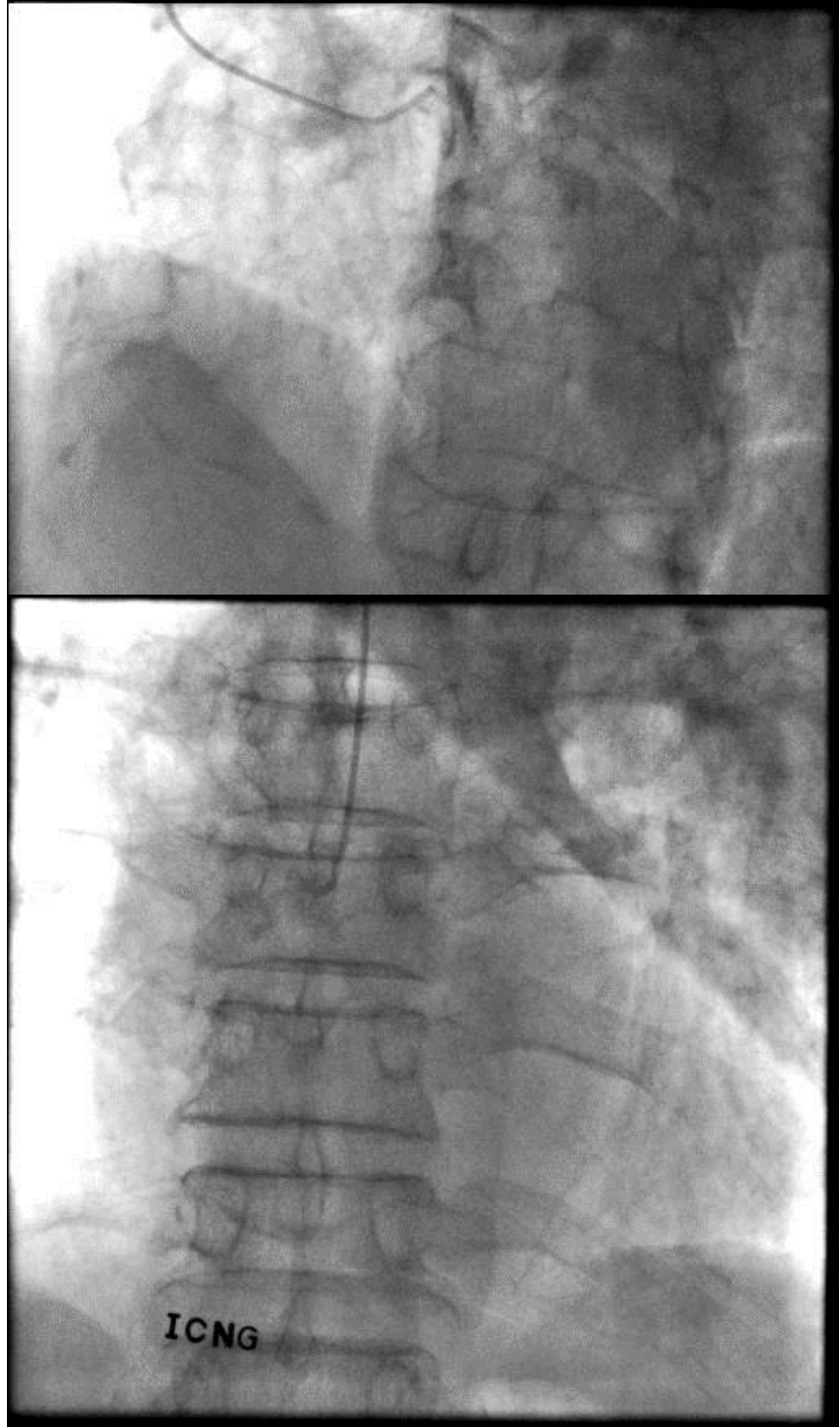
- Radiopharmaceutical
  - ^{201}Tl-Chloride : 3~3.5 mCi (2mCi at SNUH)
  - ^{99m}Tc-MIBI : 15~20 mCi (15mCi at SNUH)



- 약제 부하법
  아데노신(Adenosine)
  : 0.14mg/kg/min을 6분간 정맥 주사하고 주사 후 효과가 바로 나타나 2분내에 최대.
  반감기가 수초로 작용시간이 짧으므로 부작용이 있을 때 투여를 중지하면 즉시 회복됨.

임상 증례


Rest
Stress
Short axis(Apex--Base)
Rest
Stress
Horizontal long axis(Posterior--Anterior)
Rest
Stress
Vertical long axis(Septum--Lateral)
Rest
Septal
Lateral
Inferior
Anterior
Apex
Base


ICNG

근골격계 검사 – Bone scan

- **Indication**

  <u>whole body bone scan</u>

  - 뼈전이가 의심되거나 위험군에 속하는 암환자 (유방암, 전립선암, 골육종 등)
  - 외상 환자의 전신 검사
  - 무균성 괴사

  <u>3-phase bone scan</u>

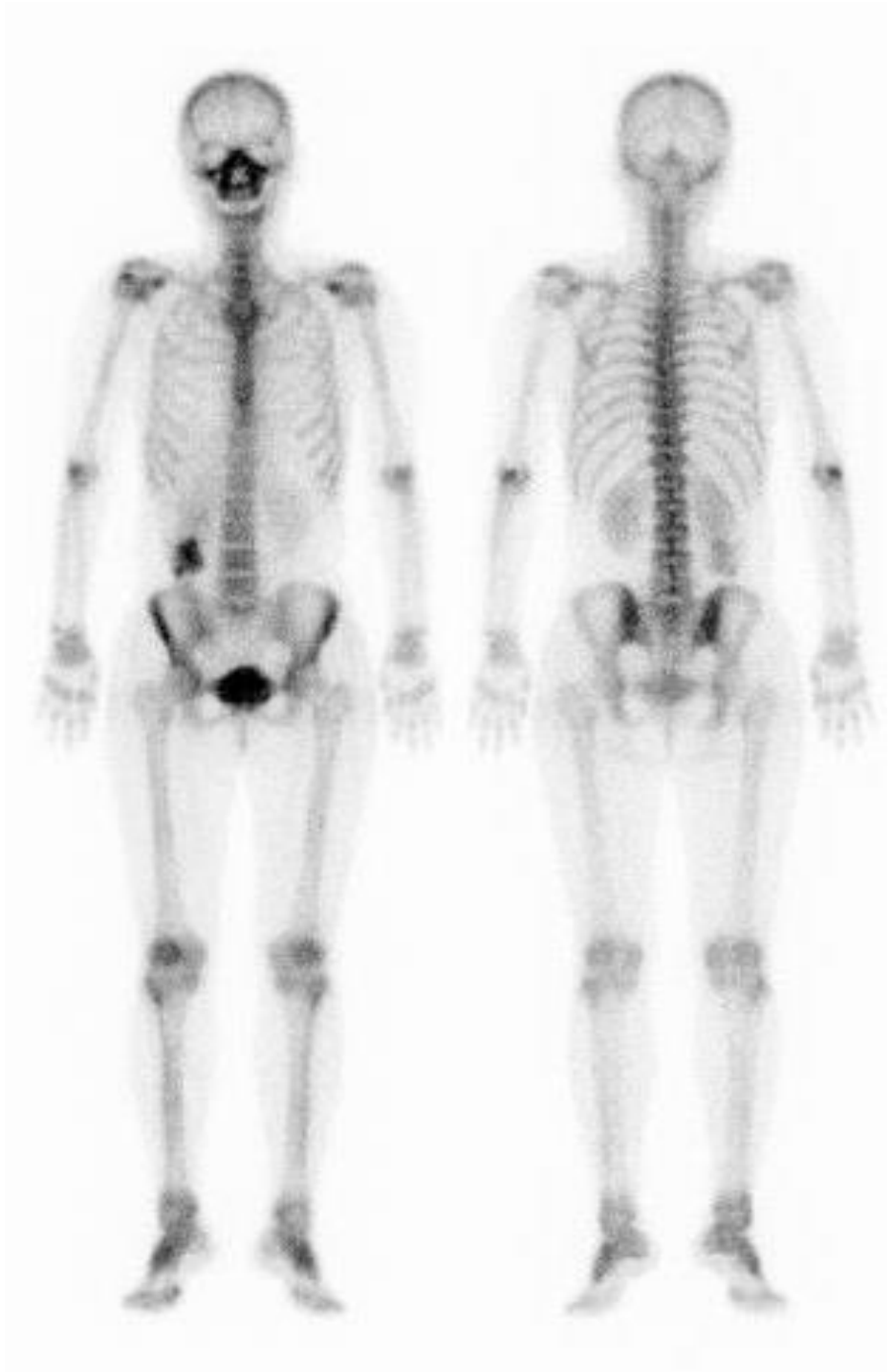
  - 골수염 의심 환자
  - 전신성 감염성 질환
  - CRPS

- **Patient Preparation**
  - 주사후 충분한 수분섭취
  - 검사직전 Emptying bladder
  - 바륨을 이용한 복부 방사선 검사 또는 다른 핵의학과 검사 시행여부 확인

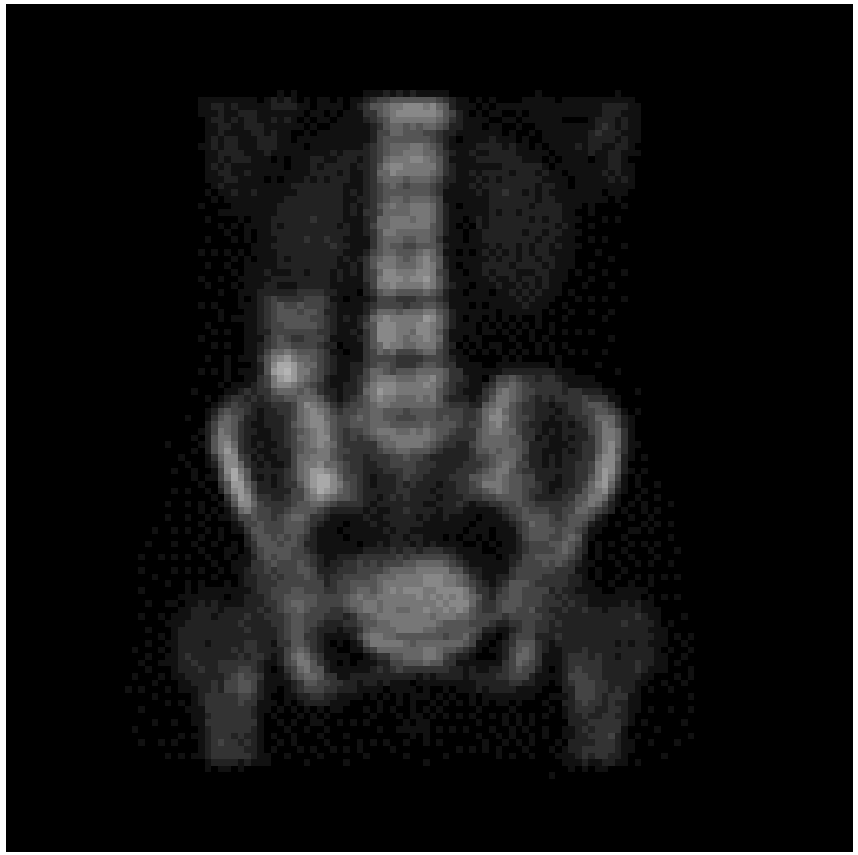
- **Radiopharmaceutical**
  - 99mTc-MDP(Methylenodiphosphonate : 20~30mCi
  - 99mTc-HEDP(Hydroxy methlene disphosphonate) : 20~30mCi

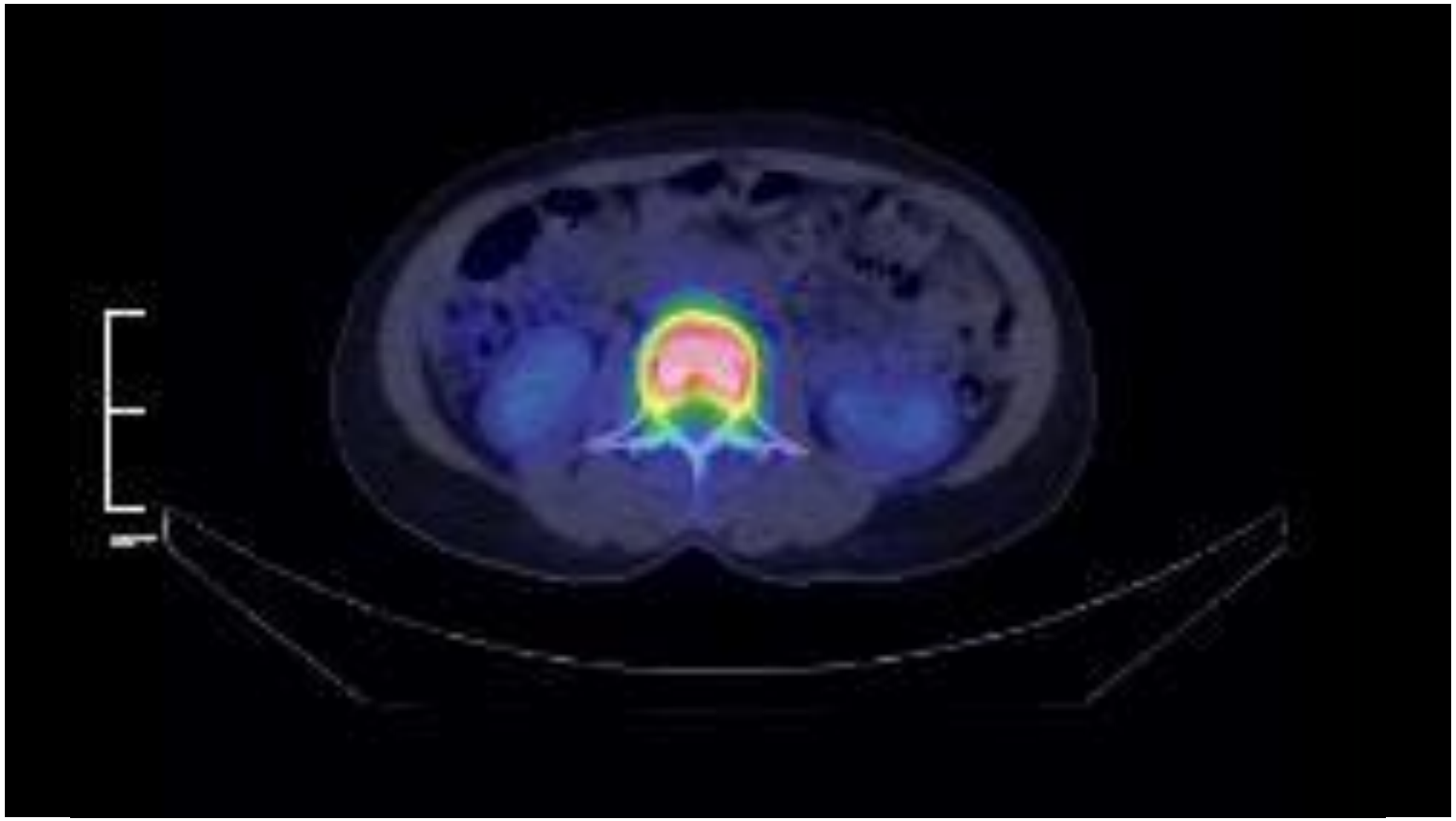
임상 증례 I

- 48세 여자 환자
- 유방암으로 수술 후, 경과 관찰



임상 증례 I

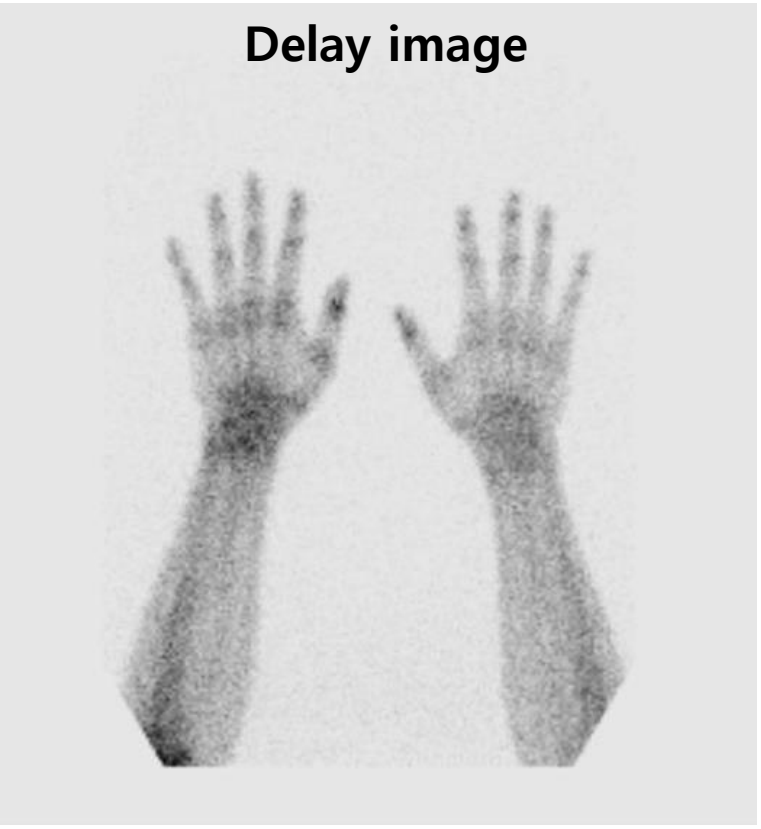




임상 증례 II

Blood pool

Delay image

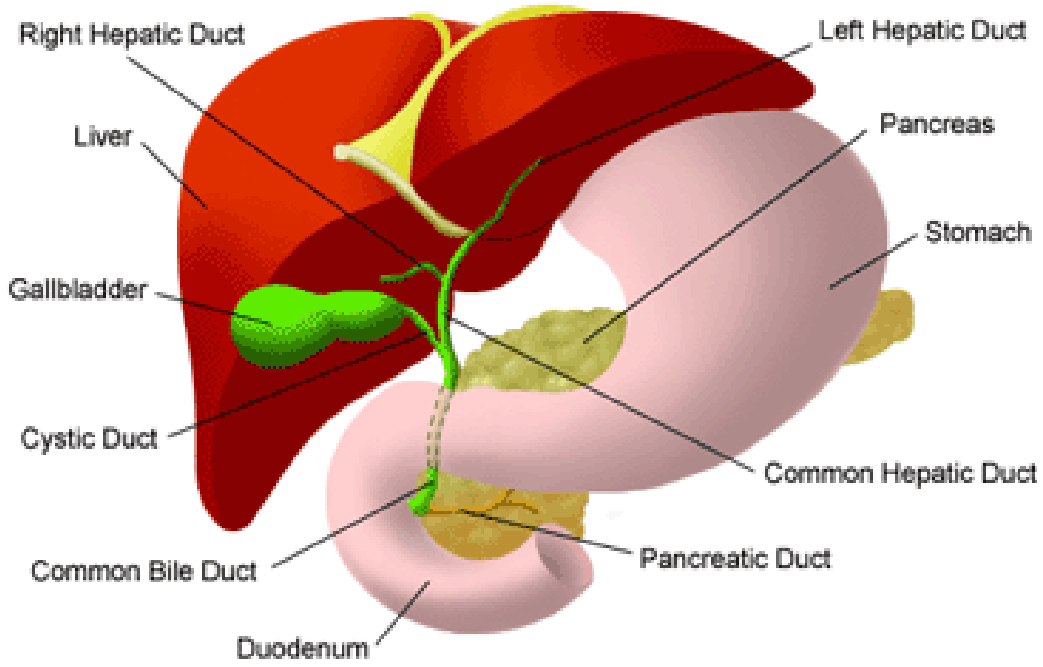


소화기 및 간담도계 검사 – Hepatobiliary Scan

- **Indication**
  - 급성담낭염
  - 황달의 감별진단
  - 담즙 누출 진단
  - 담도계 수술 후 평가

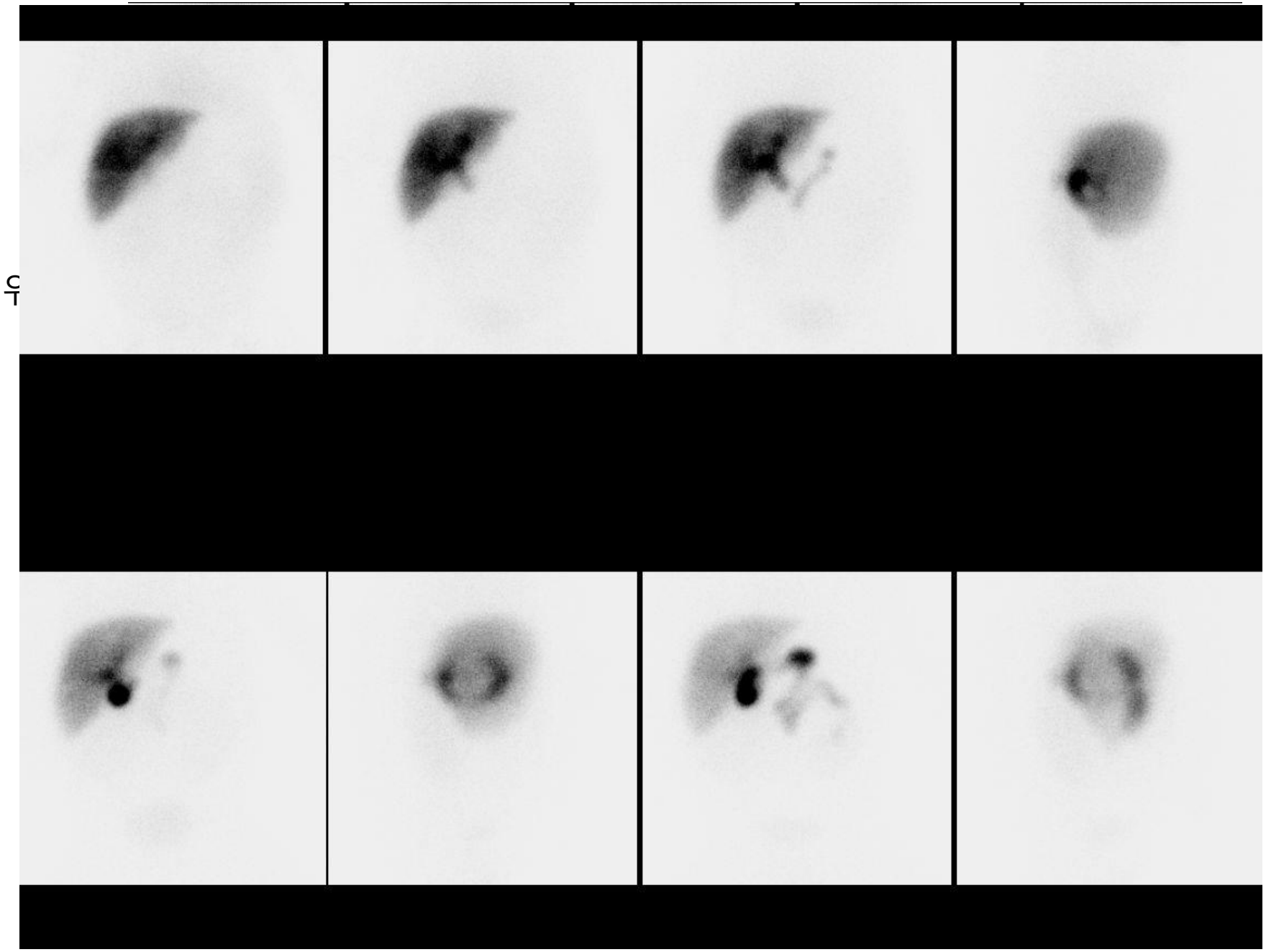
- **Patient Preparation**
  - 검사 전, 2-4시간 동안 금식

- **Radiopharmaceutical**
  - 99mTc-Mebrofenin 10-12mCi



임상 증례 I

- 8개월 여자 환아
- 황달에 대한 원인감별을 위
  검사를 시행함.



소화기 및 간담도계 검사 – Spleen Scan

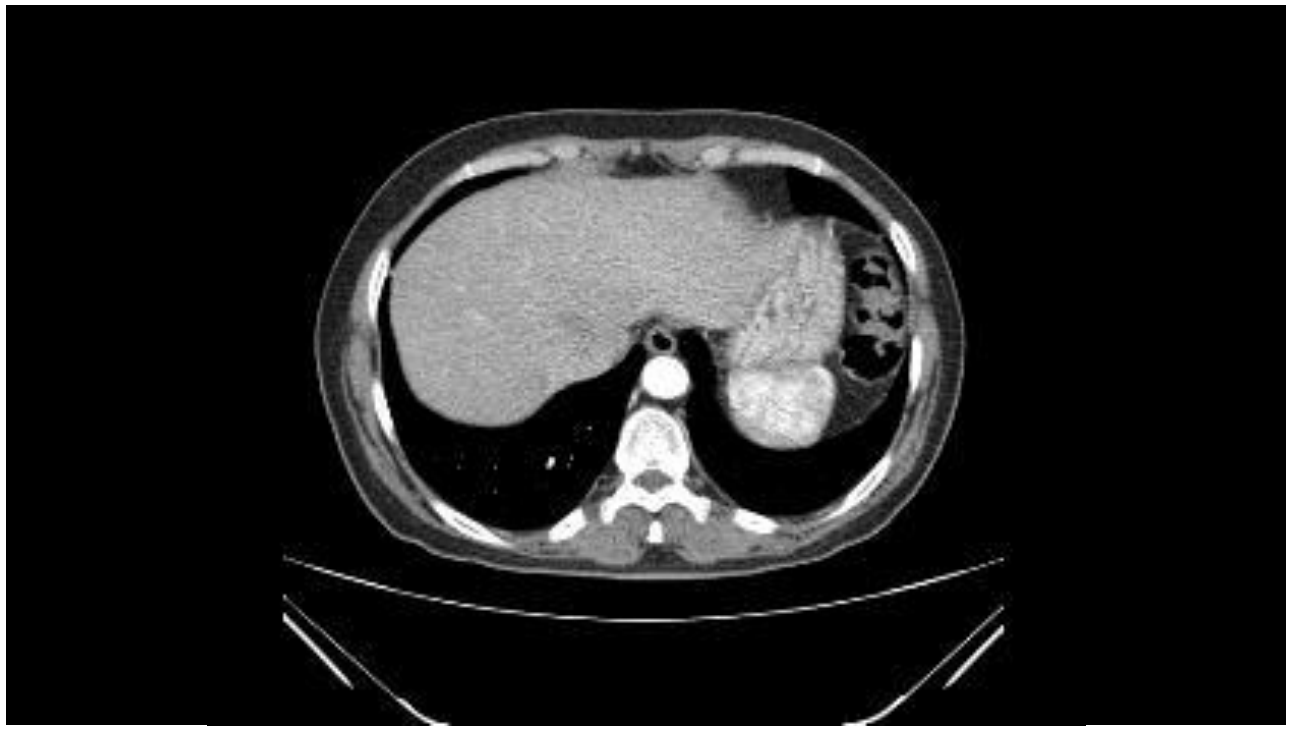
- **Indication**
  - 비장의 크기, 형태, 및 위치 판단
  - Accessory spleen or splenosis 의 진단

- **Patient Preparation**
  - RBC 표지에 영향을 줄 수 있는 약제 확인 (예> heparin 투여)

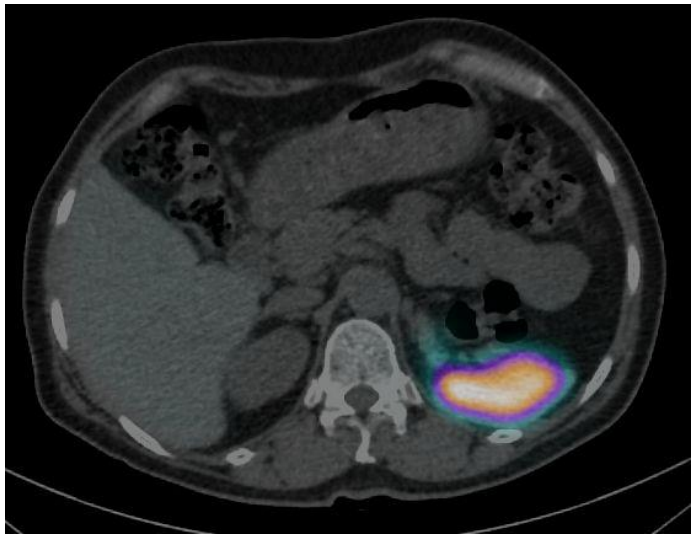
- **Radiopharmaceutical**
  - 99mTc-RBC 10-12mCi

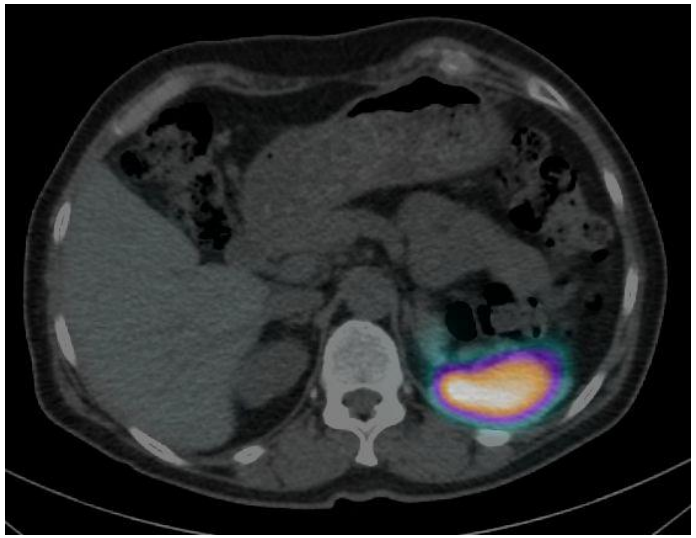
임상 증례 I

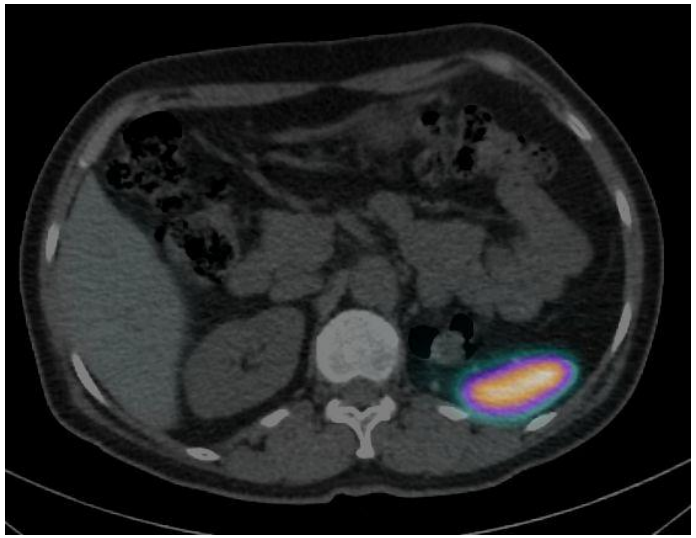
- 59세 여자 환자
- Renal cell carcinoma 로 좌측신장 절제술 시행하고 경과 관찰중임.
  경과 관찰 목적으로 시행한 CT 에서 췌장에 small nodule 이 발견되어 이에 대한 평가를 위해 검사를 시행함.

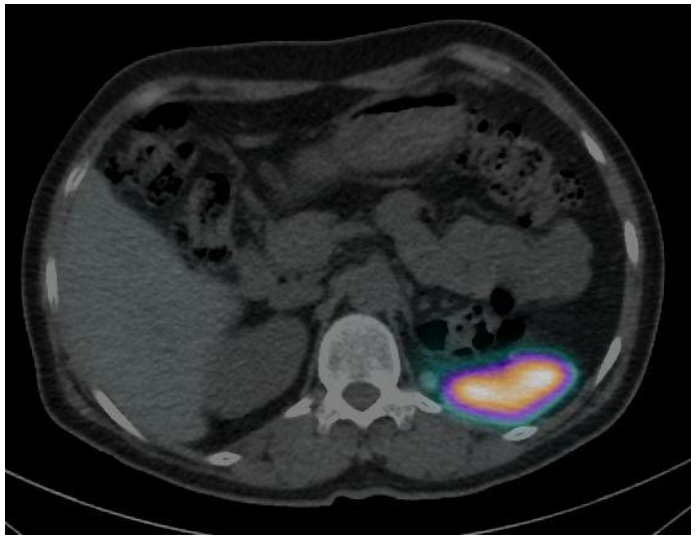


임상 증례 I









Part II. PET Imaging

- FDG PET
- Non-FDG PET

FDG PET/CT

Overview

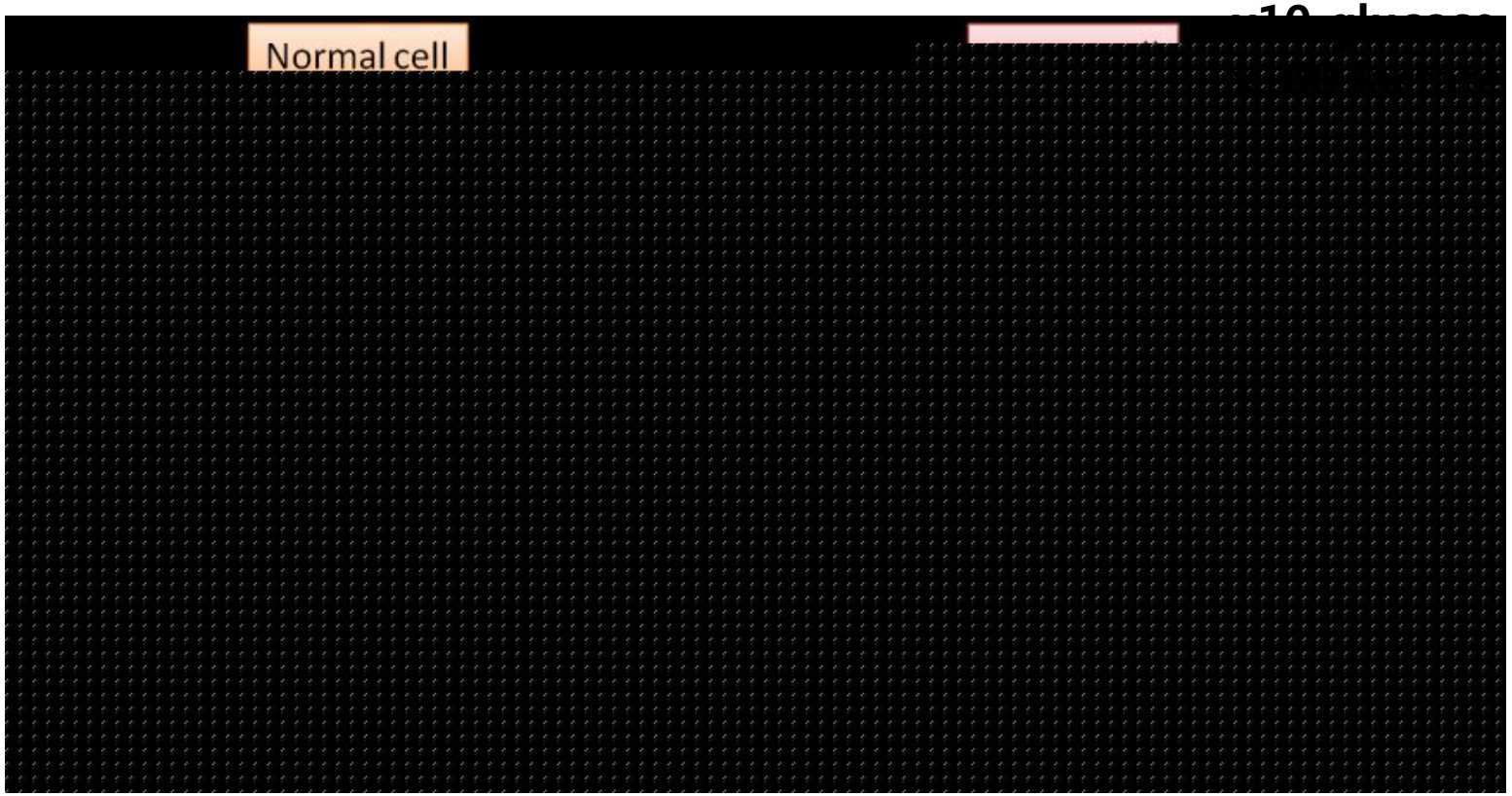
- PET basics & applications
- PET quantitative index
- Response evaluation
  - PERCIST 1.0 in solid tumors
  - New Lugano criteria in lymphoma

PET basics & applications

- PET = Positron Emission Tomography
- Functional or metabolic assessment of tissue
- Used in Oncology, Neurology, and cardiology

Warburg effect & cancer cell metabolism

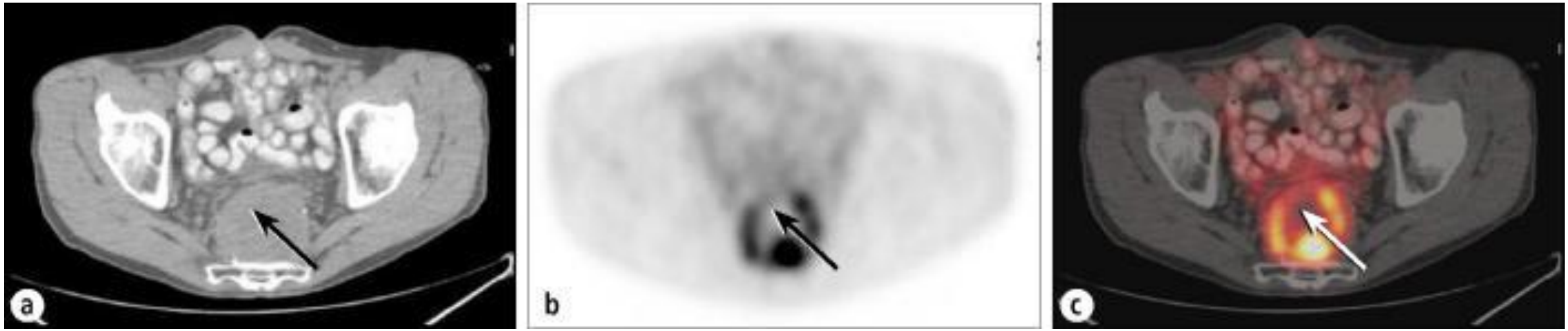
High rate of glycolysis, even under aerobic conditions



Courtesy of S. Ha

Clinical application II

Assistance with biopsy



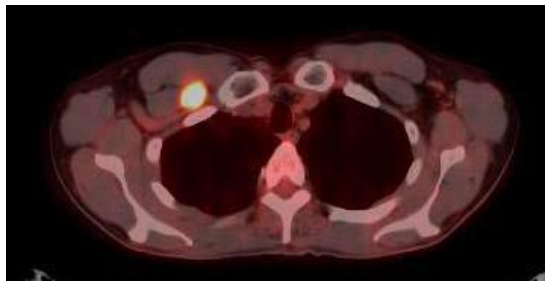
Griffeth et al, 2005

- CT-guided biopsy negative (arrow = biopsy route)
- Repeat biopsy based on PET/CT

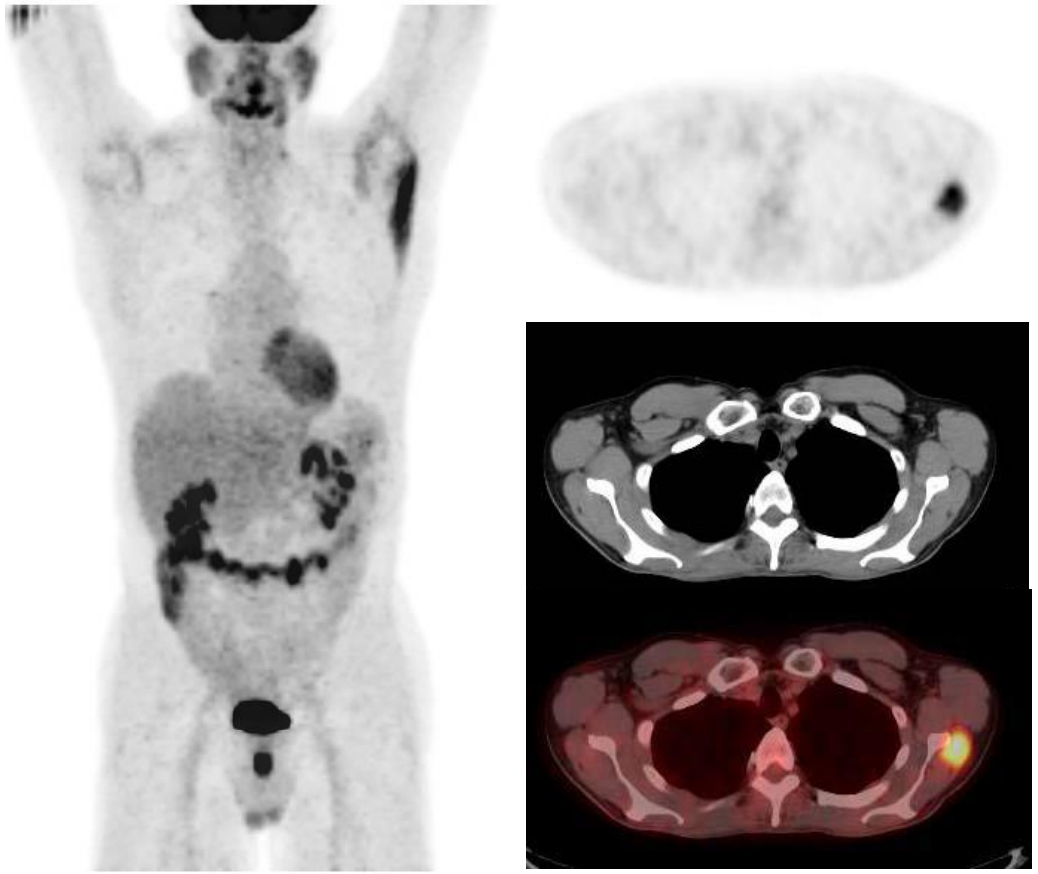
Courtesy of S. Ha

Clinical application III

Restaging/ Therapy response evaluation



Before chemotherapy

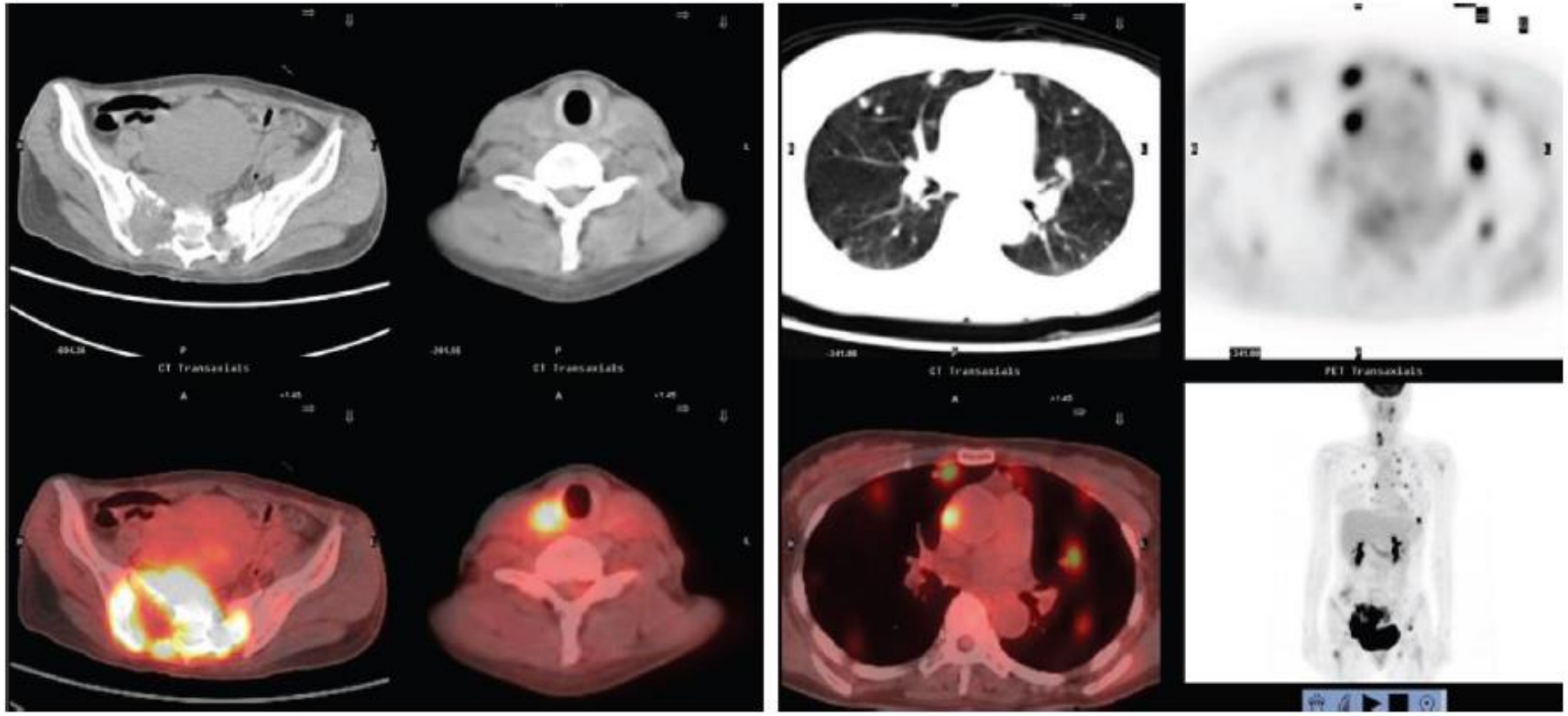


After chemotherapy

Courtesy of S. Ha

Clinical application IV

Evaluation of metastasis of unknown origin



Courtesy of S. Ha

Quantitative index

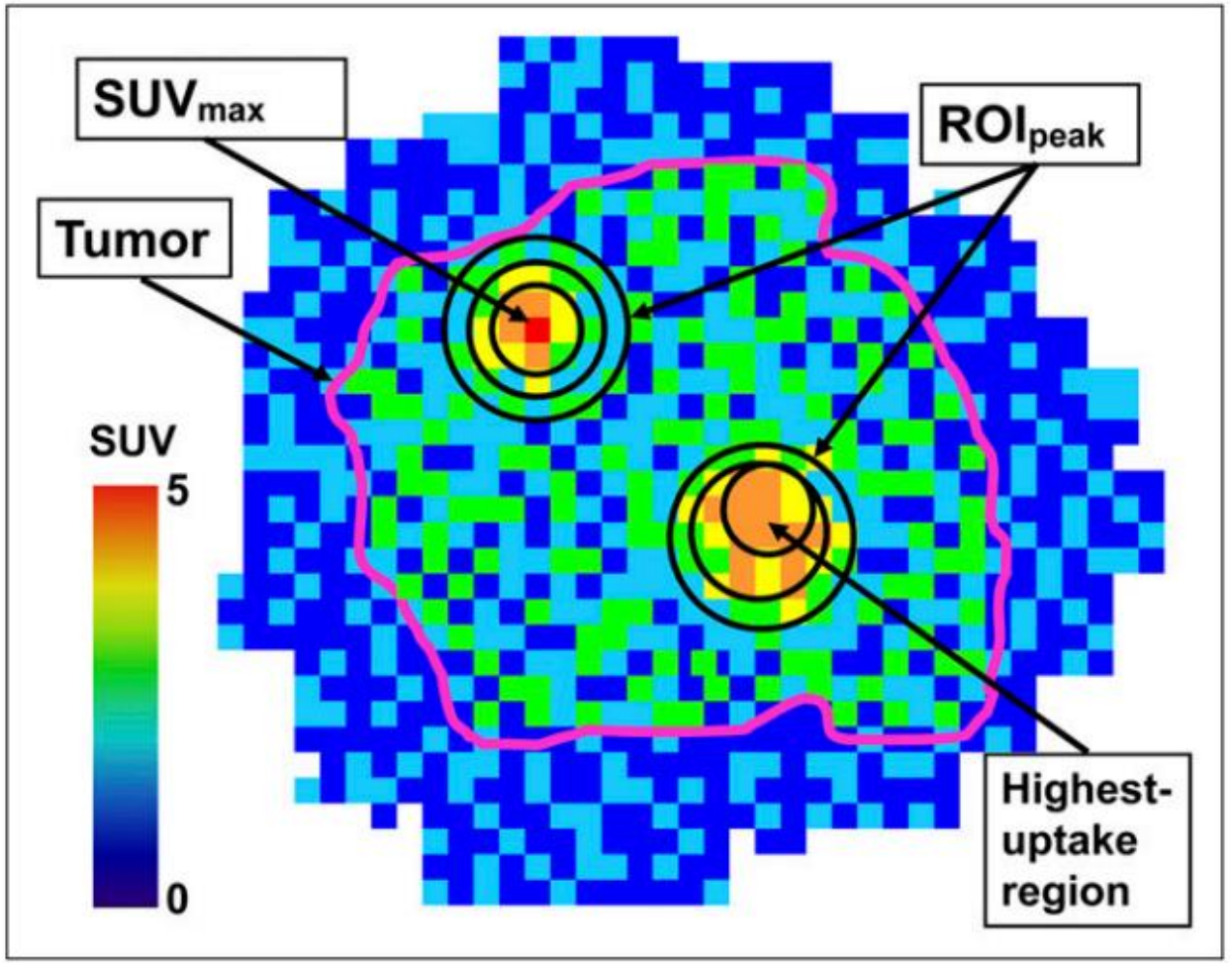
Qualitative or Quantitative interpretation

- Most applications to date have been Qualitative.
- In treatment response assessment, especially if looking for small treatment induced changes, quantitation will be needed.
- Quantitation requires greater attention to technical details than qualitative imaging.
- Standardization of methods including analytical methods is required.

Courtesy of S. Ha

What to measure

- SUVmax, SUVpeak, SUVmean,
- Volume-based Parameter
  - Metabolic Tumor Volume (MTV)
  - Total Lesion Glycolysis (TLG)



Vanderhoek, et al. JNM 2012

Courtesy of S. Ha

SUV in FDG PET

- Representative semi-quantitative index reflecting glucose metabolism
- Simple, reproducible, clinically applicable
- Dose uptake ratio
- Prognostic factor in many kinds of cancer
- Adjusted for injected dose, patient's body weight (or Lean body Mass)

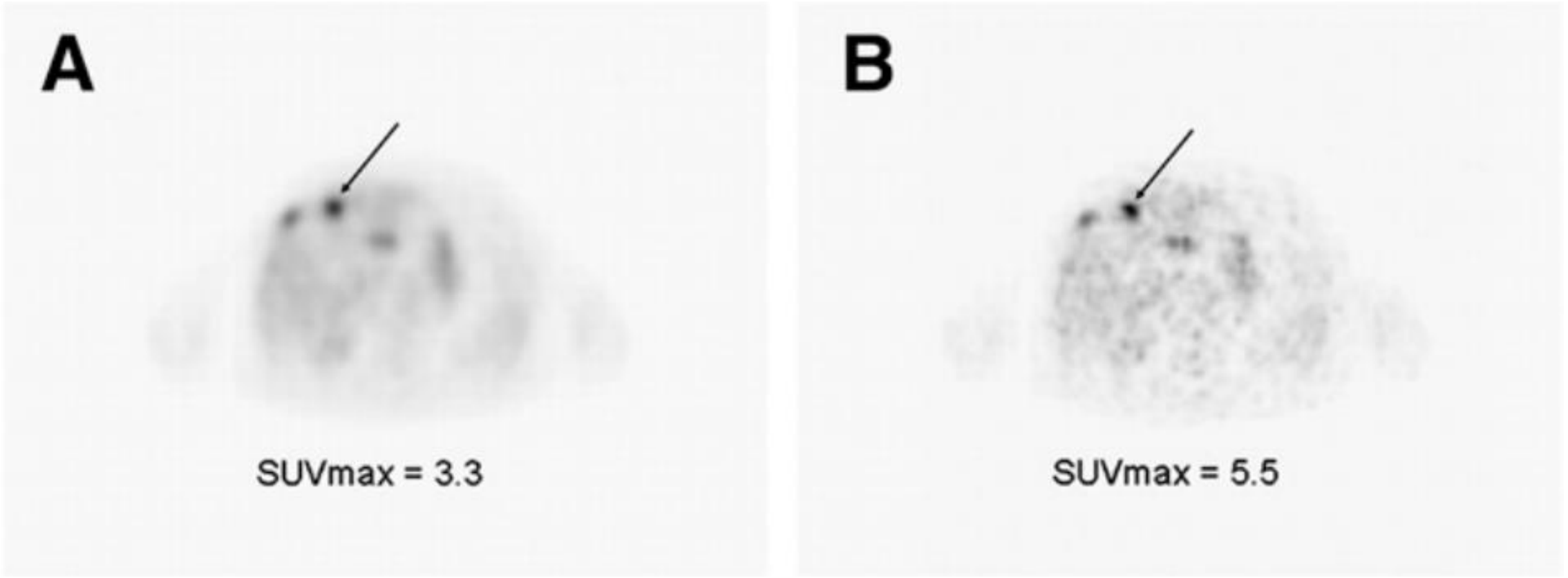
Courtesy of S. Ha

Factors Affecting ^{18}F-FDG PET Quantitation

Category	Factor
Technical errors	Calibration (10%) Residual activity in syringe (5%) Incorrect calculation of decay time (10%) Quality of administration (50%)
Biologic factors	Blood glucose level (15%) Time interval between PET acquisition and injection (15%) Patient motion (or breathing) (30%)
Physical factors	Scan acquisition parameters (15%) Image reconstruction parameters (30%) ROI (50%) Normalization factor for SUV Use of contrast agents (15%)

Boellaard, et al. JNM 2009

Effects of image reconstruction on SUV_{max}

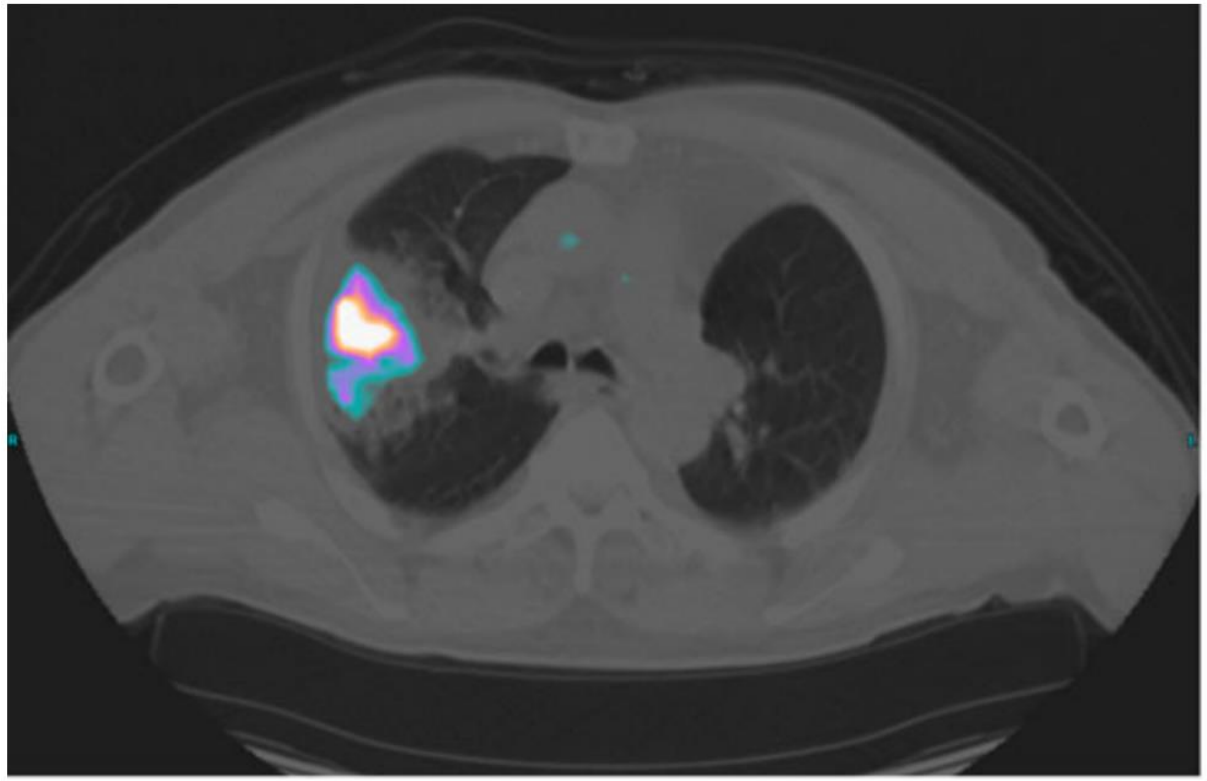


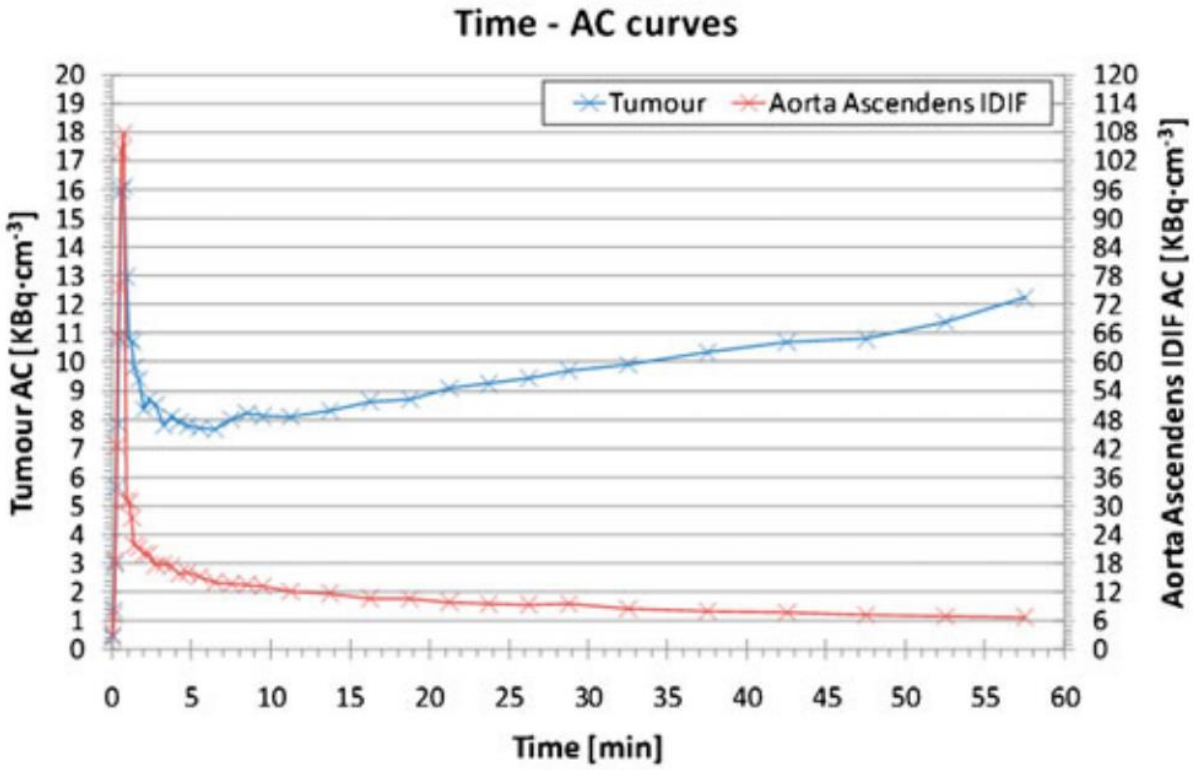
OSEM 2i 8s
Matrix size 128 * 128
FWHM 8 mm

OSEM 4i 16s
Matrix size 256 * 256
FWHM 5 mm

Courtesy of S. Ha

Effects of Uptake Time on Tumor Uptake





Vriens, et al. EJNMMI 2010

Courtesy of S. Ha

Dual Time Point Imaging (DTPI)

- Helpful in differentiating malignancy from benign

  - Tissue with high glycolysis continuously increasing amounts of FDG
  - Improved blood pool and urinary tract clearance of FDG

- Increased sensitivity

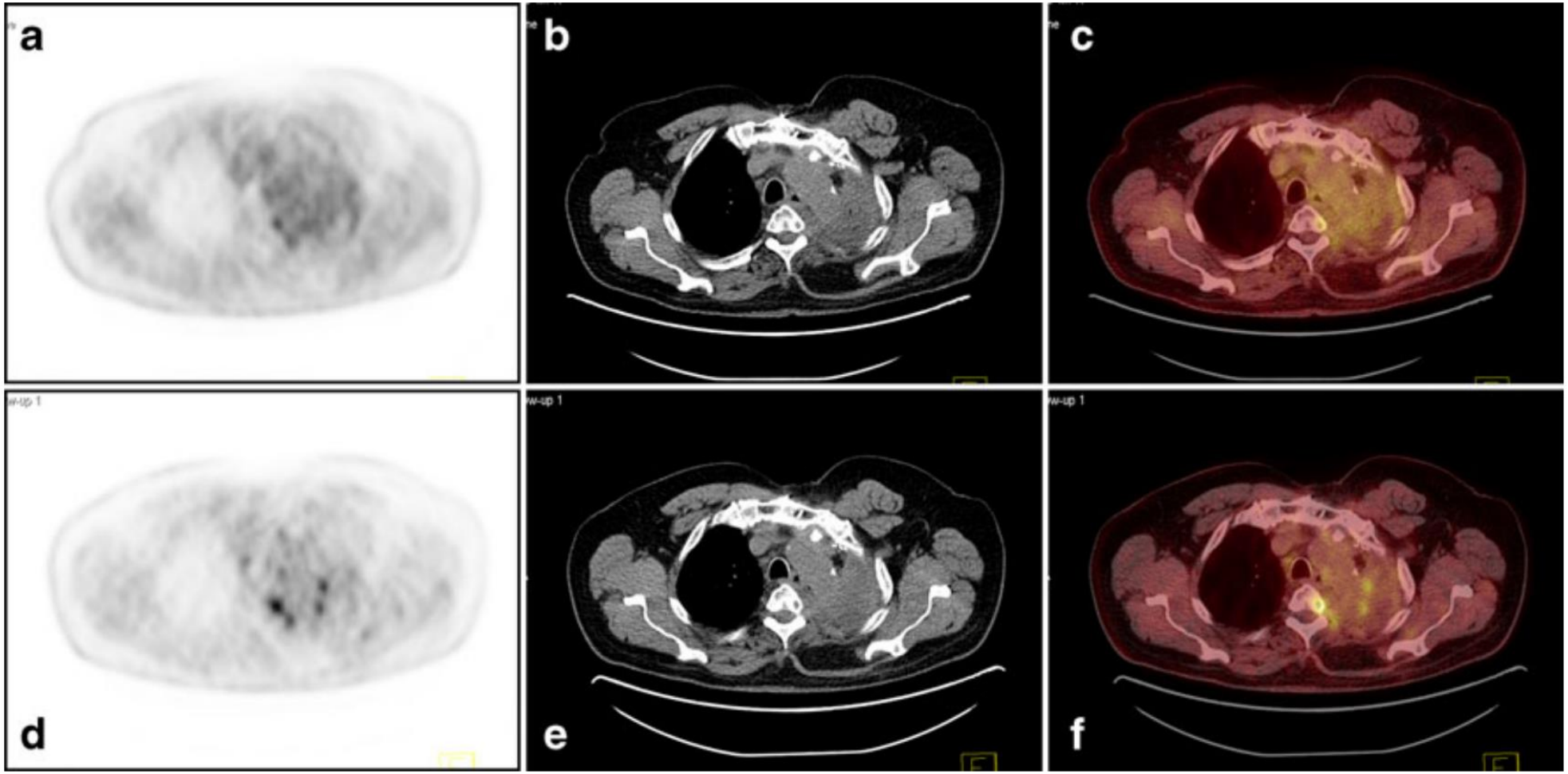
  - Detecting suspected occult lesions
    e.g.) equivocal lymph node lesion in a patient with an FDG-avid cancer
  - Defining the extent
  - Obese patient ; due to increased lesion-to-background ratio

Courtesy of S. Park

Dual Time Point Imaging (DTPI)

Initial image (64min)

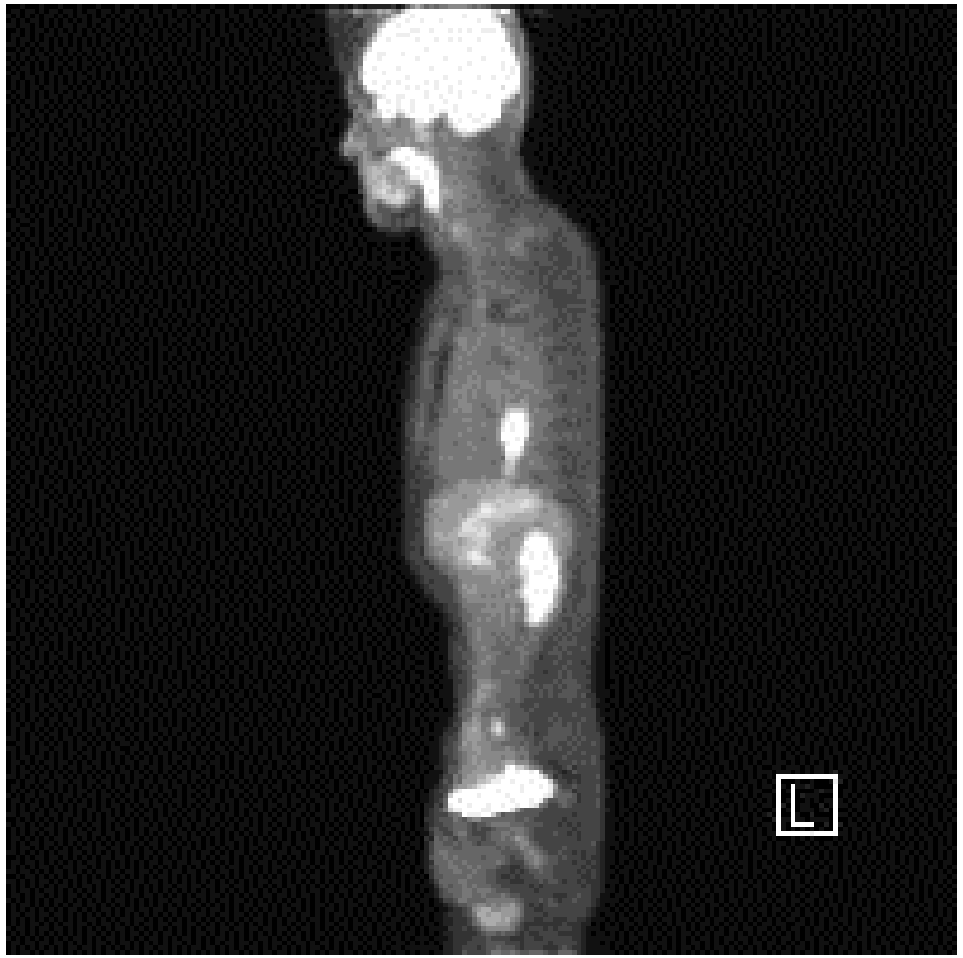
Delayed image (131min)



Cheng, et al. EJNMMI 2013

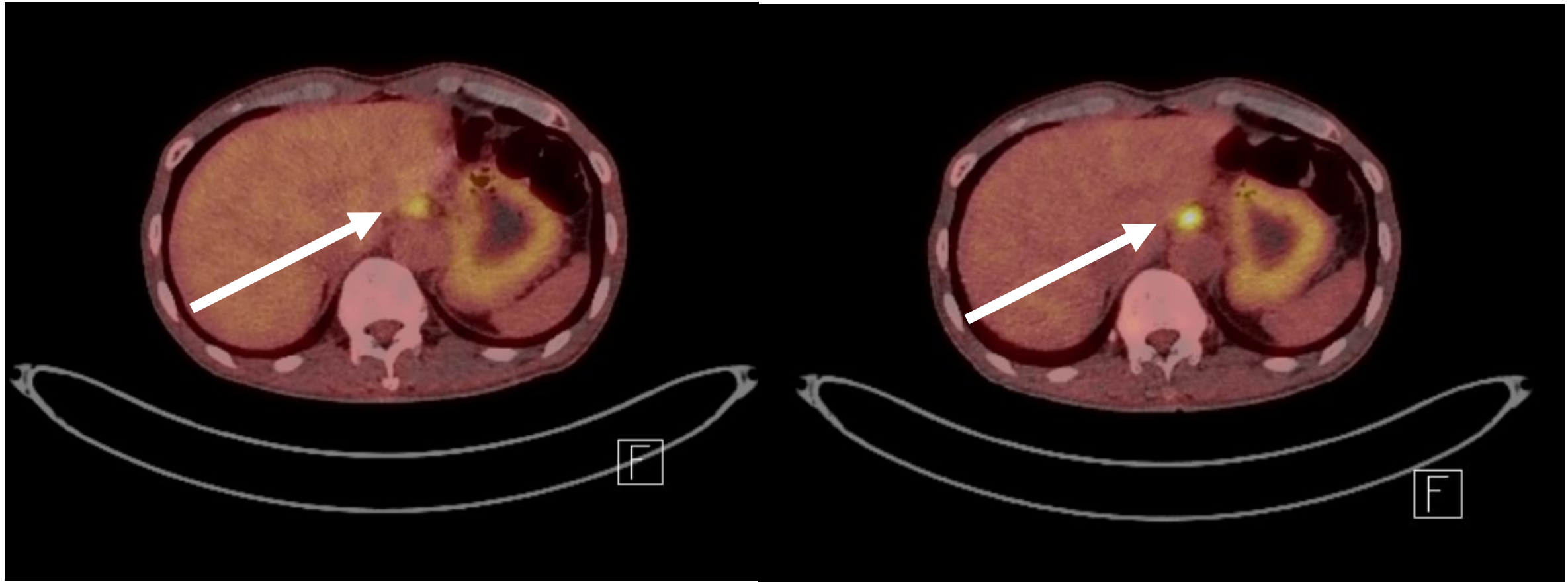
임상 증례 I

- M/64
- Initial staging for esophageal cancer



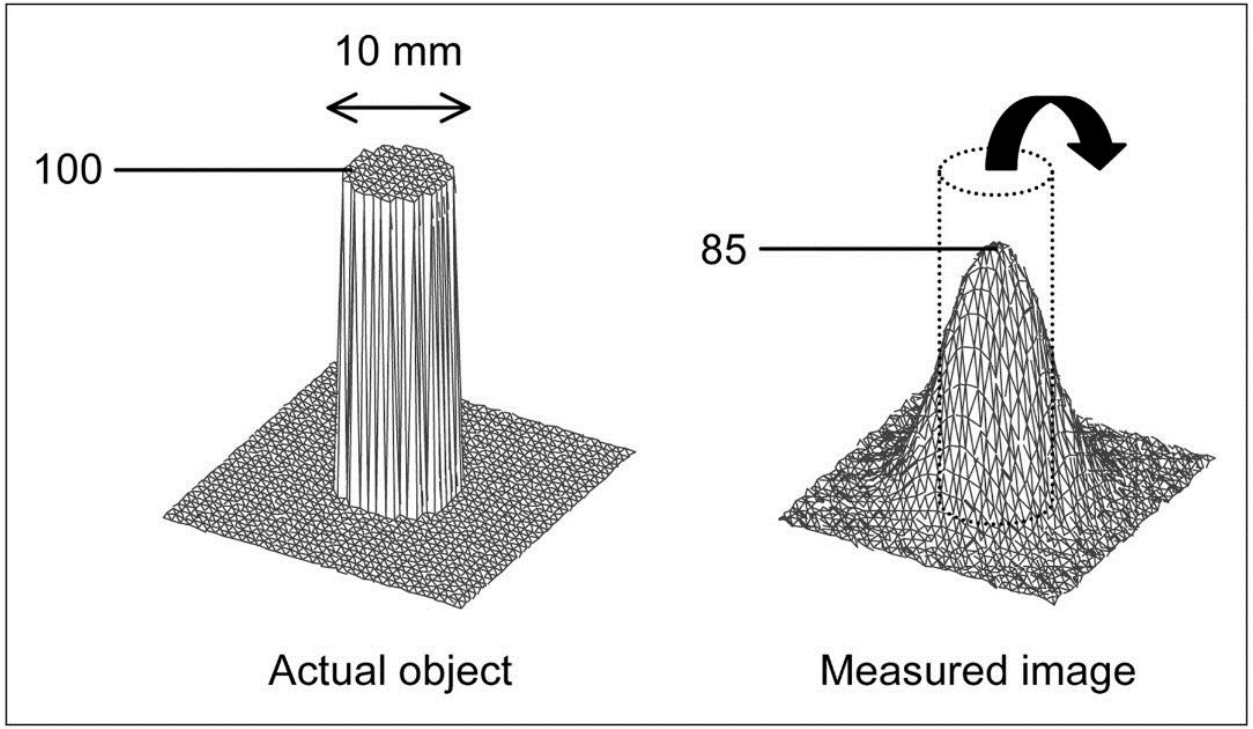
Courtesy of S. Park

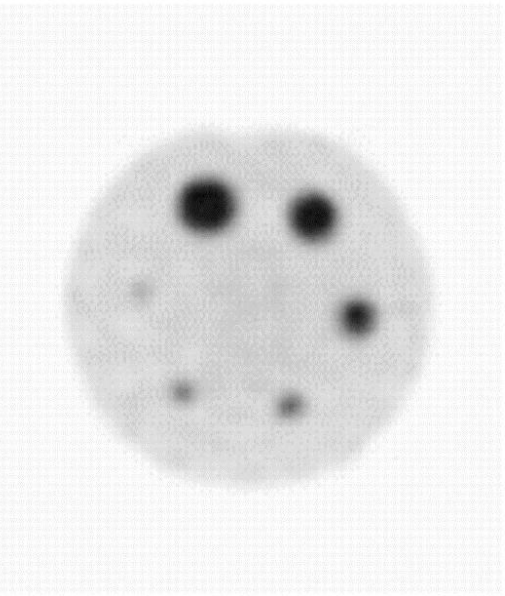
임상 증례 I

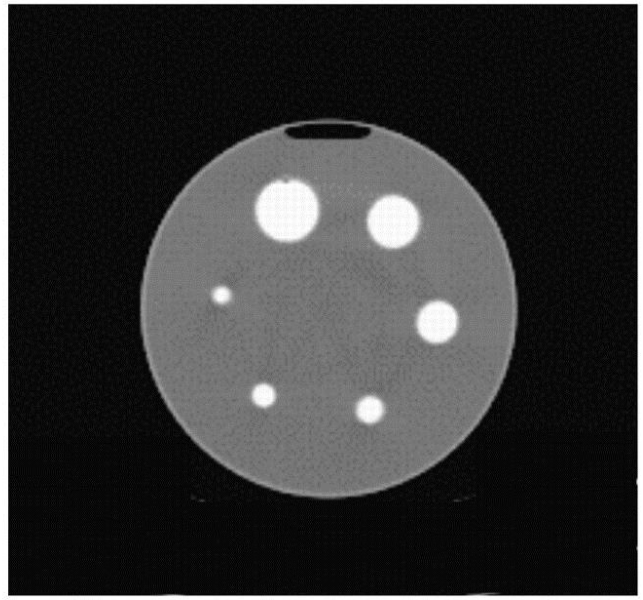


Courtesy of S. Park

Partial Volume Effect (PVE)



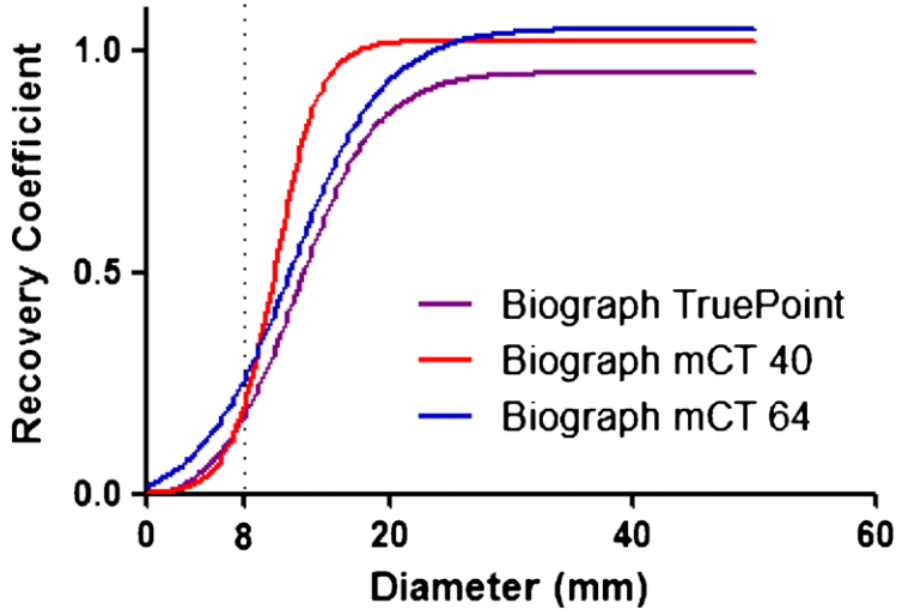


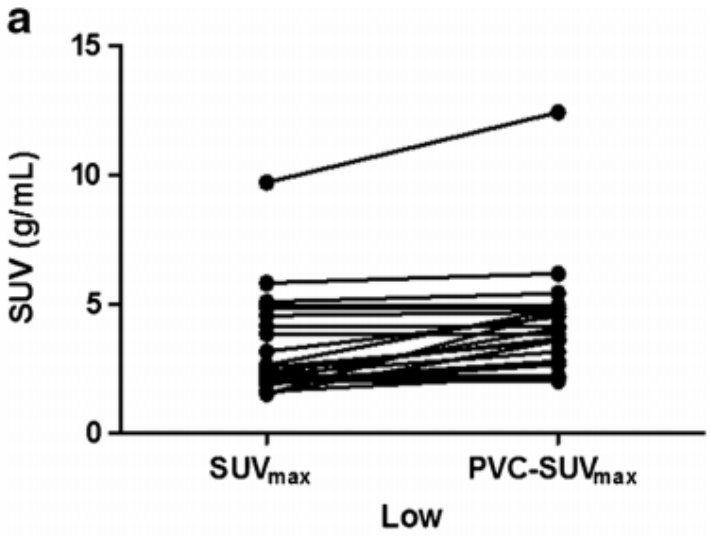


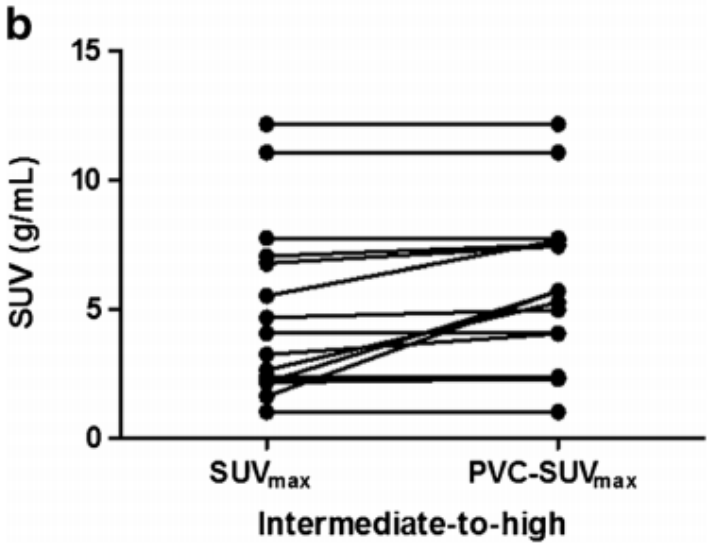
Courtesy of S. Ha

Partial Volume Correction for Small Sized Tumor

$$\text{PVC-SUVmax} = \frac{\textit{Measured SUVmax} - \textit{background activity}}{\textit{RC for SUVmax}} + \text{background activity}$$



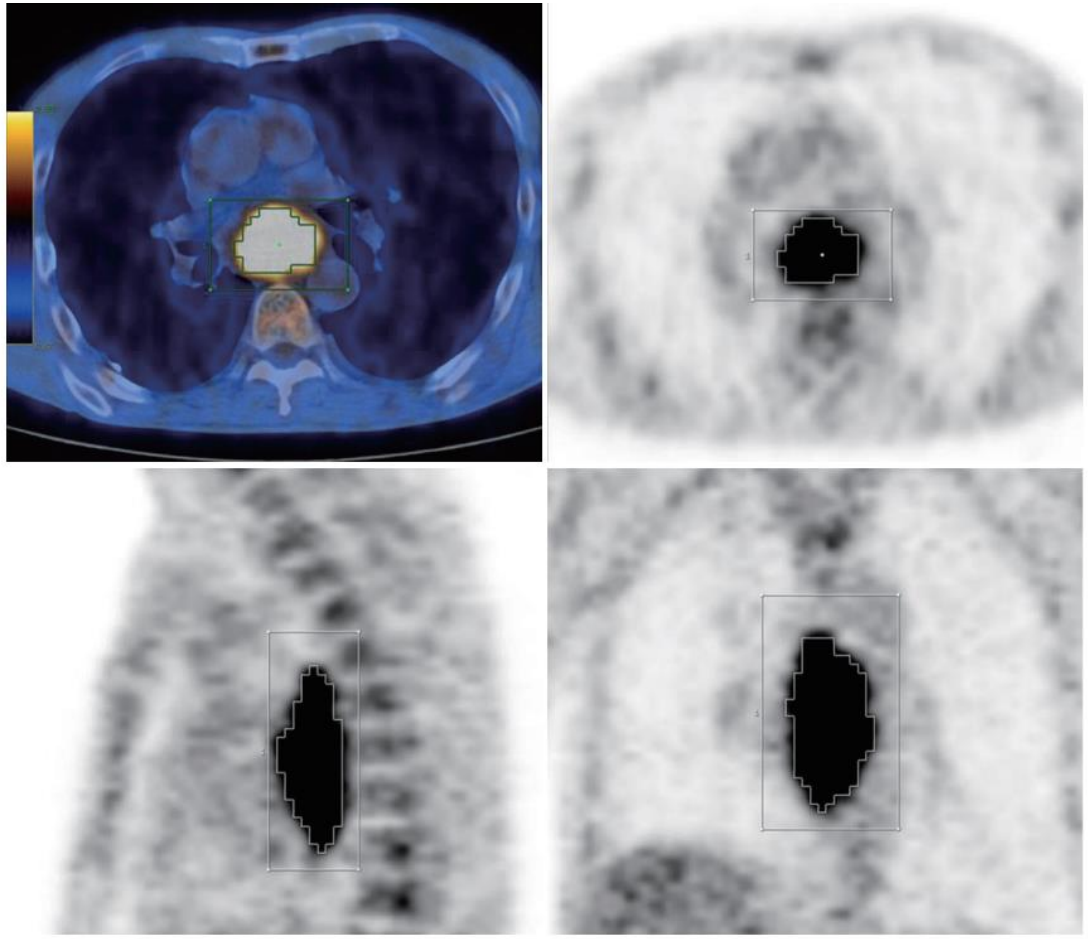




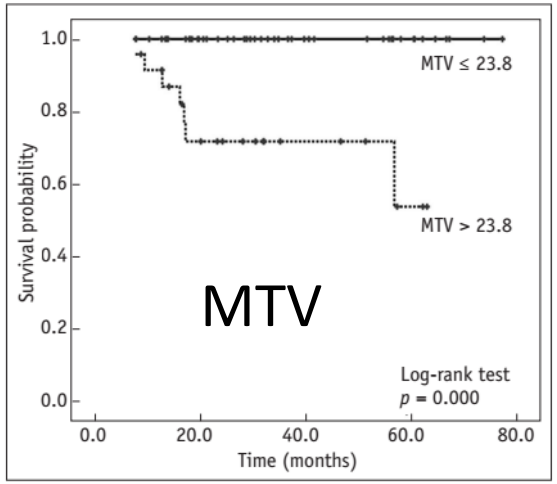
Lee & Ha, et al. EJNMMI 2016

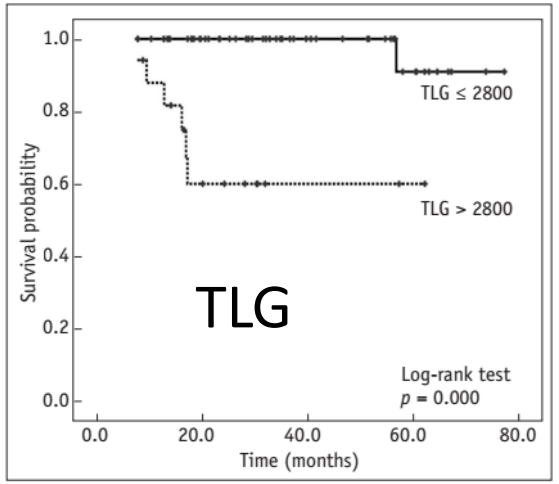
Volume-based PET parameters

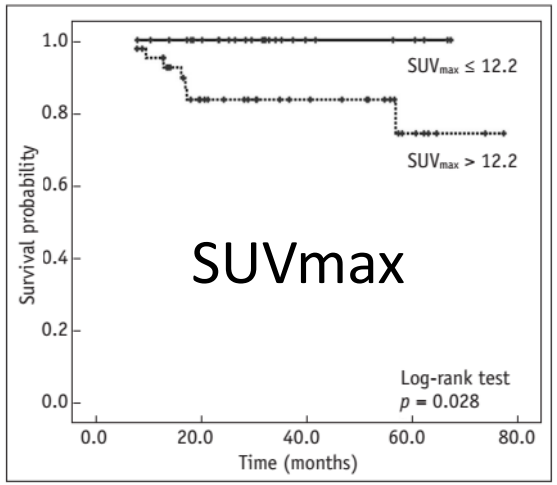
- Indices of Metabolic Tumor Burden



Esophageal cancer



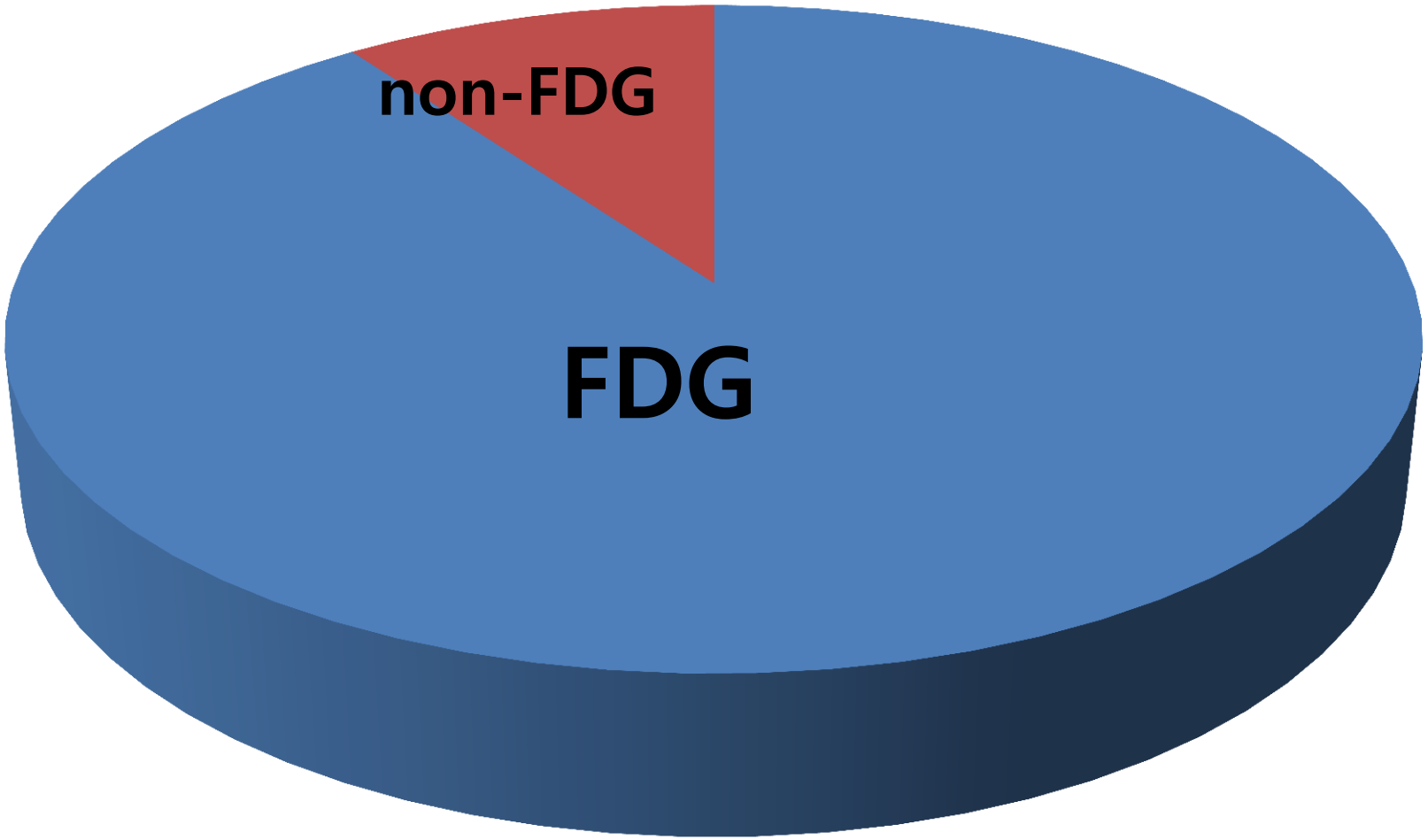




Courtesy of S. Ha

Non-FDG PET/CT

PET/CT in Cancer Imaging



Pitfalls of FDG PET

False positive
- inflammation
- physiologic uptake (brain, bowel, etc)

False negative
- FDG non-avid tumors
  (ex. HCC, stomach cancer, neuroendocrine tumors)

Non-FDG PET in Oncology

- ^{11}C-Choline / ^{18}F-Choline
- ^{11}C-Acetate
- ^{11}C-Methionine
- ^{18}F-FLT
- ^{18}F-FET
- ^{18}F-MISO / ^{64}Cu-ATSM
- ^{18}F-FDOPA
- ^{68}Ga-PSMA
- ^{68}Ga-DOTA-somatostatine analogues

검사명	신의료기술 고시번호	신의료기술 고시상 적응증 (질환)	방사성의약품
F-18 NaF PET (제한)	제2010-105호	악성종양의 뼈 전이	조제실제제/품목허가
C-11 Acetate PET	제2010-105호	간암	조제실제제
F-18 FLT PET	제2012-92호	폐암	품목허가
F-18 FPCIT PET (제한)	제2012-112호	파킨슨증	품목허가
N-13 Ammonia PET (비급여)	제2012-112호	관상동맥질환	조제실제제/품목허가
C-11 Methionine PET (제한)	제2013-114호	뇌종양, 부갑상선기능항진증, 전립선암, 폐암	조제실제제
F-18 FDOPA PET	제2014-89호	뇌종양, 신경내분비종양	조제실제제/품목허가
Ga-68 DOTATOC PET (급여)	제2014-198호	신경내분비종양	조제실제제
F-18 FMISO PET	제2015-58호	악성종양	조제실제제

검사명	신의료기술 고시번호	신의료기술 고시상 적응증 (질환)	방사성의약품
F-18 Florbetaben PET (비급여)	제2015-73호	인지 장애 환자 및 인지 장애 의심 환자	품목허가
F-18 Flutemetamol	제2015-209호	인지 장애 환자 및 인지 장애 의심 환자	품목허가
C-11 Methionine PET	제2016-449호	신장암 (제한적 사용)	조제실제제
Radioiodine SPECT/CT (급여)	제2012-131호	갑상선암	
I-123 FPCIT SPECT (제한)	제2012-112호	파킨슨	
Ra-223 (Xofigo)			품목허가

Amino acid

- Increased amino acid transporter in malignant transformation

- Low uptake in normal brain tissue
  → higher tumor to normal tissue contrast

^{11}C-methionine

^{18}F-FDOPA

^{18}F-FET

DNA synthesis

- High proliferative rate in malignant tumor cells

- Very low uptake in normal brain tissue
  → higher tumor to normal tissue contrast

^{11}C-Thymidine

^{18}F-FLT

Fatty acid synthesis

- Increased de novo fatty acid synthesis in tumors for membrane biogenesis
  - glucose dependent de novo lipogenesis

- Alternative salvage lipogenic pathway
  - direct production of acetyl-CoA from free acetate in cytosol

^{11}C-Acetate

^{11}C-Choline

^{18}F-FCH

Somatostatin Receptor

High expression

- Neuroendocrine tumors (SSRT1 and SSRT2)
  - pheochromocytoma/paraganglioma
  - Medullary thyroid cancer
  - Carcinoids
- Prostate cancer (SSRT1)

^{68}Ga-DOTA-TOC

^{68}Ga-DOTA-NOC

^{68}Ga-DOTA-TATE

Hypoxia

- Tumor Hypoxia
  well-recognized cause of resistance of radiation and chemotherapy

- Measurement of hypoxia
  → functional imaging

^{64}Cu-ATSM

^{18}F-FMISO

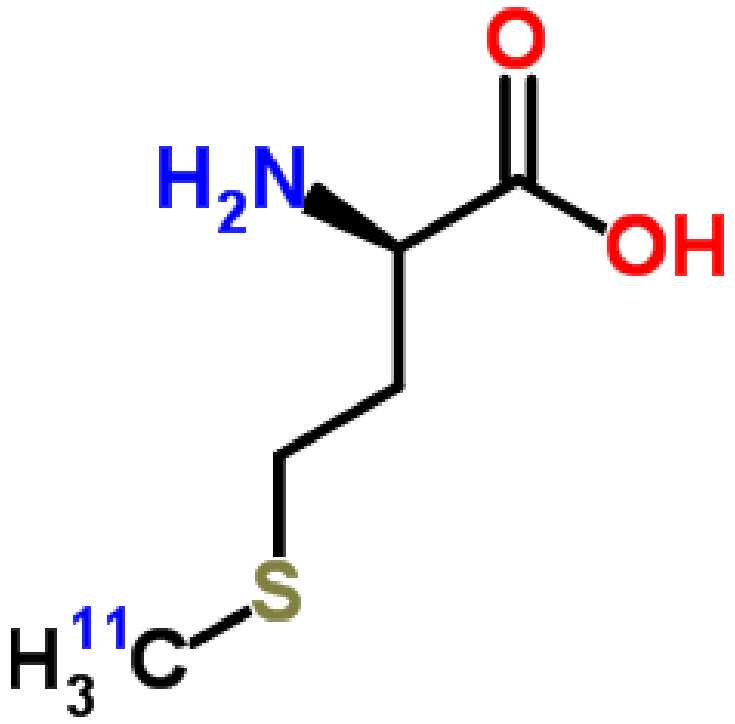
^{18}F-FAZA

^{11}C-Methionine

L-Methyl-[11C]methionine

- 조제실제제

- 적응증
  - 뇌종양
  - 부갑상선기능항진증
  - 전립선암
  - 폐암



^{11}C-Methionine PET/CT acquisition protocol

- **Patient preparation**

- fasting > 4hr

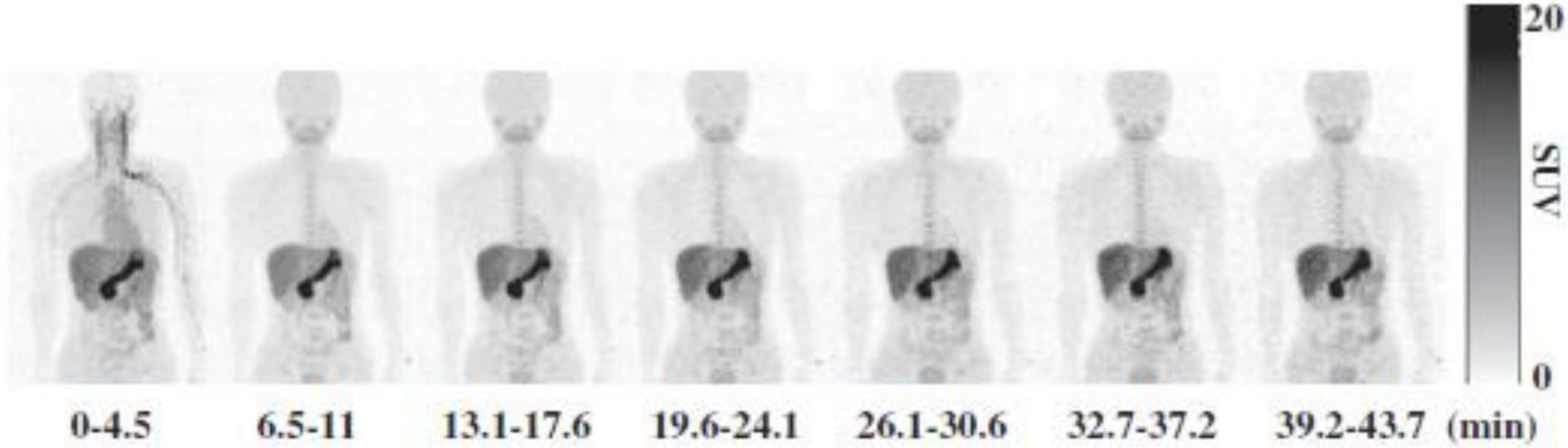
- **Dose**

- 185~370 MBq/70kg

- **Image acquisition**

- 10 min post injection

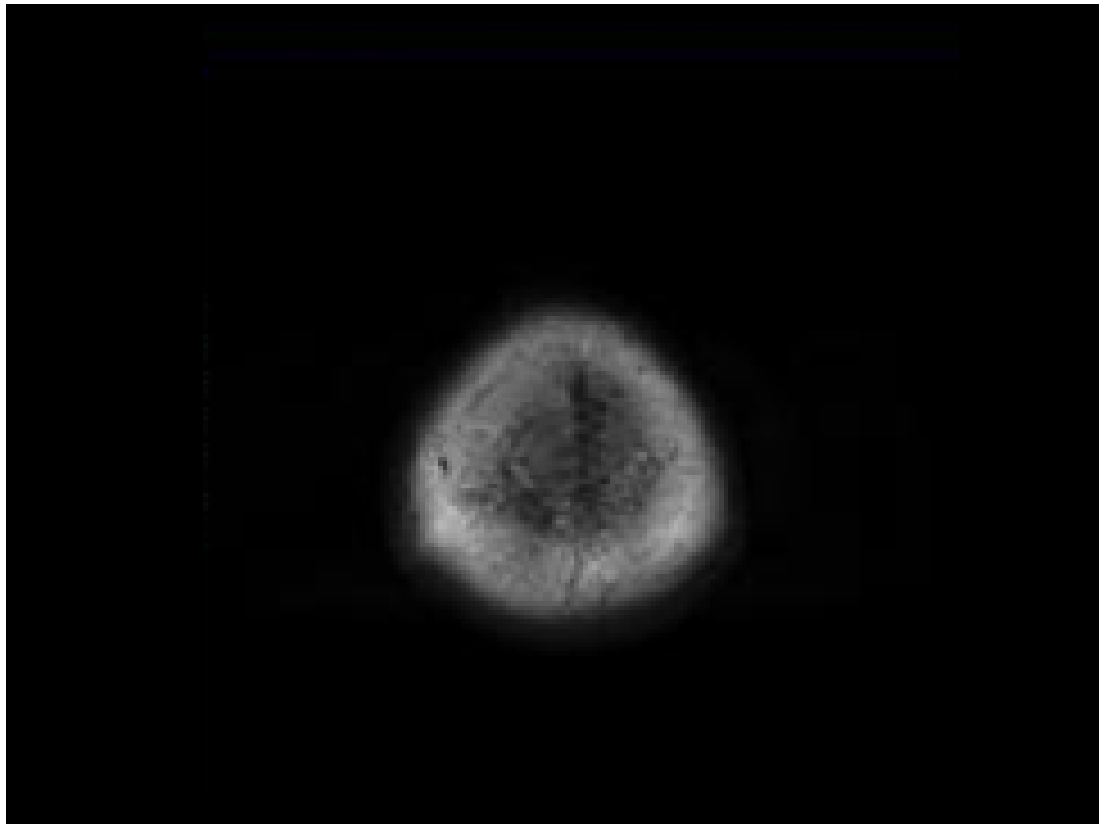
^{11}C-Methonine PET – normal distriburion

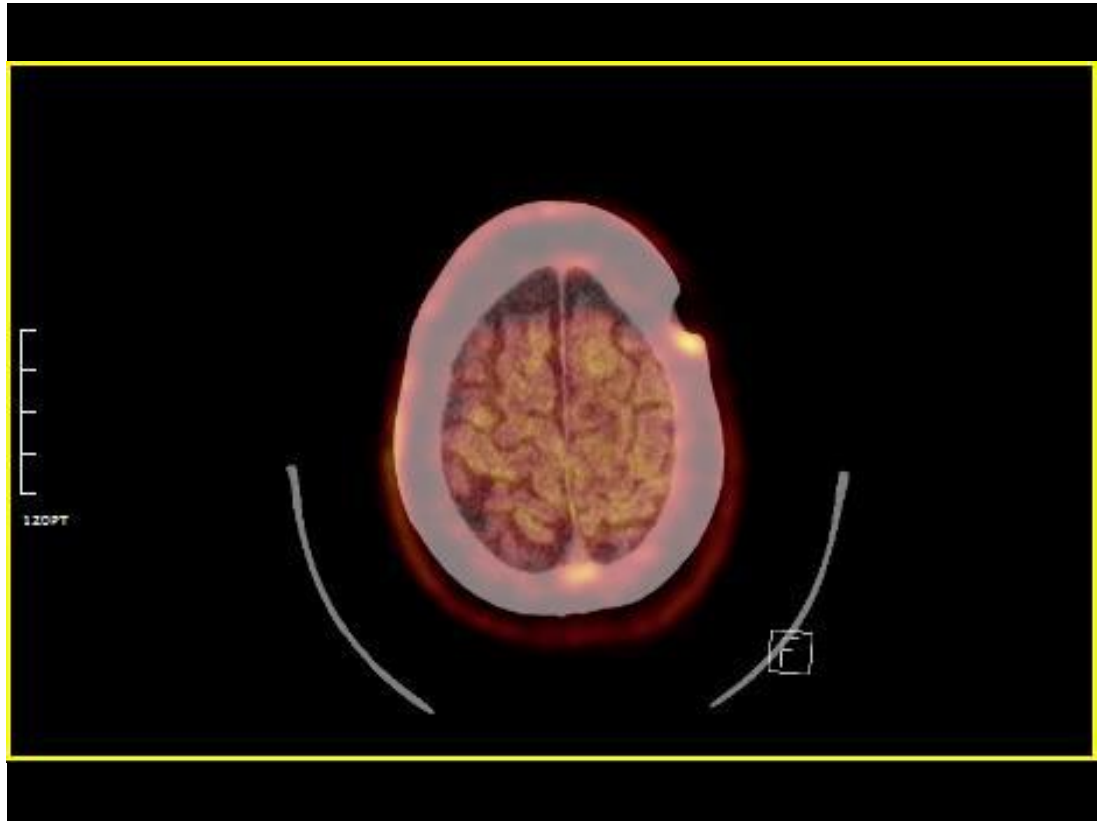


Insight Imaging 2010

임상 증례 I

- 55/M GBM
- Recurrence vs radiation-related change

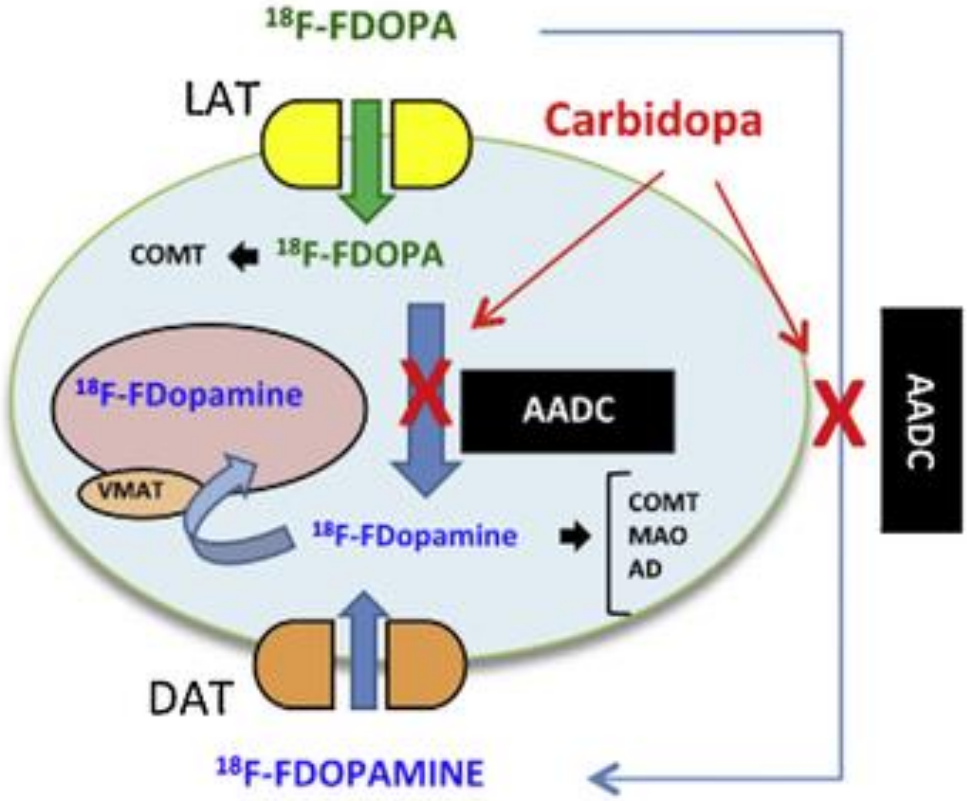




^{18}F-FDOPA

6-fluoro-(^{18}F)-L-3,4,-dihydroxy-phenylalanine

- 품목허가
- 적응증
  - 뇌종양
  - 신경내분비종양



JNM 2009

^{18}F-FDOPA PET/CT acquisition protocol

▪Patient preparation

- fasting > 4hr
- suspension of antiparkinsonian Tx. for 12hr for neurological indications
- carbidopa premedication : optional

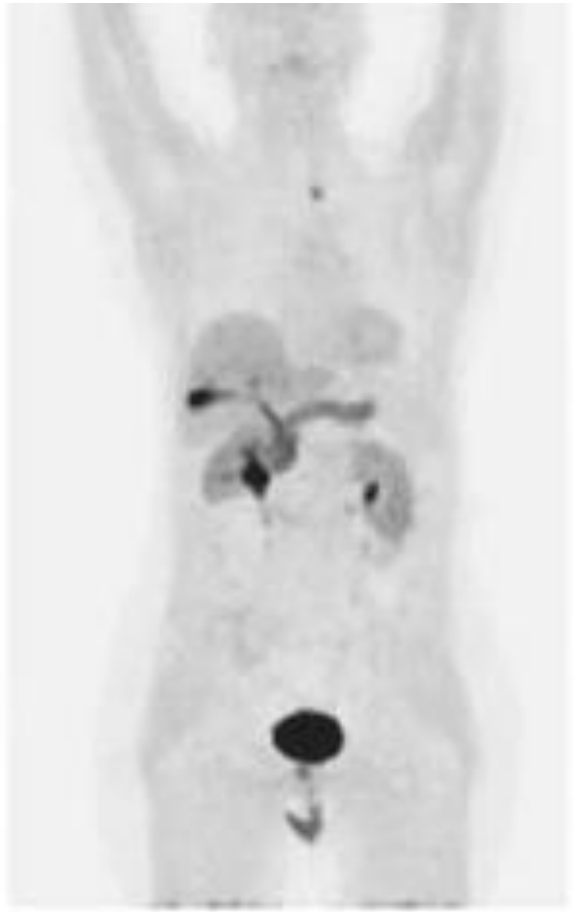
▪Dose

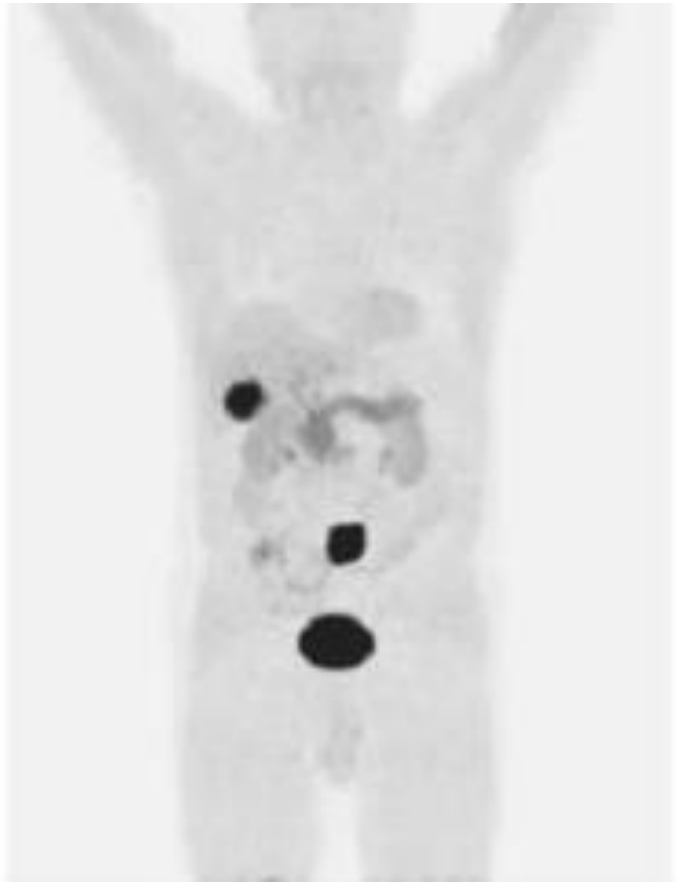
- 4 MBq/kg (oncology), 2 MBq/kg (neurology)
- 7 mSv/70kg adult

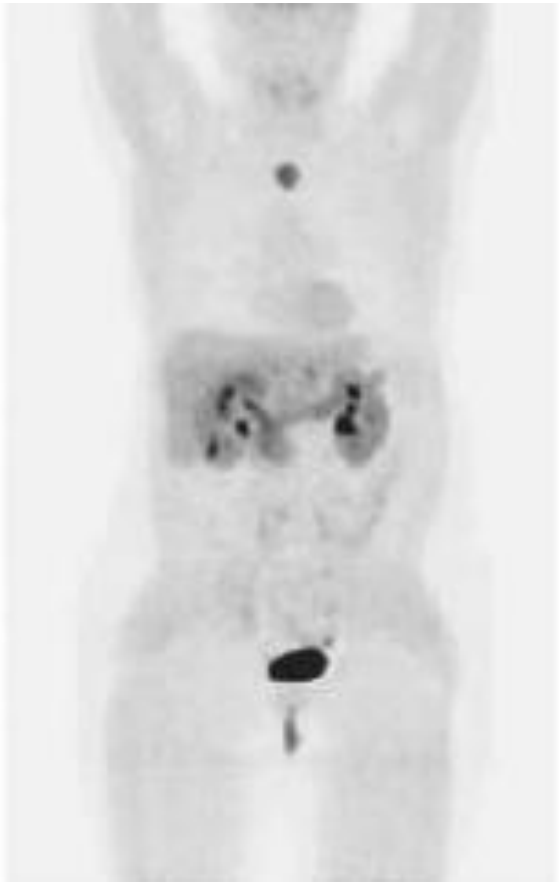
▪Image acquisition

- brain tumors : 10 ~ 30 min post injection
- whole-body : usually 60 min post injection

^{18}F-FDOPA PET – normal distribution



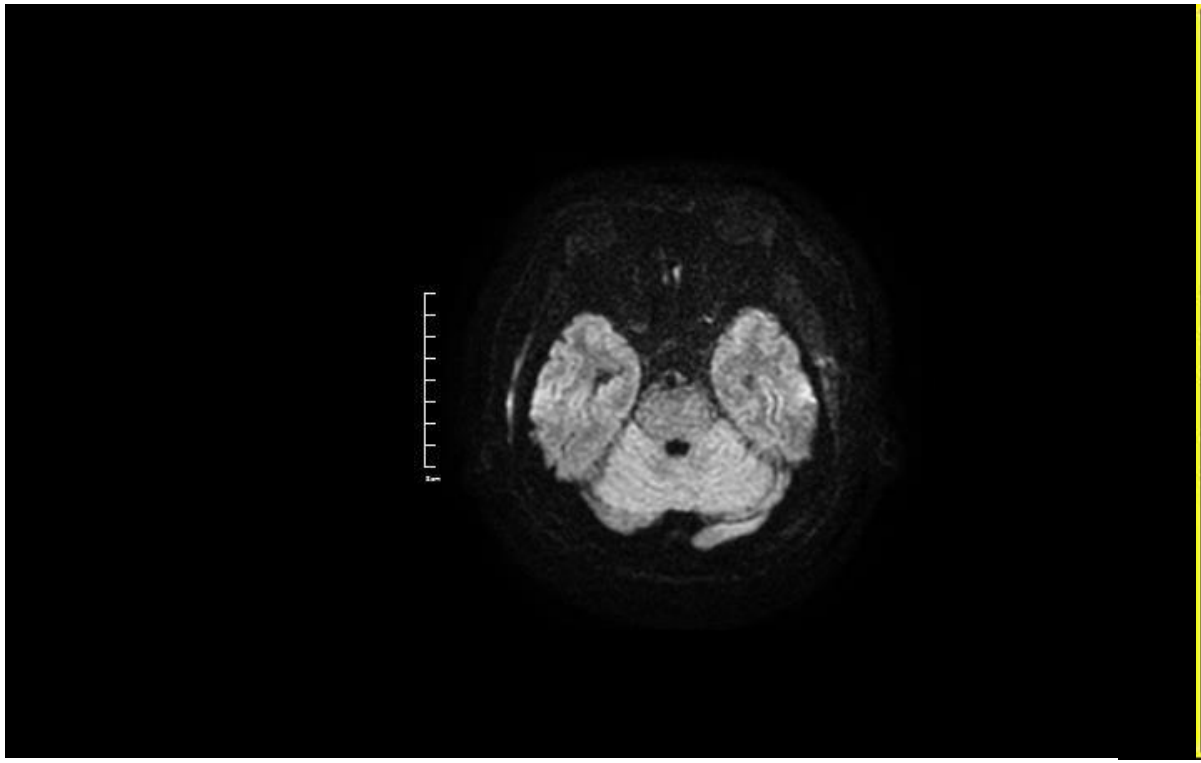


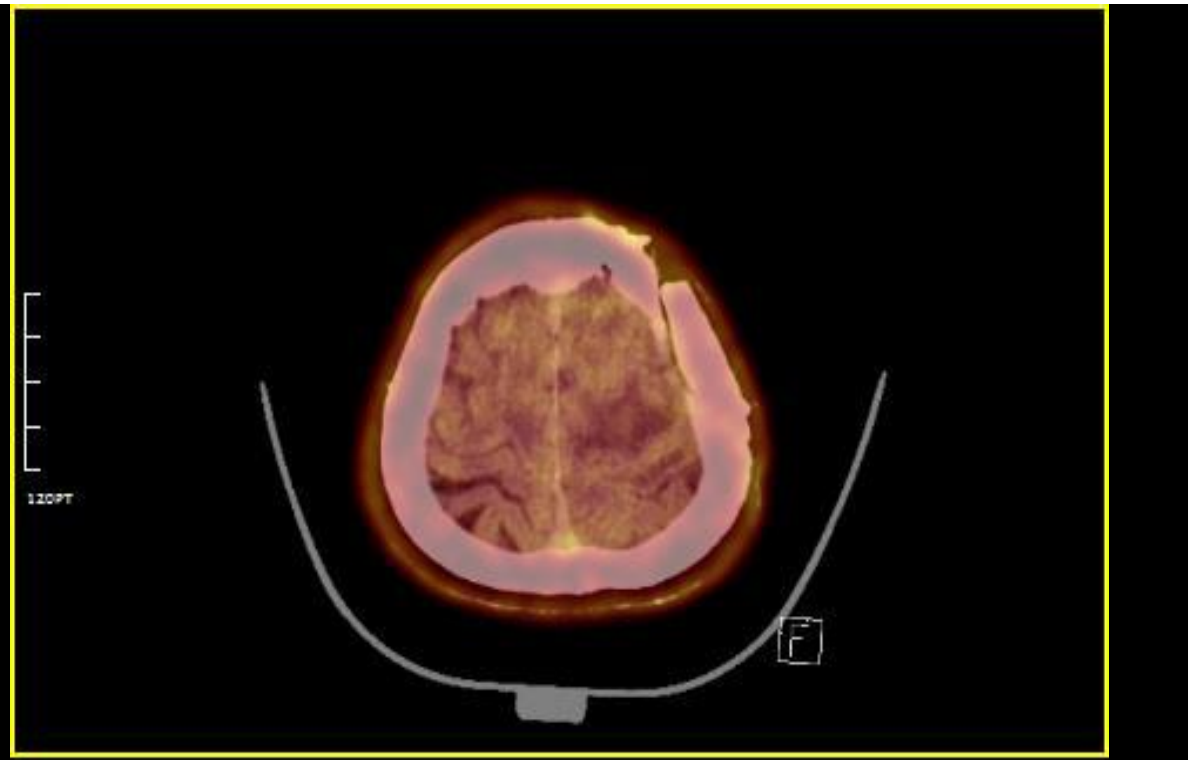


NMC 2013

임상 증례 I

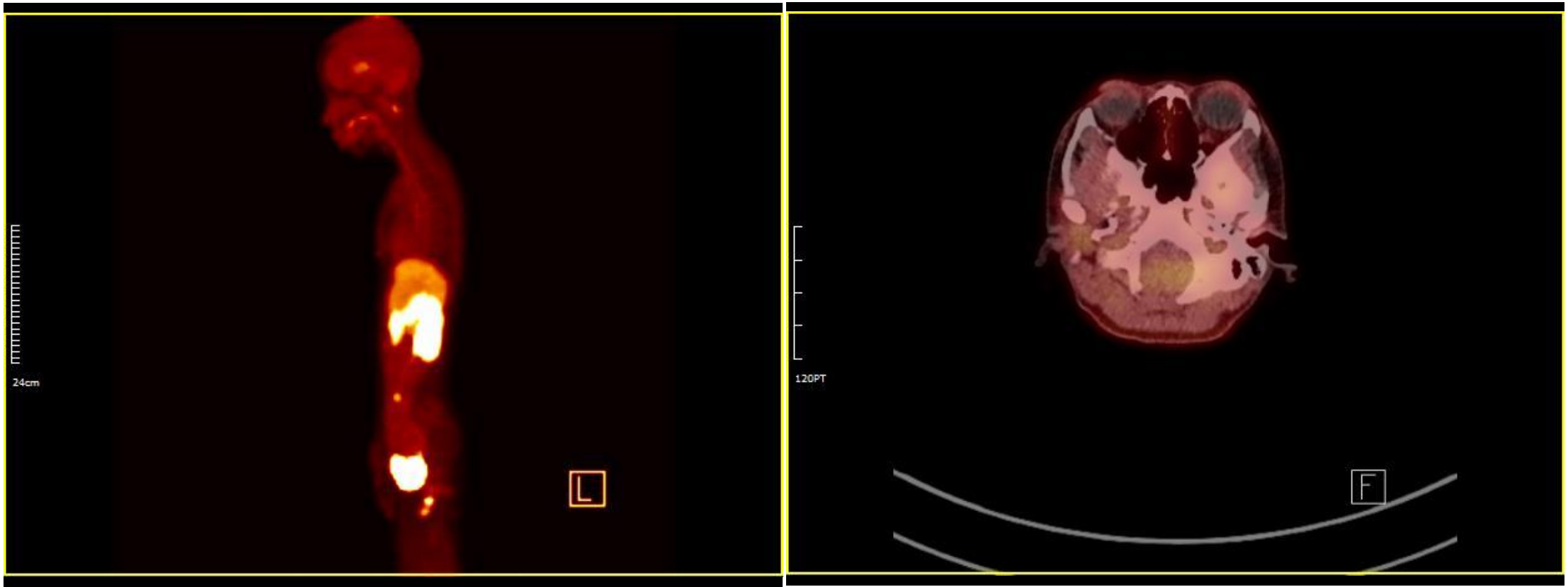
- 61/M with GBM
- radiation-related change vs recurrence





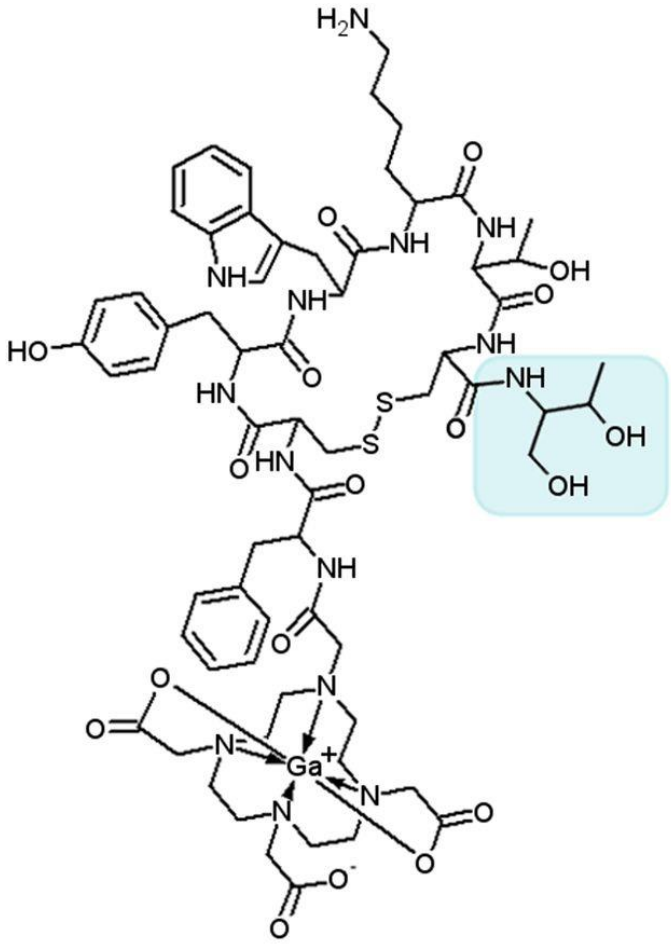
임상 증례 II

- 34/F with MTC
- Newly developed lymph node on SONO Neck
- Metastasis vs benign lymph node

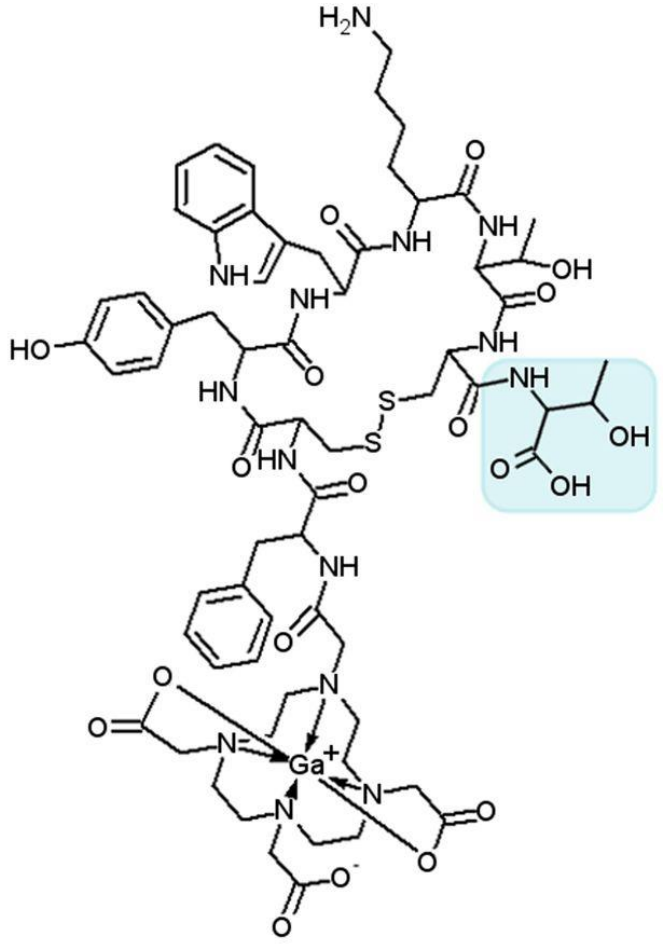


^{68}Ga-DOTA-TOC

- **DOTA-TOC**
  - DOTA-Tyr^3-Octreotide
- 조제실제제
- 적응증
  - 신경내분비종양



^{68}Ga-DOTATOC



^{68}Ga-DOTATATE

J Nucl Med 2014

^{68}Ga-DOTA-TOC PET/CT acquisition protocol

- **Patient preparation**
  - fasting > 4hr

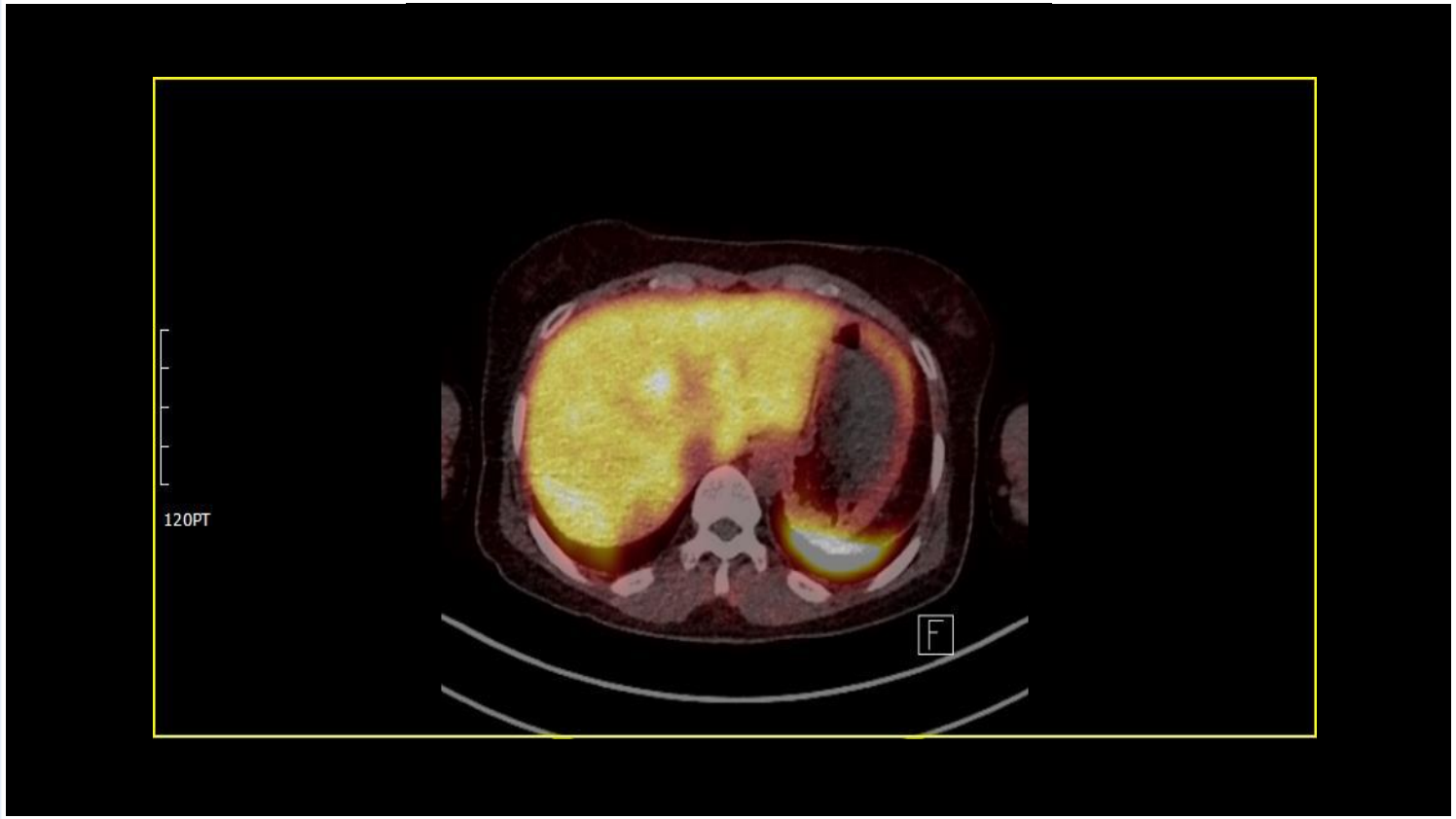
- **Dose**
  - 100-200 MBq / 70kg

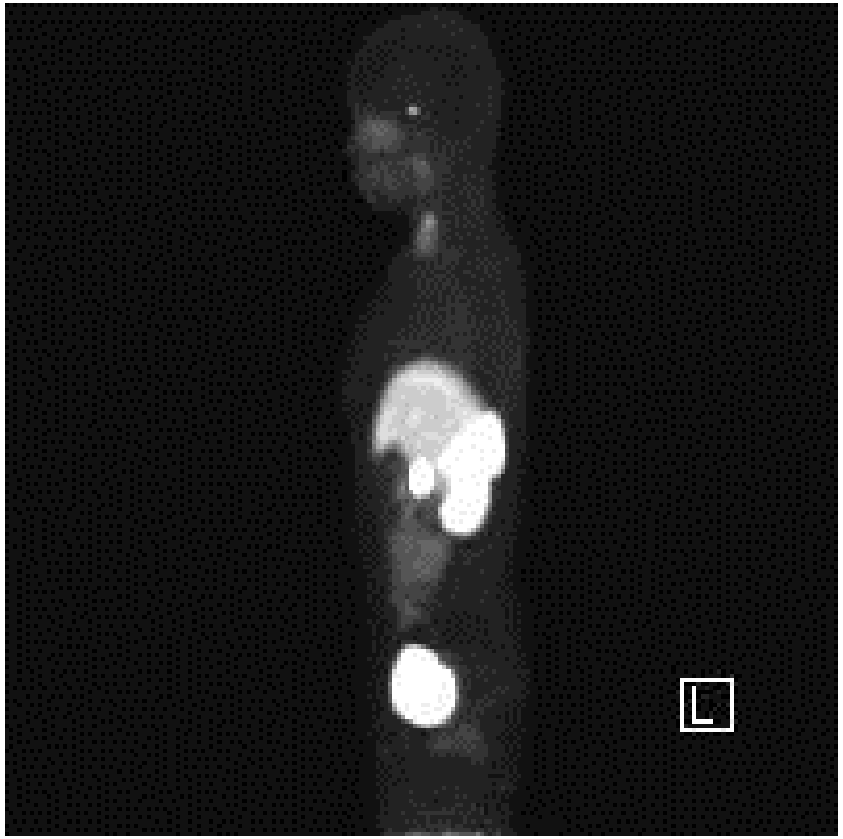
- **Image acquisition**
  - 60 min post injection

^{68}Ga-DOTA-TOC – Normal Distribution

임상 증례 I

- 55/F pancreatic mass
  r/o PNET





Evaluation of Neurodegenerative diseases

- Parkinsonism
- Alzheimer’s disease

Evaluation of Dopaminergic Function

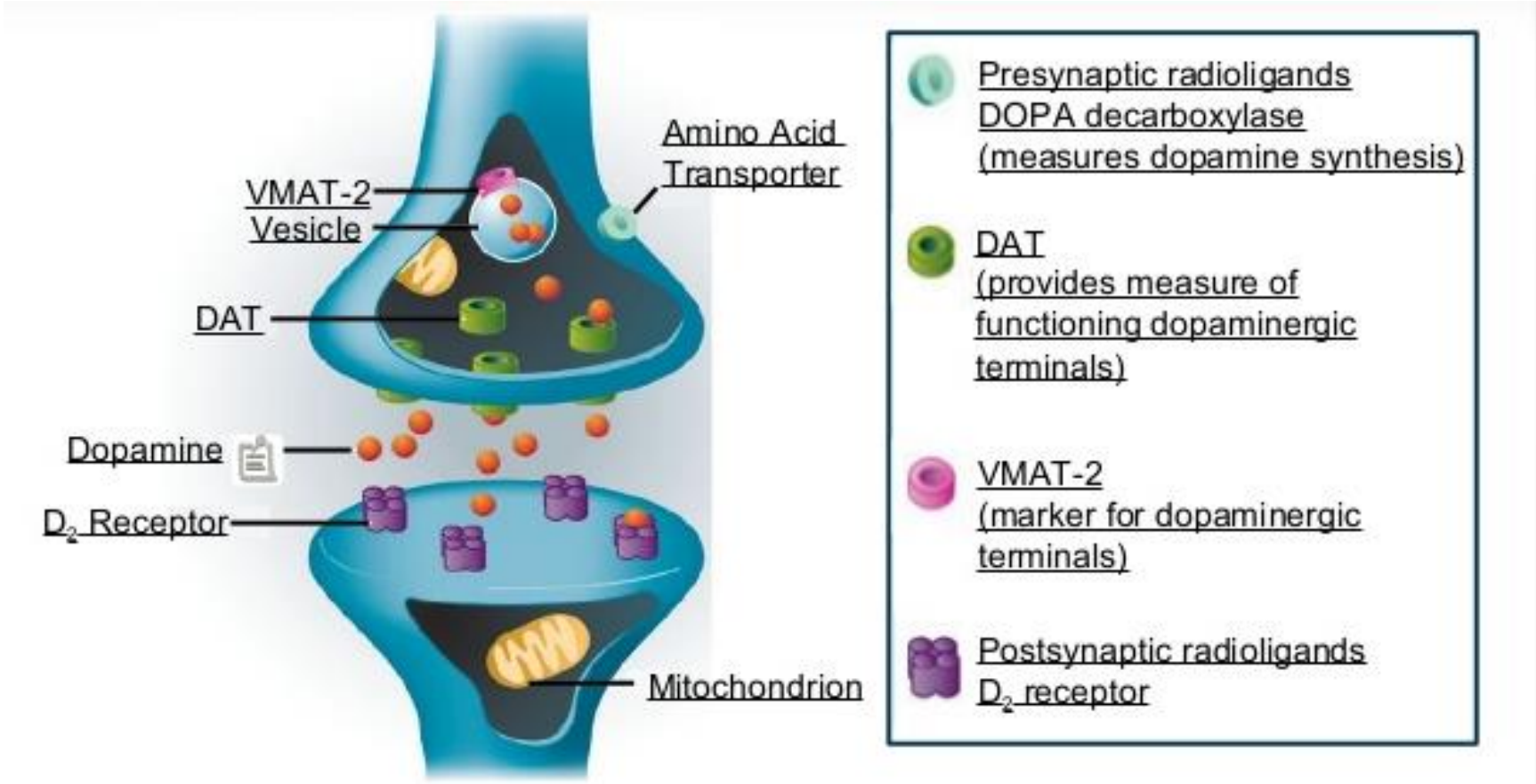
Parkinsonian disorders

- Idiopathic Parkinson disease

- Atypical parkinsonian disorders
  - progressive supranuclear palsy (PSP)
  - multiple-system atrophy (MSA)

- Other conditions
  - Essential tremor
  - Drug-induced parkinsonism
  - Vascular parkinsonism
  - Alzheimer disease

Radiopharmaceuticals for Measurement of Dopaminergic Function



Cummings JL, et al.[21] Adapted with permission.

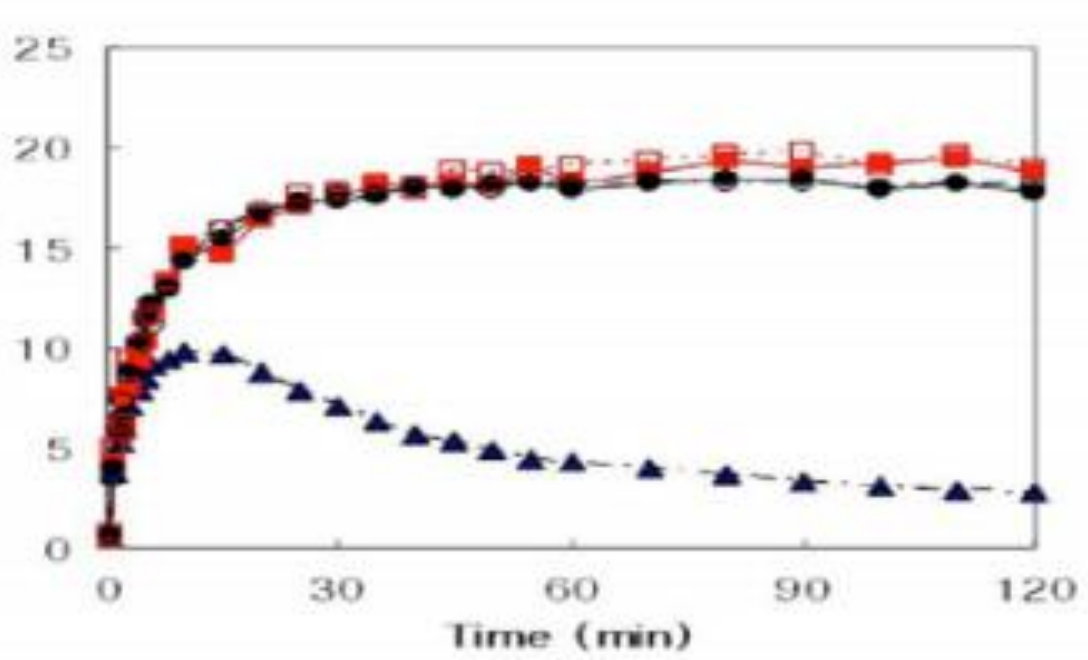
Imaging for dopaminergic function

- ^{18}F-FDOPA; measurement of AADC activity

- DAT binding tracers (CIT, CFT, PE21, etc)
  - more specific for dopaminergic terminals
  - Very sensitive in preclinical or early PD

- VMAT2 (^{11}C-DTBZ)

FP-CIT PET scan

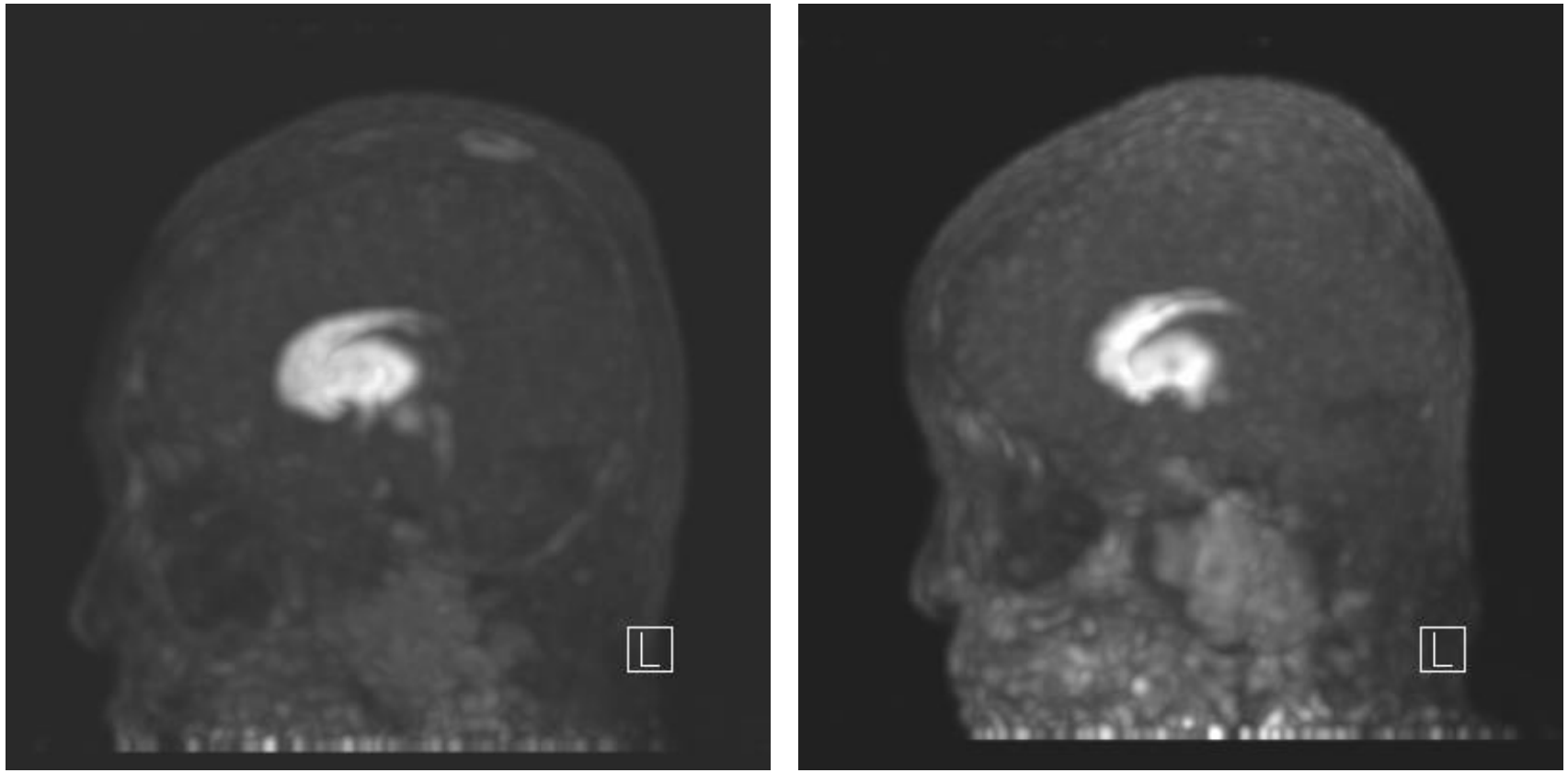


- 전 처치
  : 필요하지 않음

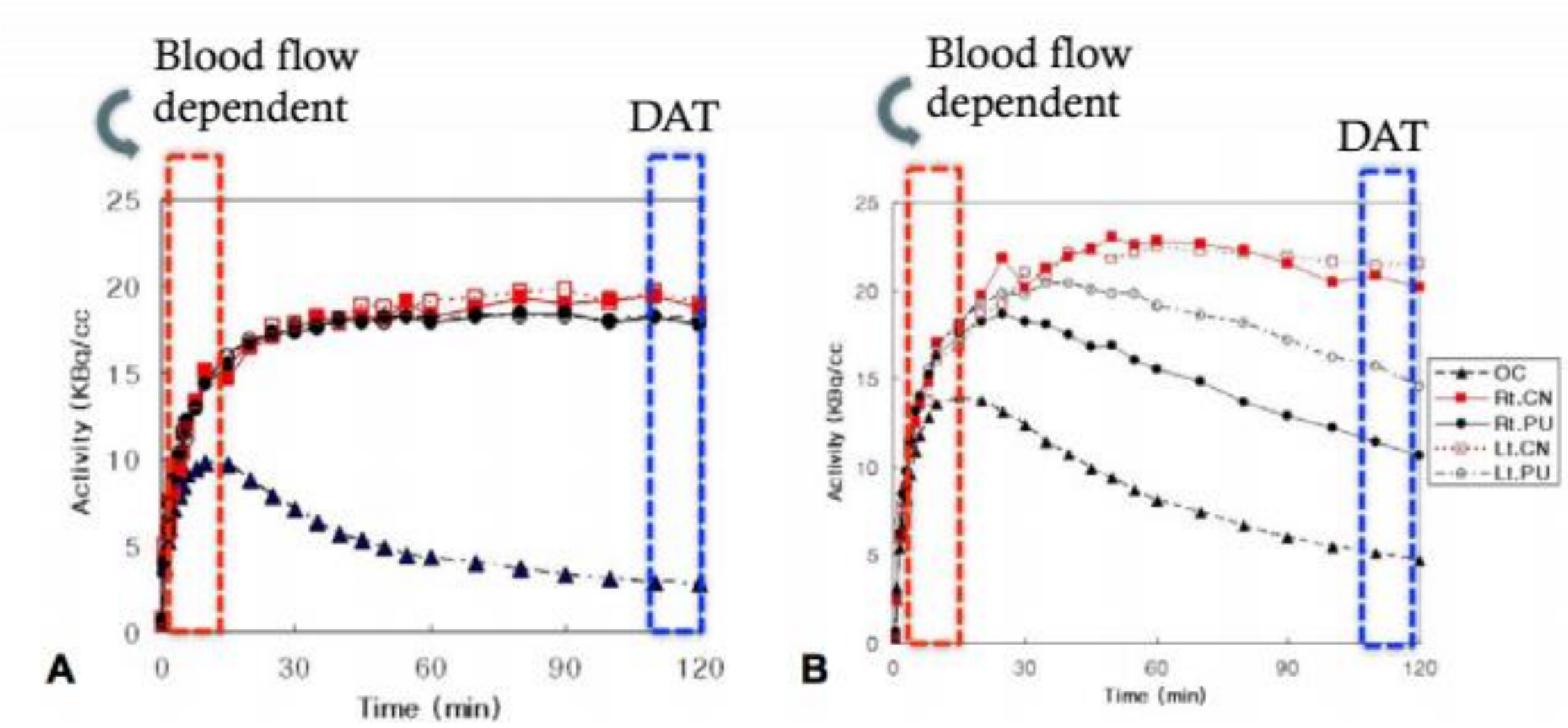
- Radiotracer
  : FP-CIT 5~8 mCi

- Scan Protocol
  Scan time : 10min at two hours after injection
  Recon method : TrueX
  Iterations : 6 , Subsets : 24
  Filter : Gaussian , FWHM : 2mm

^{18}F-FP-CIT PET scan



Dual Phase FP-CIT

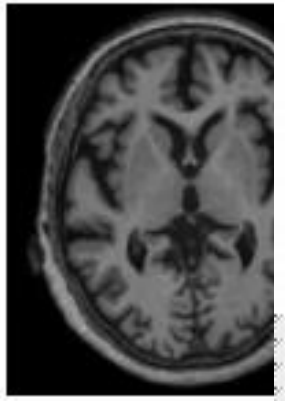


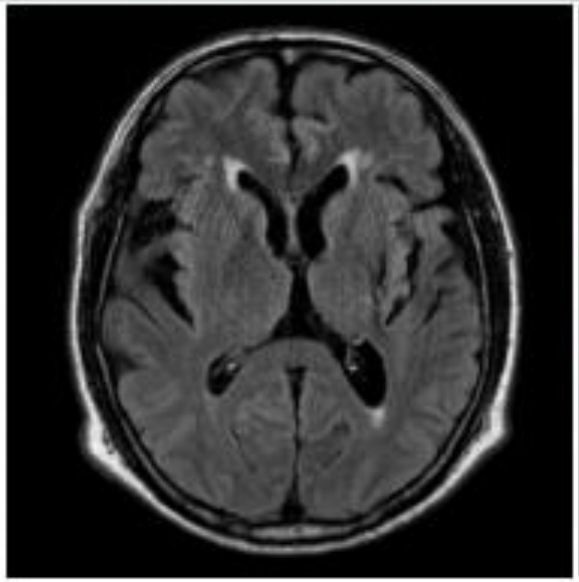
Dual Phas

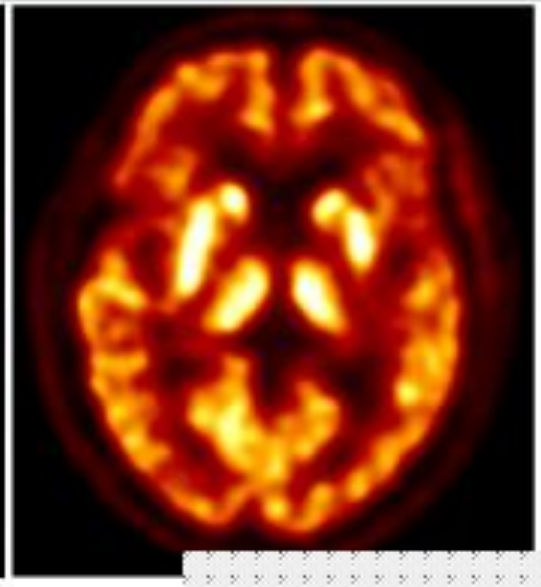
Early phase (perfusion)

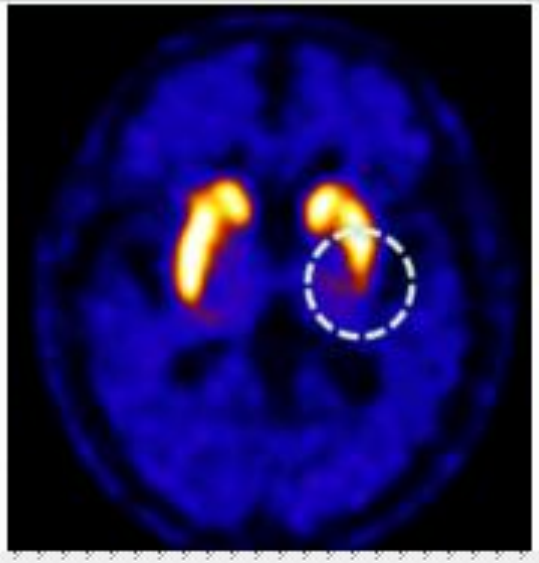
Delayed phase (DAT density)

Healthy

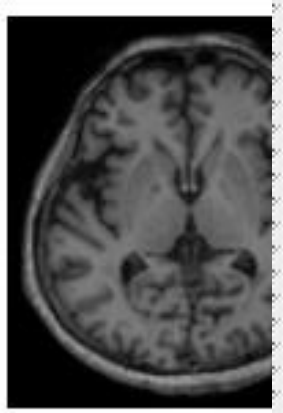








Early PD



Xofigo®(radium Ra 223 dichloride)

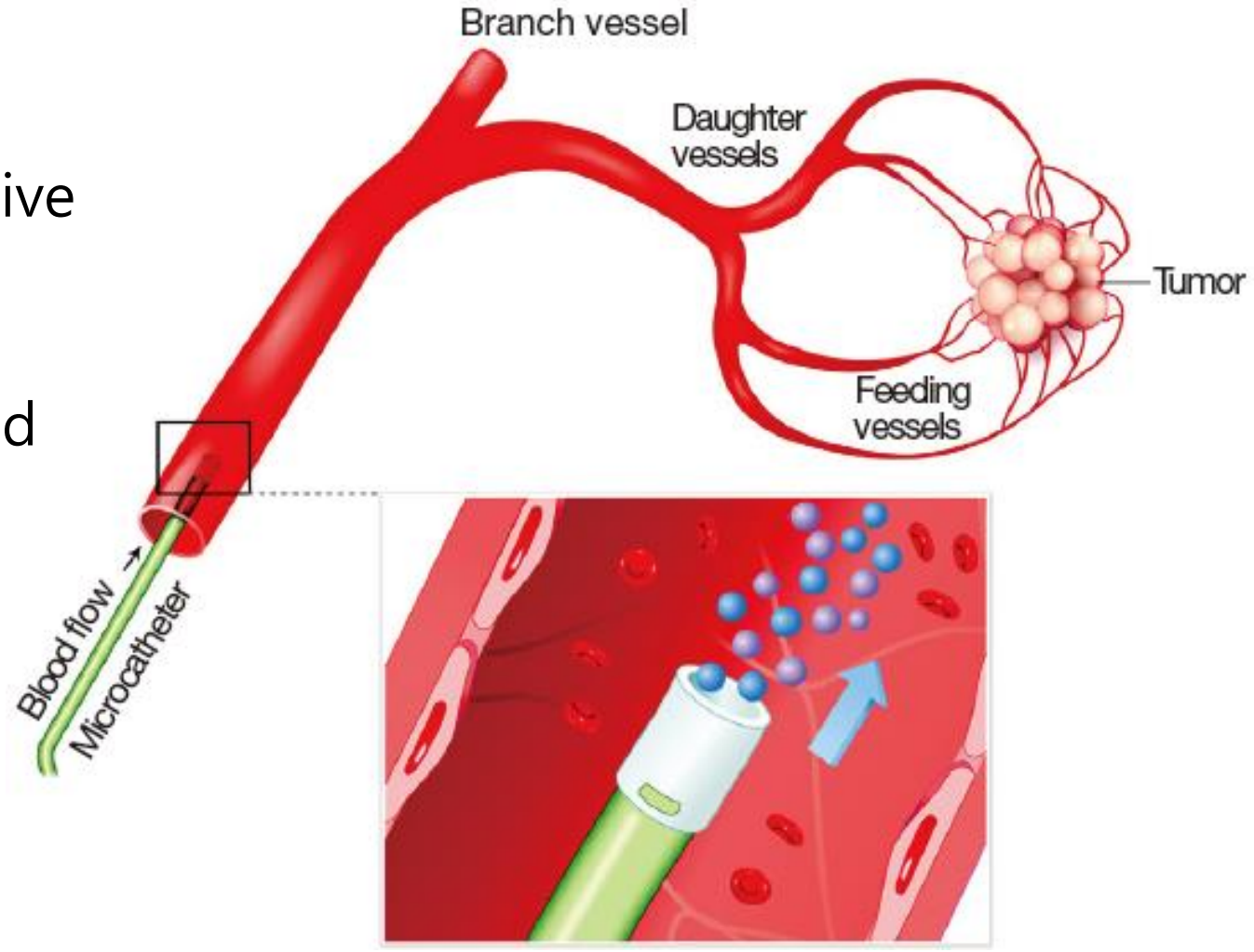
- **Alpha emitters with high linear energy transfer**

- **Indication**
  for prostate cancer that is resistant to medical
  or surgical treatments that lower testosterone and has spread to your bones with symptoms, but not to other parts of your body.
  The medical term for this condition is **metastatic castration-resistant prostate cancer, or mCRPC**.

- **Doses**
  50 kBq per kg body weight, given at 4-week intervals for six injections

Y-90 therapy

- Trans-arterial delivery of radioactive ^{90}Y-labeled microspheres
- Microspheres (20-30 mm) trapped in tumor capillary vessels
- β emissions from trapped ^{90}Y-microspheres



Kennedy A. J Gastrointest Oncol 2014;5

Commercial ^{90}Y-microsphere Products

SIR-Spheres	Therasphere
Insoluble, biocompatible resin matrix	Insoluble, biocompatible glass matrix
30–35 mm glass spheres	20–30 mm glass spheres
3 GBq (81 mCi) activity = 30-60 x 10^6 spheres	3 GBq (81 mCi) activity = ~1.2 x 106 spheres
Maximum activity available : 3GBq (81mCi)	Maximum activity available : 20 GBq (540 mCi)

Overview of ^{90}Y microsphrere therapy

Patient imaging prior to ^{90}Y-microsphere therapy

Calculation of the lung shunt fraction

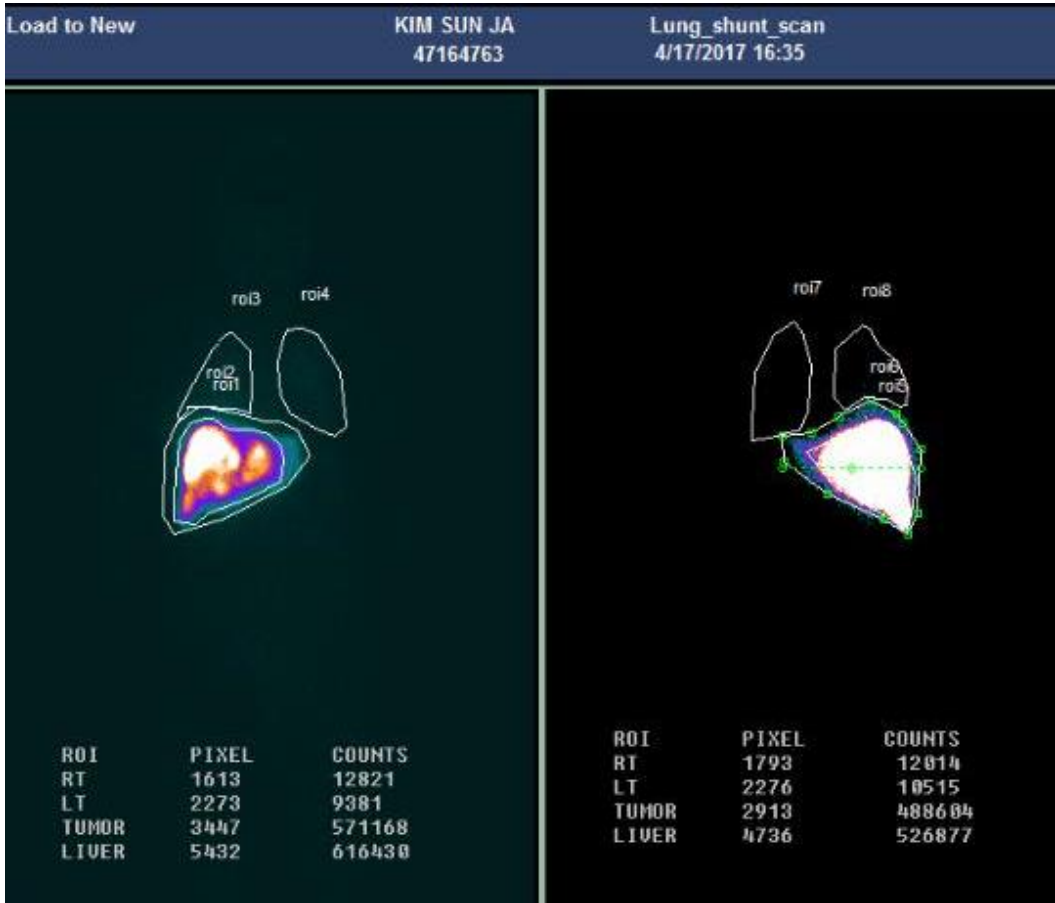
90Y-microsphere therapy dose calculations

Patient imaging post ^{90}Y-microsphere therapy

Lung Shunt Calculation

- LS (%) = Lung GM-counts / (Lung GM-counts + Liver GM-counts) x 100
  = 22364 / (22364 + 569897) x 100 = 3.78%

- TheraSphere : 30 Gy lung dose limit
  → 222 mCi ^{90}Y activity limit



Q & A