

**Azienda Ospedaliero-Universitaria di Bologna**  
**Policlinico S.Orsola-Malpighi**



ALMA MATER STUDIORUM  
UNIVERSITÀ DI BOLOGNA

# **MEDICINA NUCLEARE**

## Nuclear medicine imaging

The most exciting thing for all of us is movies ~~and~~ movie stars.

(Kenneth Edmonds)



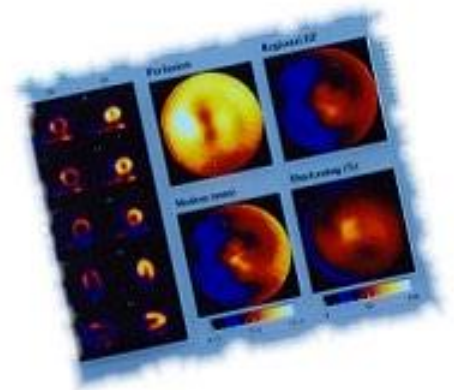
**MEDICINA NUCLEARE**

**DIAGNOSTICA**

**SCINTIGRAFIA**

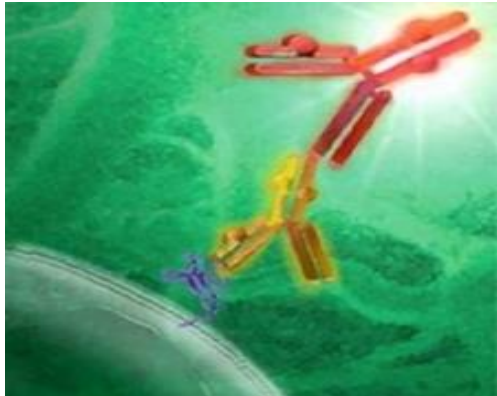
**SPET**

**PET**



**MEDICINA NUCLEARE**

**TERAPEUTICA**



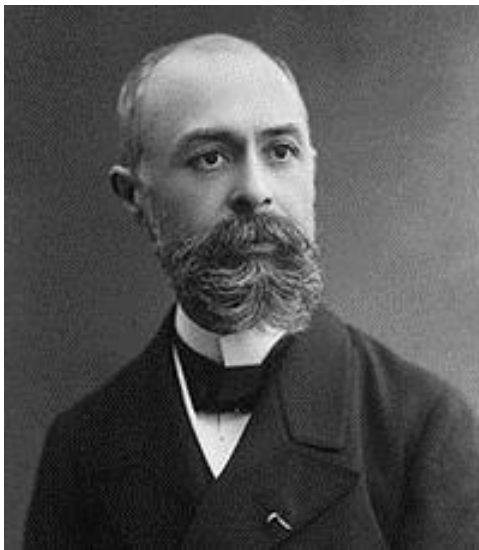
**RADIOMETABOLICA**



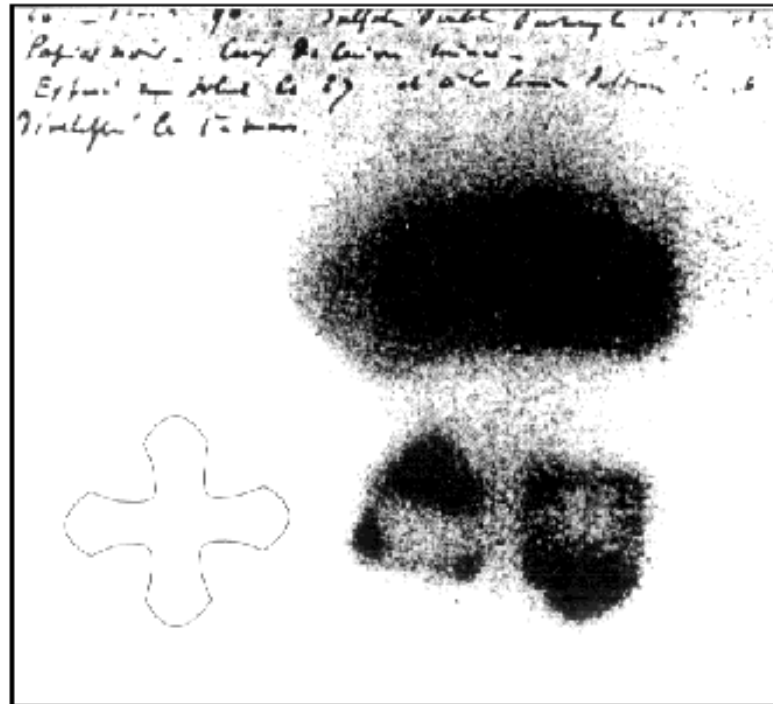
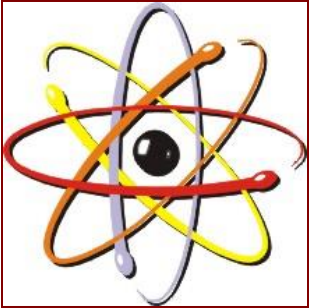


# MEDICINA NUCLEARE

HENRI BECQUEREL



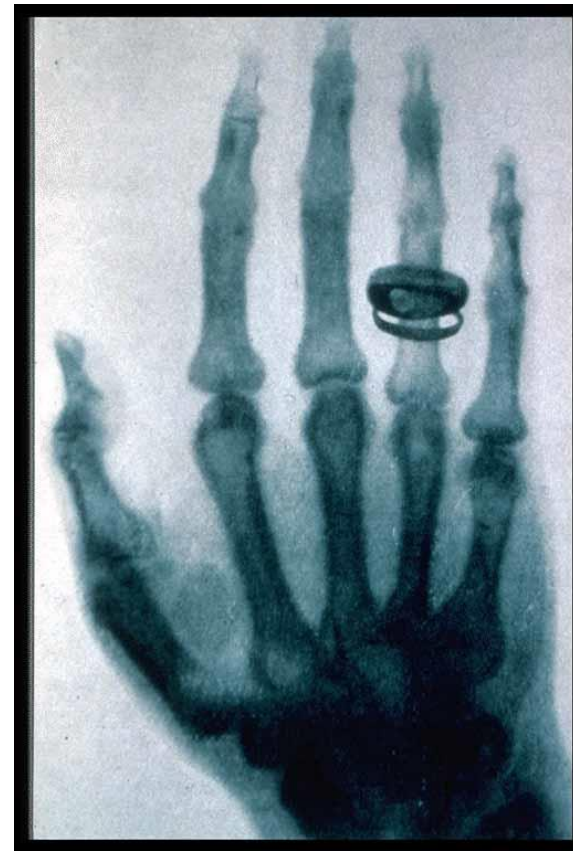
# MEDICINA NUCLEARE



1896

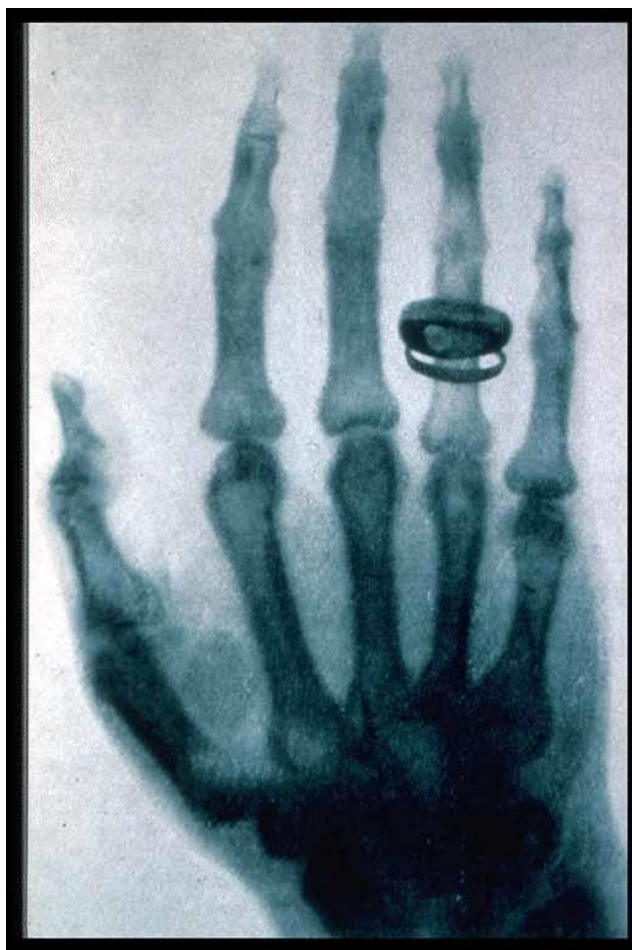


# WILHELM RONTGEN



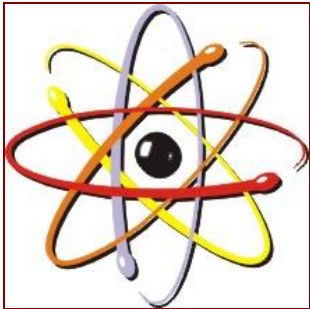
**1895**







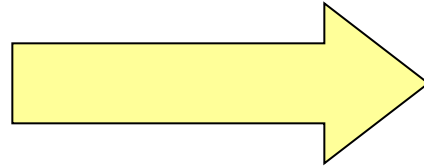
# MEDICINA NUCLEARE



**ECO**

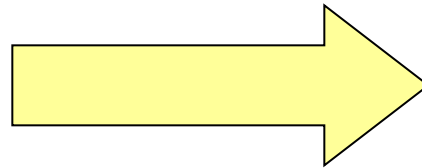
**TC**

**RM**



**IMAGING  
MORFOLOGICO**

**MN**



**IMAGING  
FUNZIONALE**



# IMAGING MORFOLOGICO

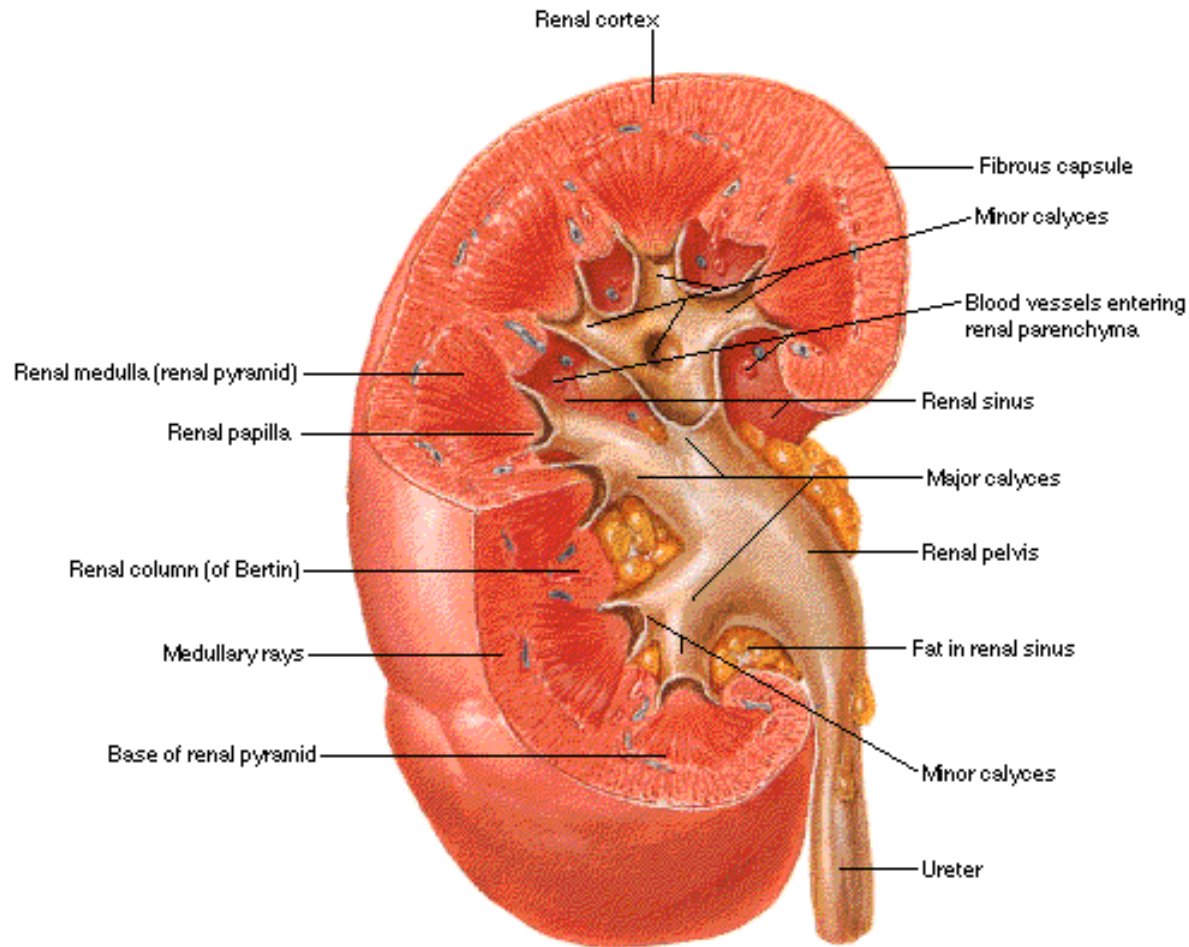


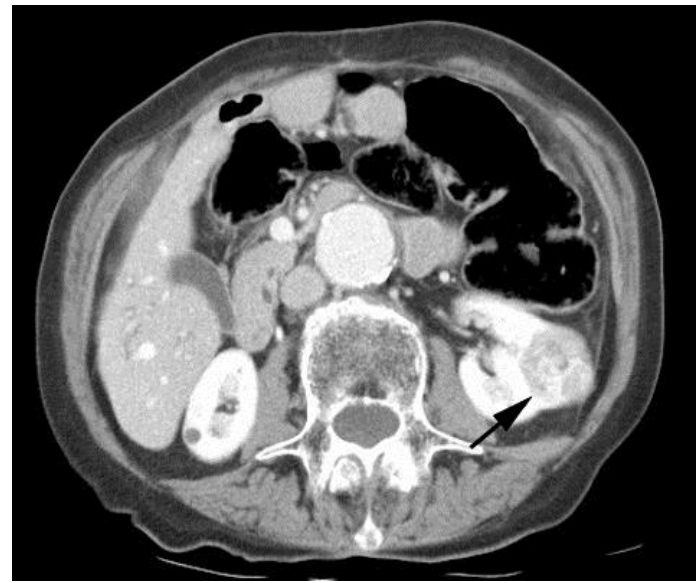
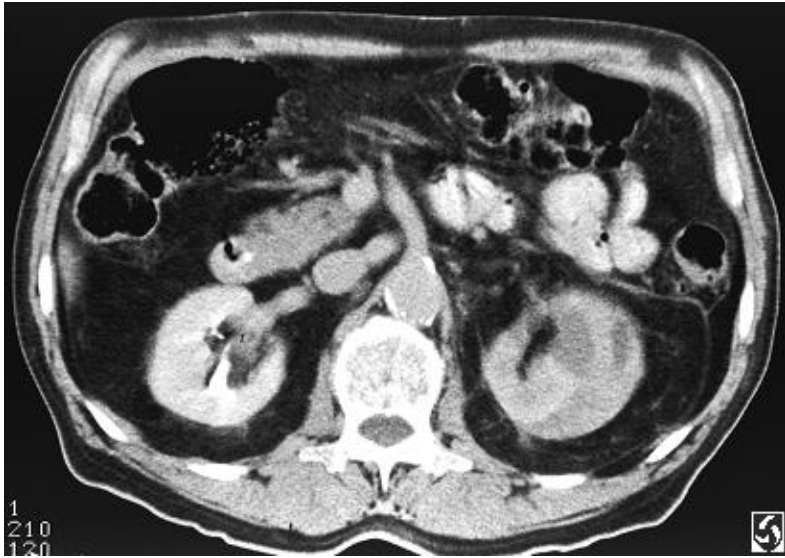
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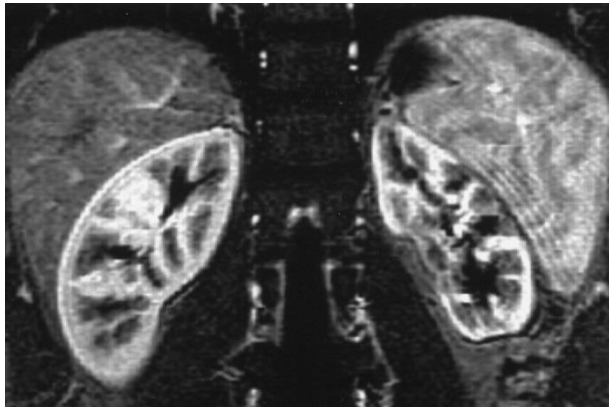




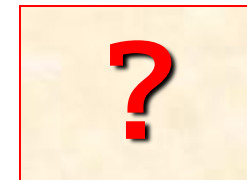
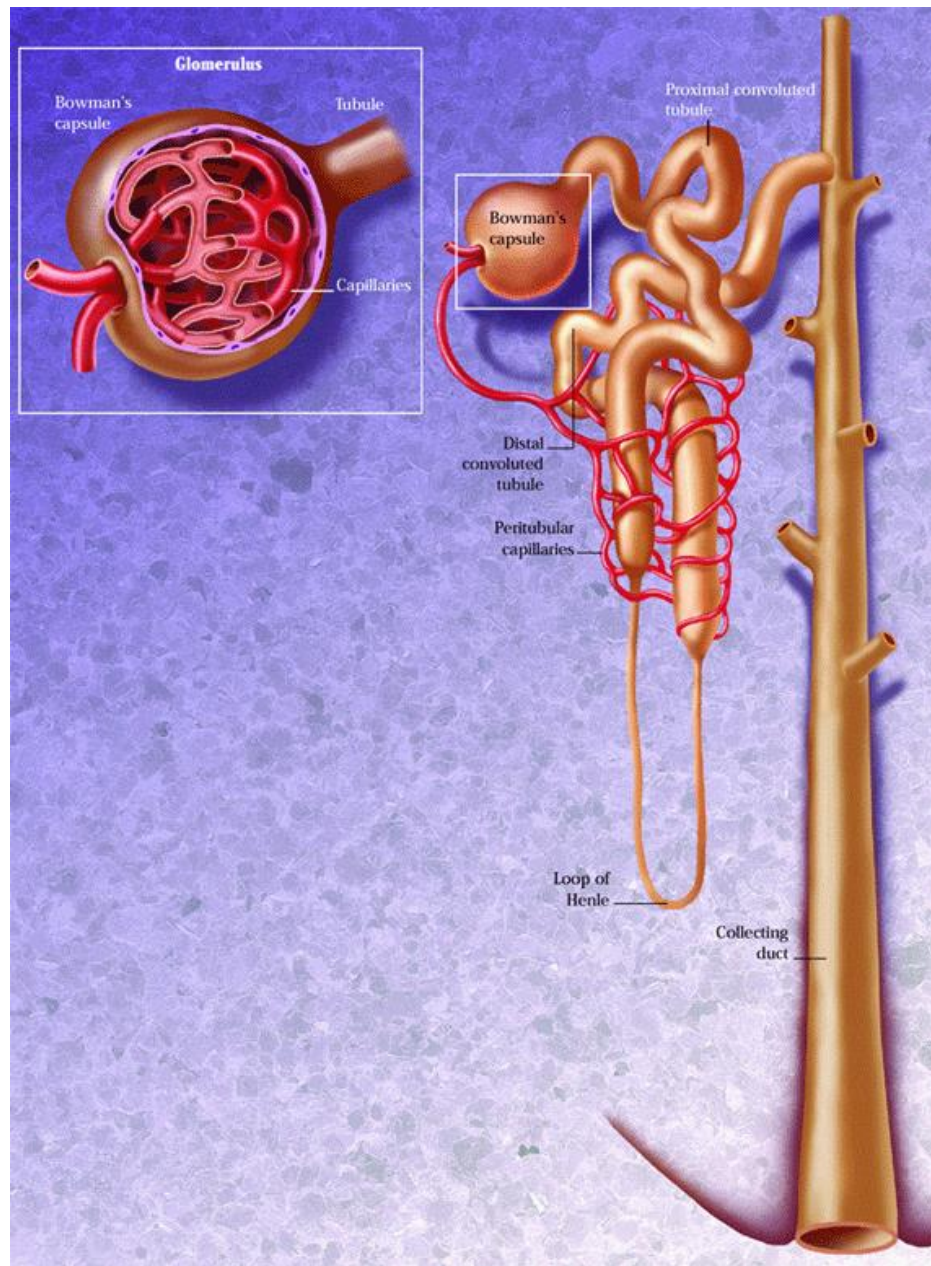
# Right Kidney Sectioned in Several Planes













# CREATININE

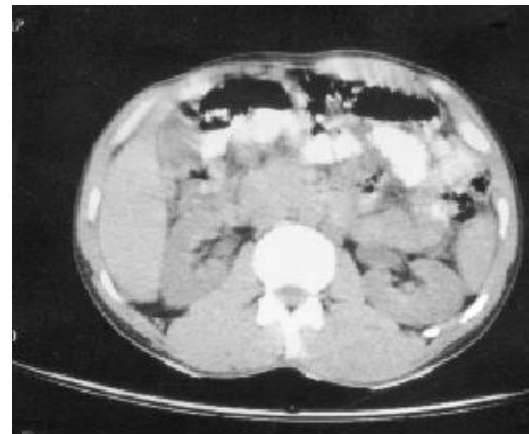
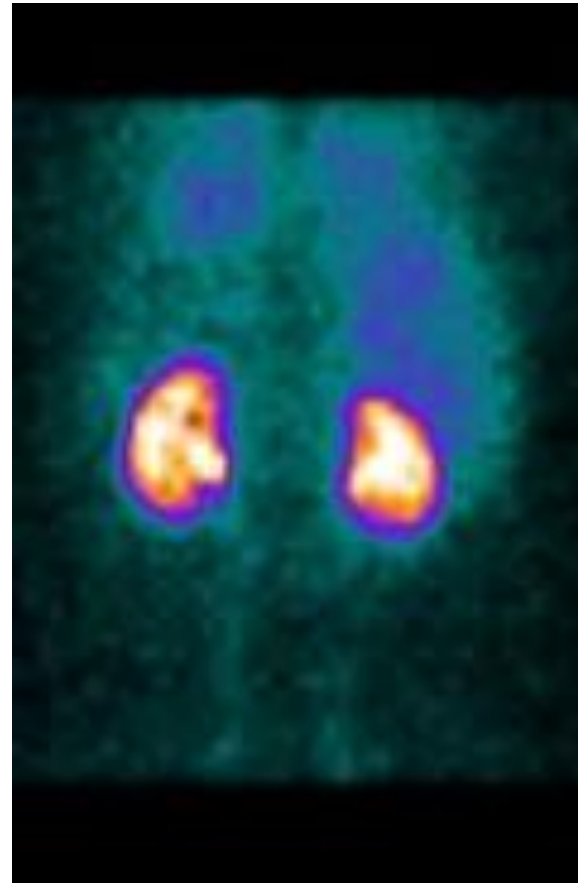
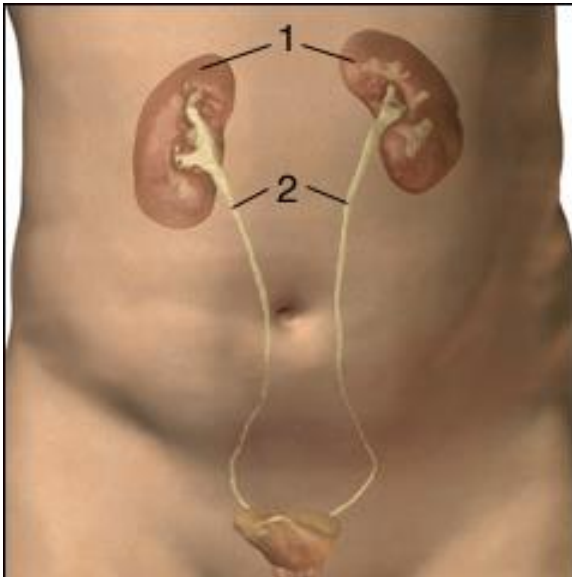


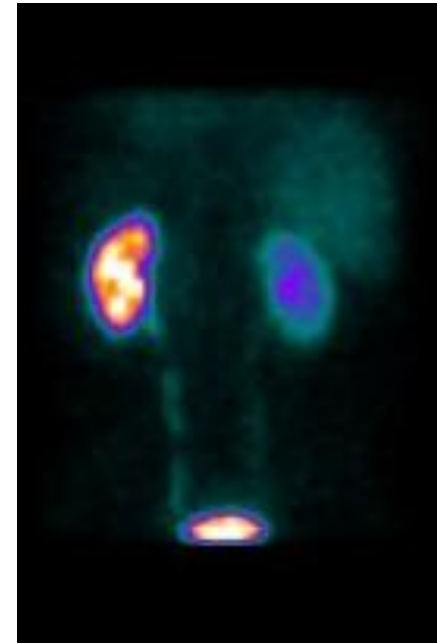
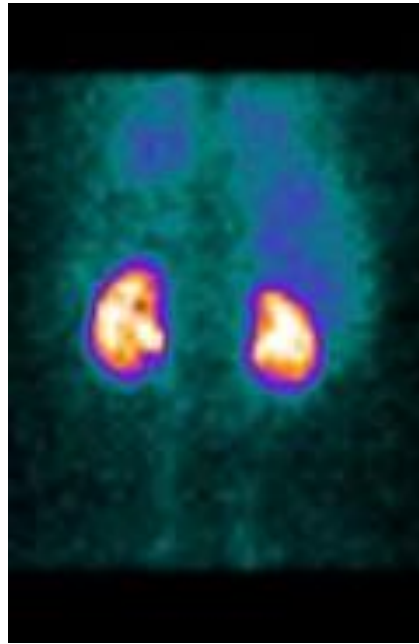
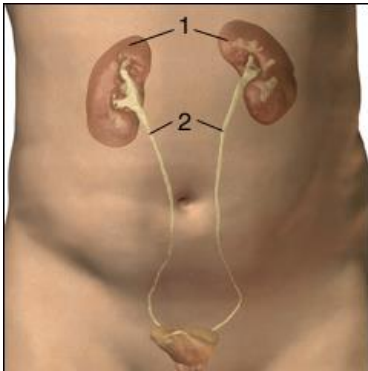
Fig.1: CT abdomen showing medullary type of nephrocalcinosis in both the kidneys.



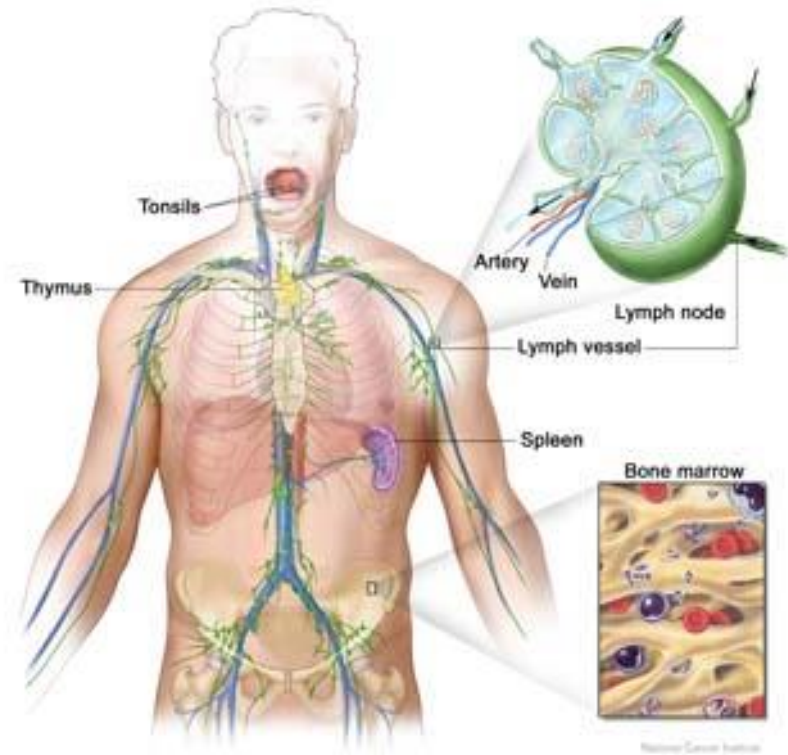
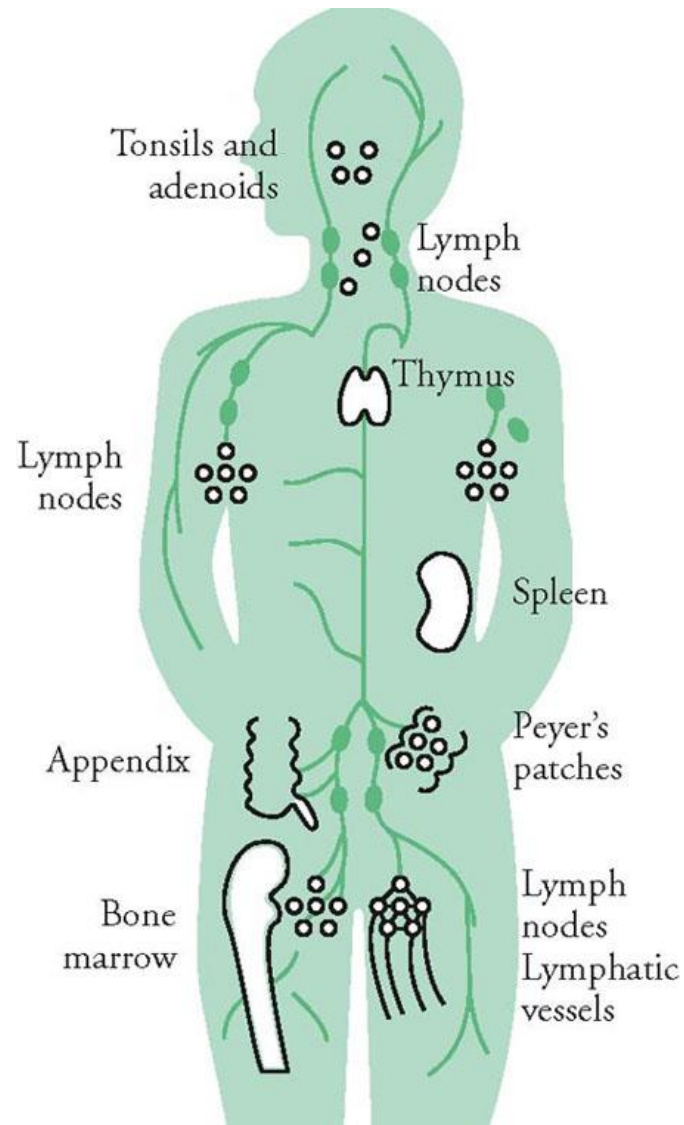
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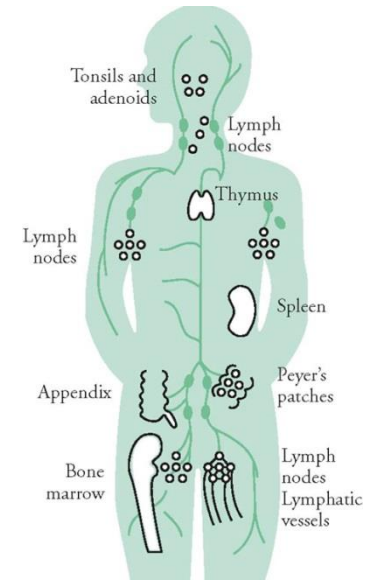
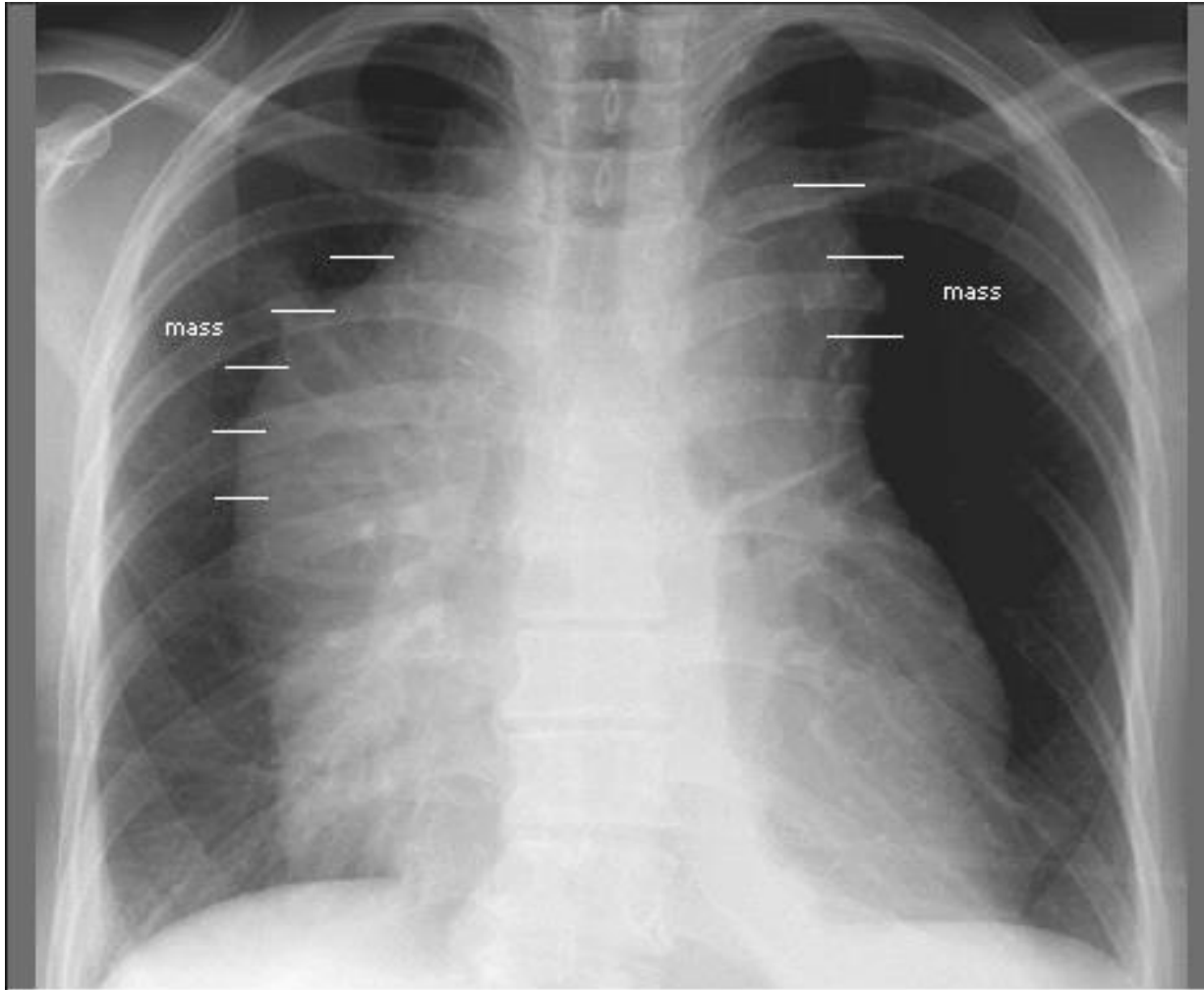
# SCINTIGRAFIA RENALE

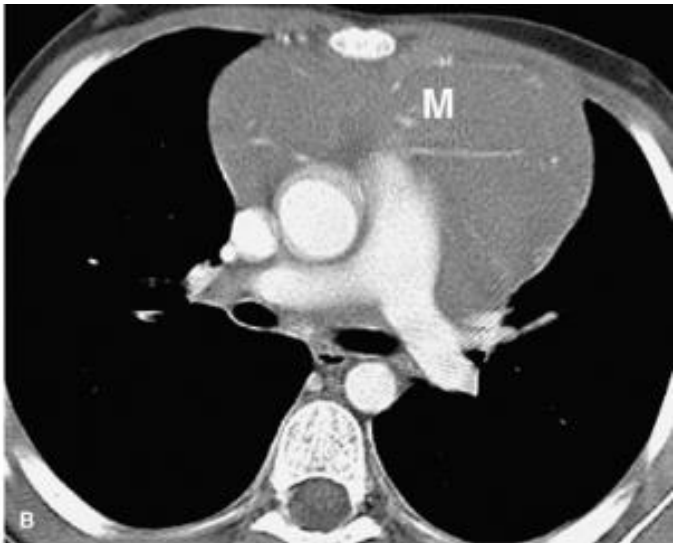
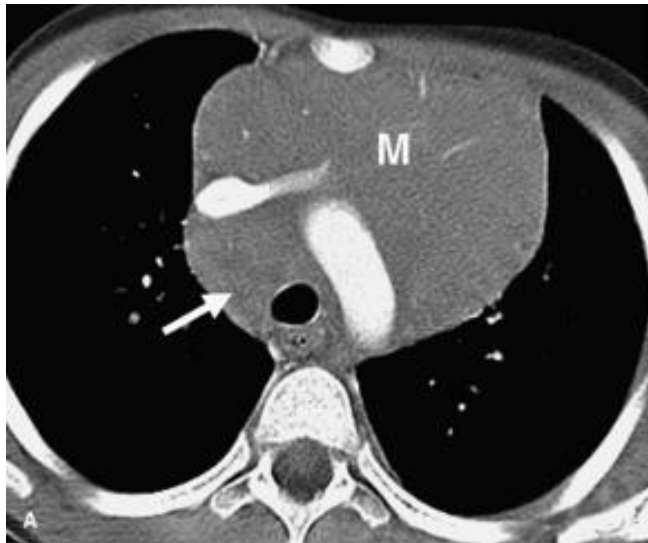


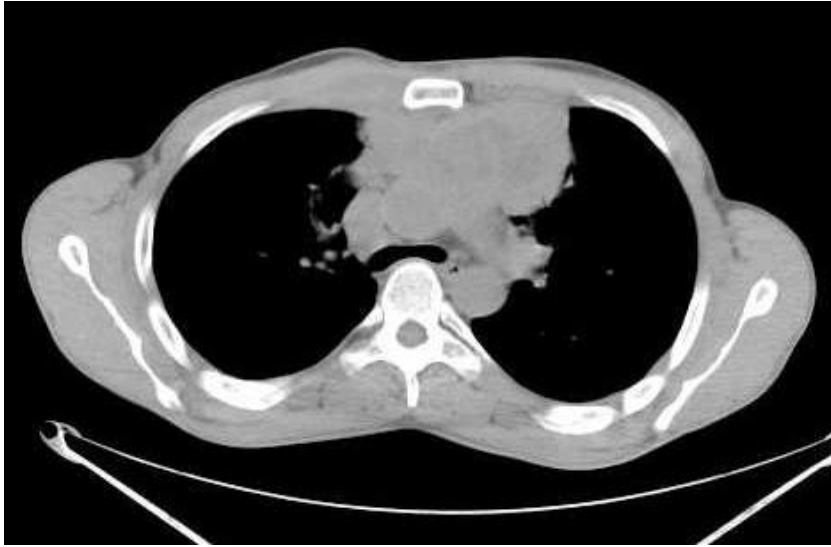




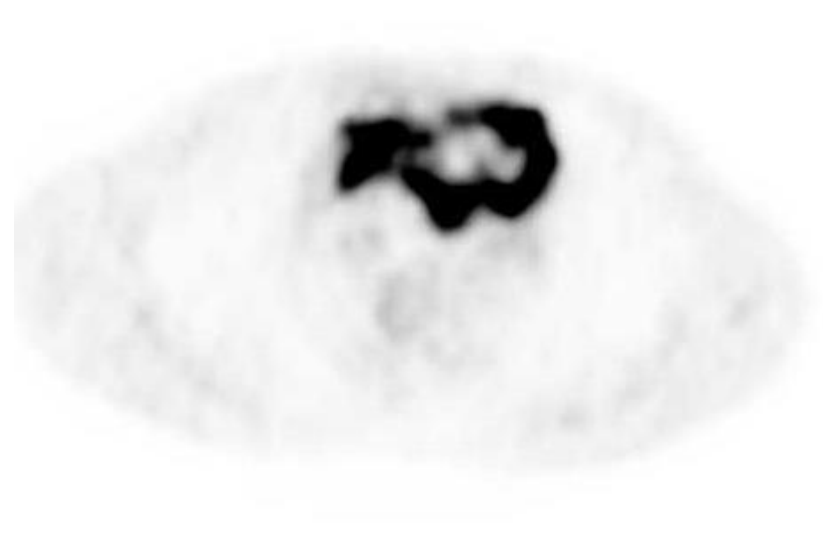






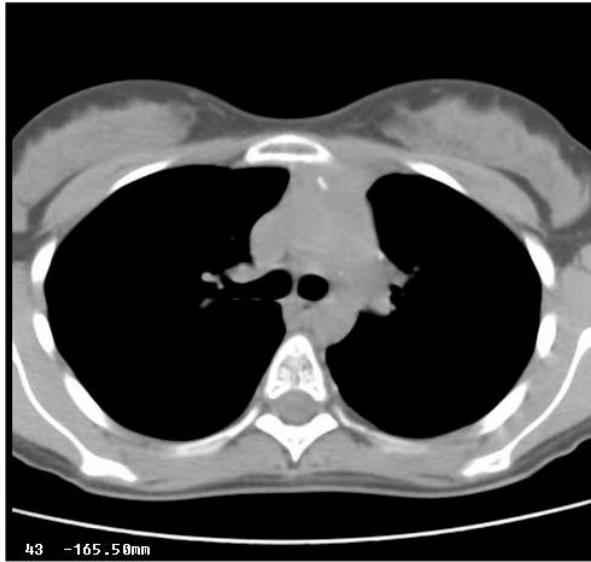


**IMAGING  
MORFOLOGICO**

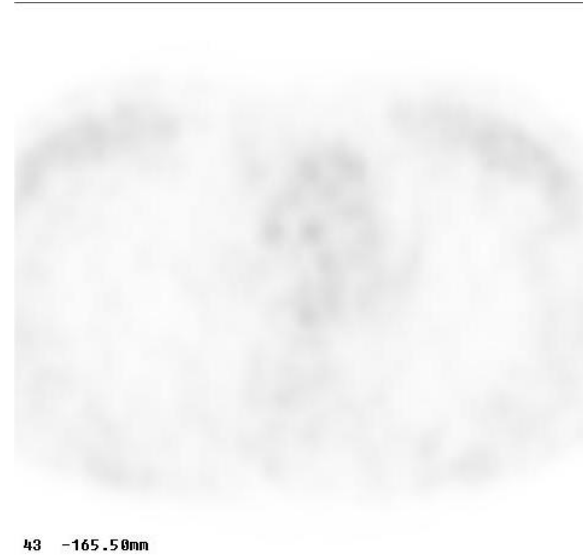


**IMAGING  
FUNZIONALE**





**IMAGING  
MORFOLOGICO**



**IMAGING  
FUNZIONALE**



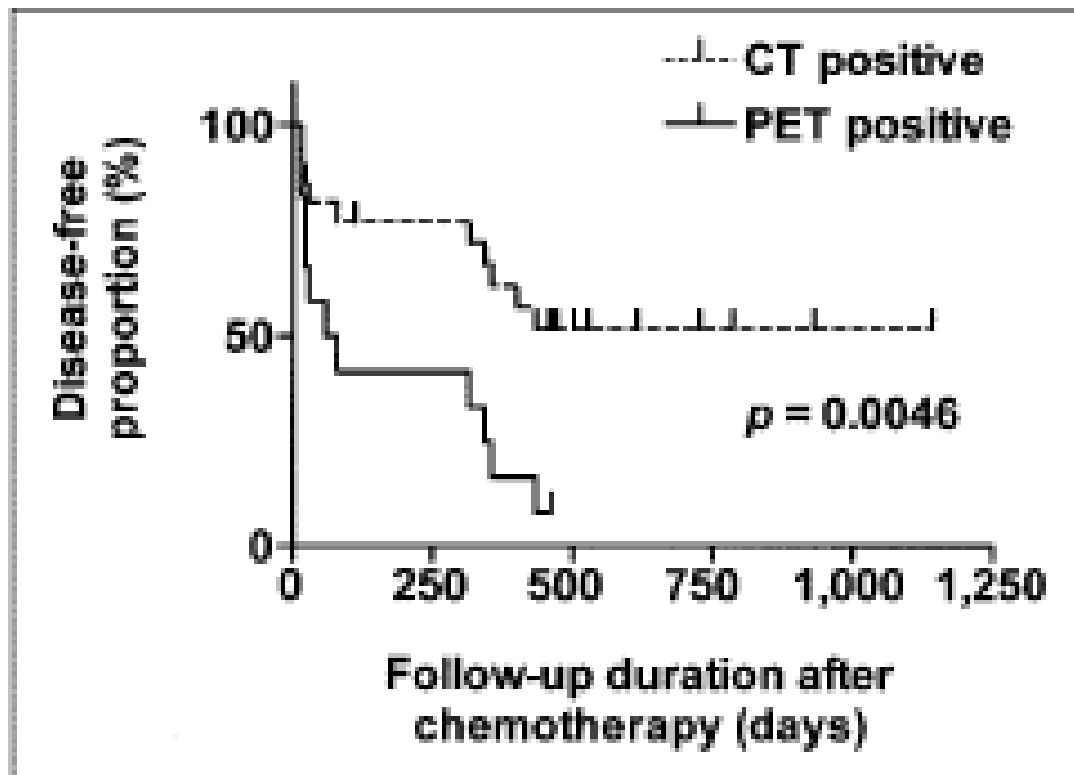
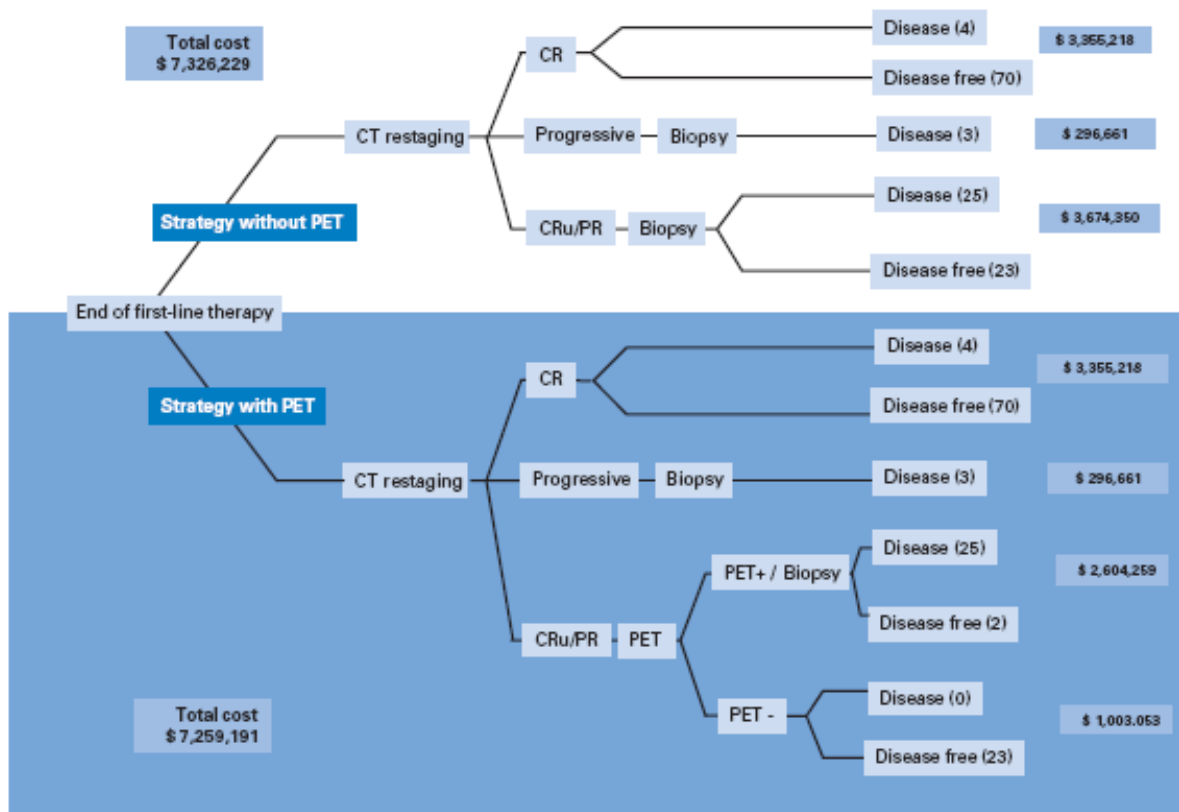


FIGURE 3. Kaplan-Meier estimate of disease-free interval in patients with positive CT or  $^{18}\text{F}$ -FDG PET studies. In patients with either negative CT or PET study, survival curves were almost identical and showed very low rate of relapse. Time intervals are in days.



# COST EFFECTIVENESS



Cost Effectiveness of Positron Emission Tomography in Patients With Hodgkin's Lymphoma in Unconfirmed Complete Remission or Partial Remission After First-Line Therapy

Juliano J. Cerci, Evelinda Trindade, Luis F. Pracchia, Felipe A. Pitella, Camila C.G. Linardi, José Soares Jr, Dominique Delbeke, Leigh-Ann Topfer, Valeria Buccheri, and José C. Meneghetti



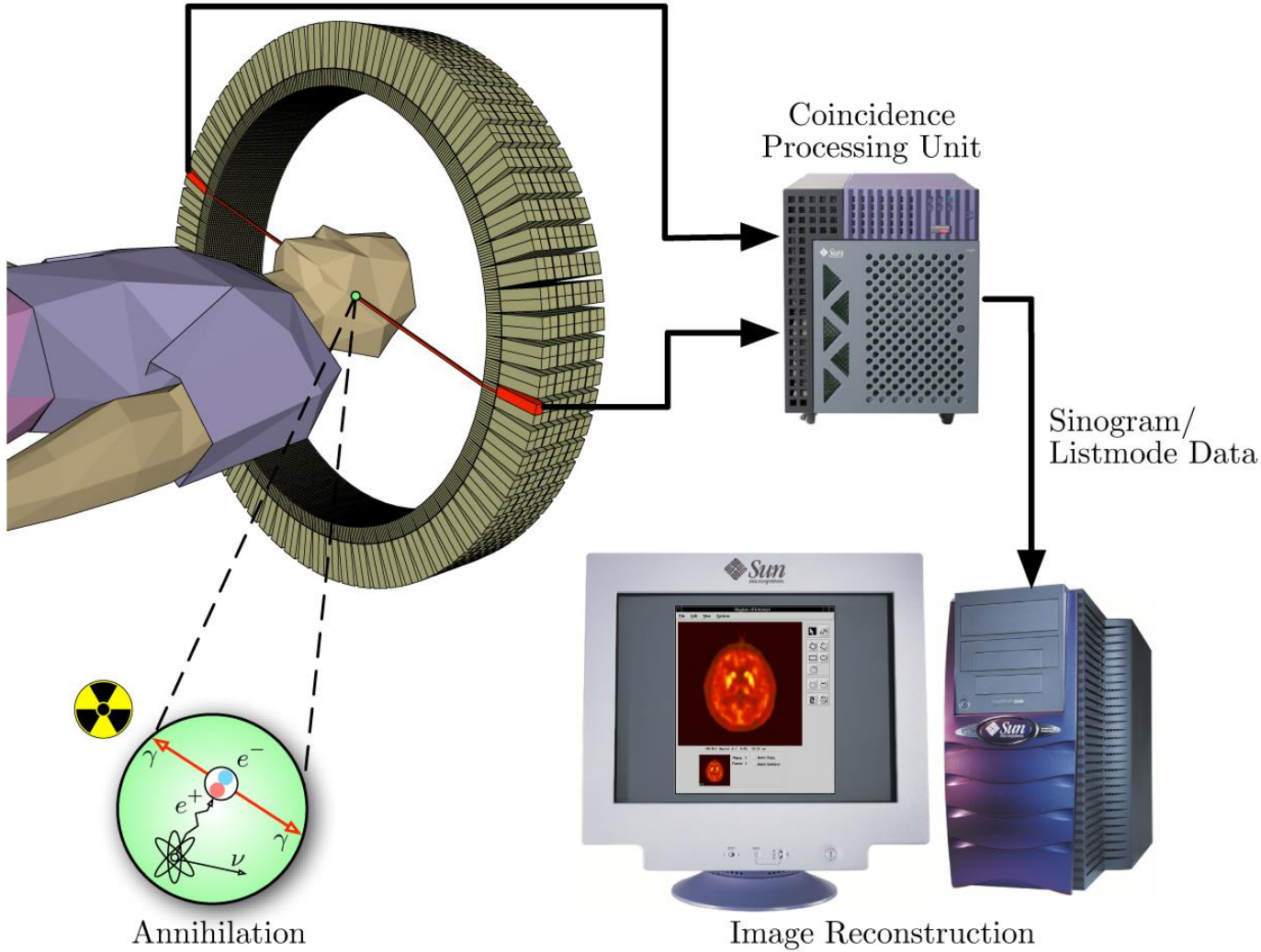
**PET**

**P** OSITRON  
**E** MISSION  
**T** OMOGRAPHY





# PET





# IMAGING METABOLICO

Le molecole impiegate nella PET vengono sviluppate a partire dalla identificazione di un processo fisiopatologico da studiare e successivamente sintetizzando un tracciante attraverso cui documentare il processo in oggetto.

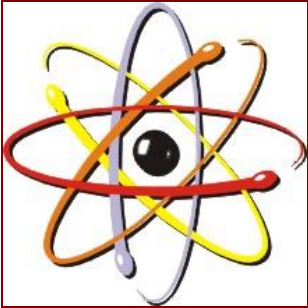


# MEDICINA NUCLEARE

**GYORGY HEVESY**



# MEDICINA NUCLEARE



## APPLICATION OF RADIOACTIVE INDICATORS IN BIOLOGY<sup>1</sup>

By G. HEVESY

*Institute for Theoretical Physics,  
The University, Copenhagen, Denmark*

Natural radioactive isotopes of some of the heaviest elements are easily available and labelled lead, bismuth, and thorium were used in biological research at an early date. The circulation of lead in plants (1) and that of lead, bismuth, and thorium in both normal (2, 3) and carcinomatous (4) animals was investigated by this method. Extended use was made of radioactive bismuth in the study of the rate of absorption of the various bismuth preparations used in syphilis therapy (5). The discovery of artificial radioactivity and the rapid and successful development following this important event (6) made it possible to obtain "artificial" radioactive isotopes of numerous elements and opened thus a vast field for the application of isotopic indicators in biology. Among the elements of biological importance, hydrogen has no radioactive isotope, while nitrogen, oxygen, and carbon have such short half lives that their application for most purposes is excluded, though the radioactive isotope of carbon has met with some very useful applications (see pp. 658, 659). The discovery of heavy hydrogen and the recent progress (7) in the separation of the isotopes of oxygen, nitrogen, and carbon have made it possible to make use of labelled hydrogen, nitrogen, oxygen, and carbon, the tagged elements being identified by density measurements and mass-spectrographic determinations respectively. No fundamental difference is to be found between the application of radioactive and of stable isotopes as indicators. To limit the scope of discussion, however, it may be preferable to treat the application of radioactive indicators separately from that of the nonradioactive ones. In what follows, we will first discuss the use of radioactive phosphorus for labelling purposes. This isotope has found so far the most extensive application; furthermore, in view of its importance both in the study of inorganic and of organic metabolism, its application presents very suitable examples of the type of problems which can be successfully attacked by the use of tagged elements.

1940



# IMAGING METABOLICO

ONCOLOGIA

Le cellule tumorali presentano caratteristiche alterazioni a livello genetico, a cui corrispondono modificazioni del comportamento metabolico.



# IMAGING METABOLICO

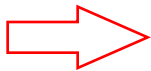
## ONCOLOGIA

La maggior parte delle cellule tumorali ha un aumentato metabolismo del glucosio.

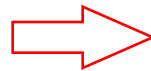


# IMAGING METABOLICO

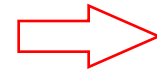
GL



GL



GL 6P



trasporto all'interno  
della cellula

fosforilazione enzima  
esochinasi

ulteriore  
metabolizzazione



# IMAGING METABOLICO

analogo del  
glucosio



**Il FDG rimane intrappolato nei tessuti tumorali con attiva glicolisi**







# STATE OF THE ART

NON SMALL CELL LUNG CANCER

COLO-RECTAL CANCER

MALIGNANT LYMPHOMA

MELANOMA

HEAD AND NECK CANCER

ESOPHAGEAL CANCER

CERVICAL CANCER

CANCER UNKNOWN PRIMARY

GIST

BREAST CANCER

OVARIAN CANCER

THYROID CANCER

SARCOMA

SEMINOMA

PANCREATIC CANCER

BONE TUMOURS

GASTRIC CANCER

MULTIPLE MYELOMA

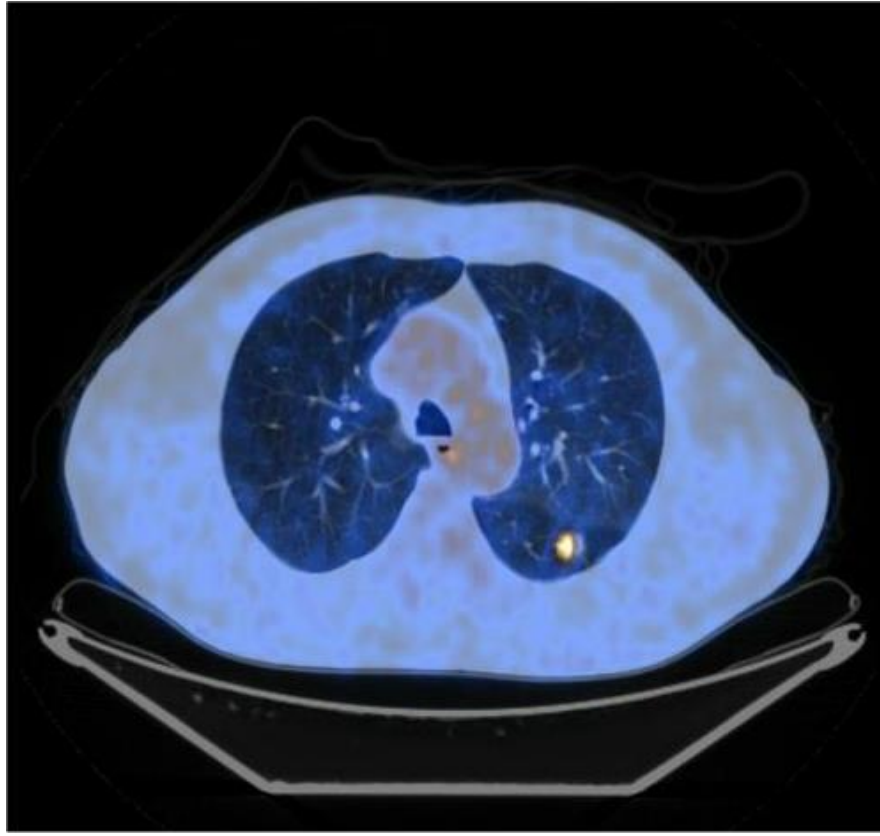
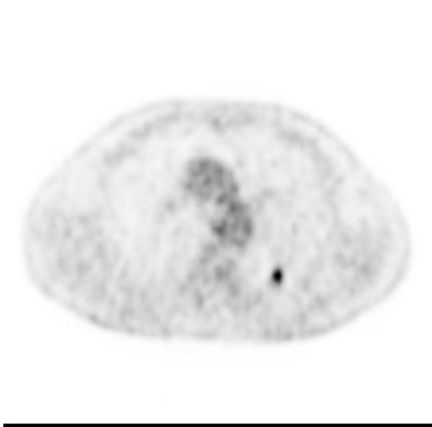
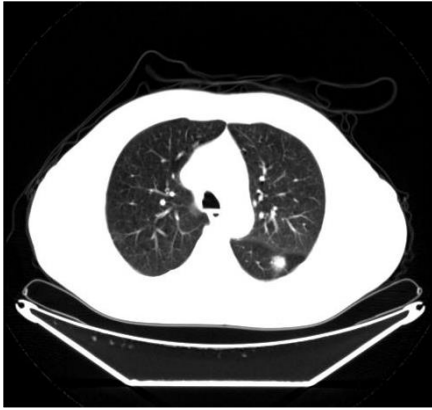


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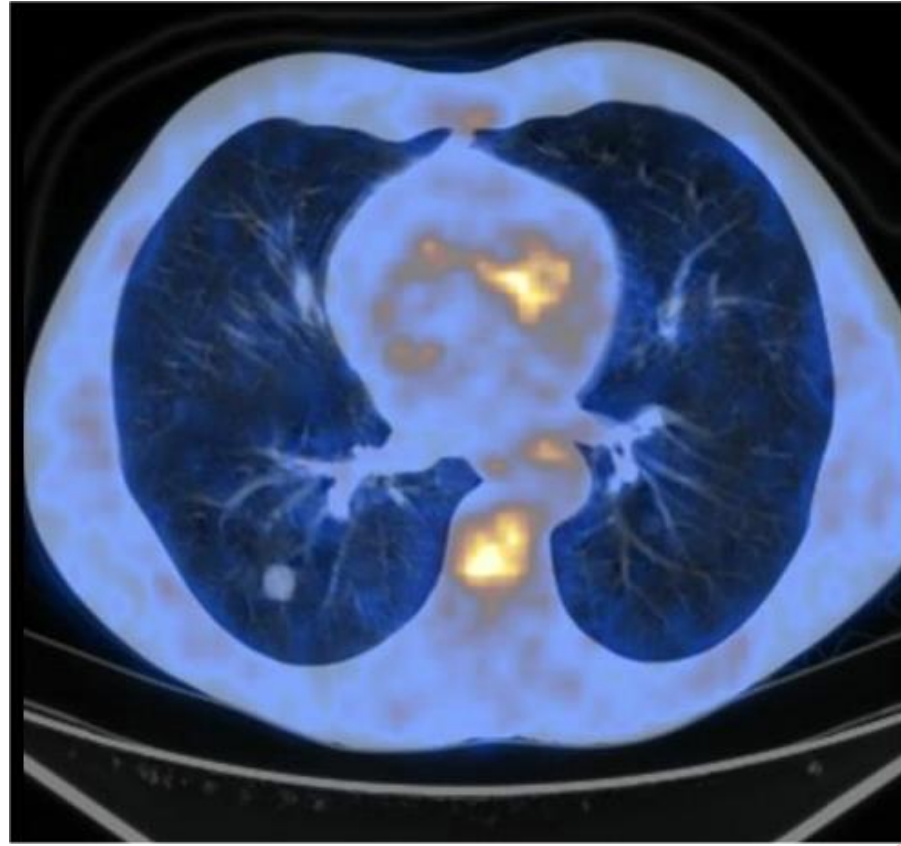
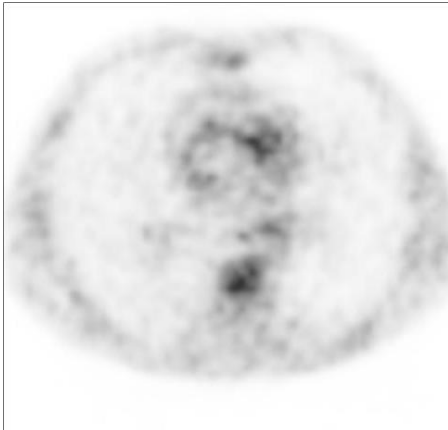
## VALUTAZIONE NODULI POLMONARI



# CA POLMONE (NSCLC)



# CA POLMONE (NSCLC)



Rohren EM et al.

## UPDATE IN PET IMAGING IN NSCLC

Sem Nucl Med 2004

**PET**

**SENSIBILITA' 95 %**

**SPECIFICITA' 82 %**

**TC**

**SENSIBILITA' 98 %**

**SPECIFICITA' 58 %**

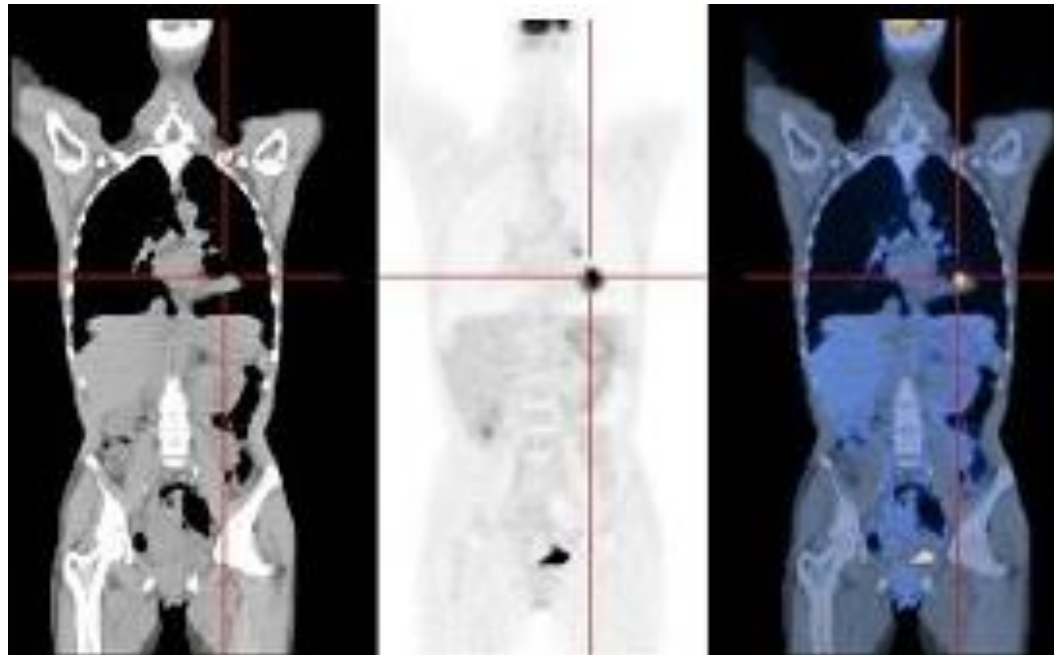


# STADIAZIONE TUMORE POLMONARE





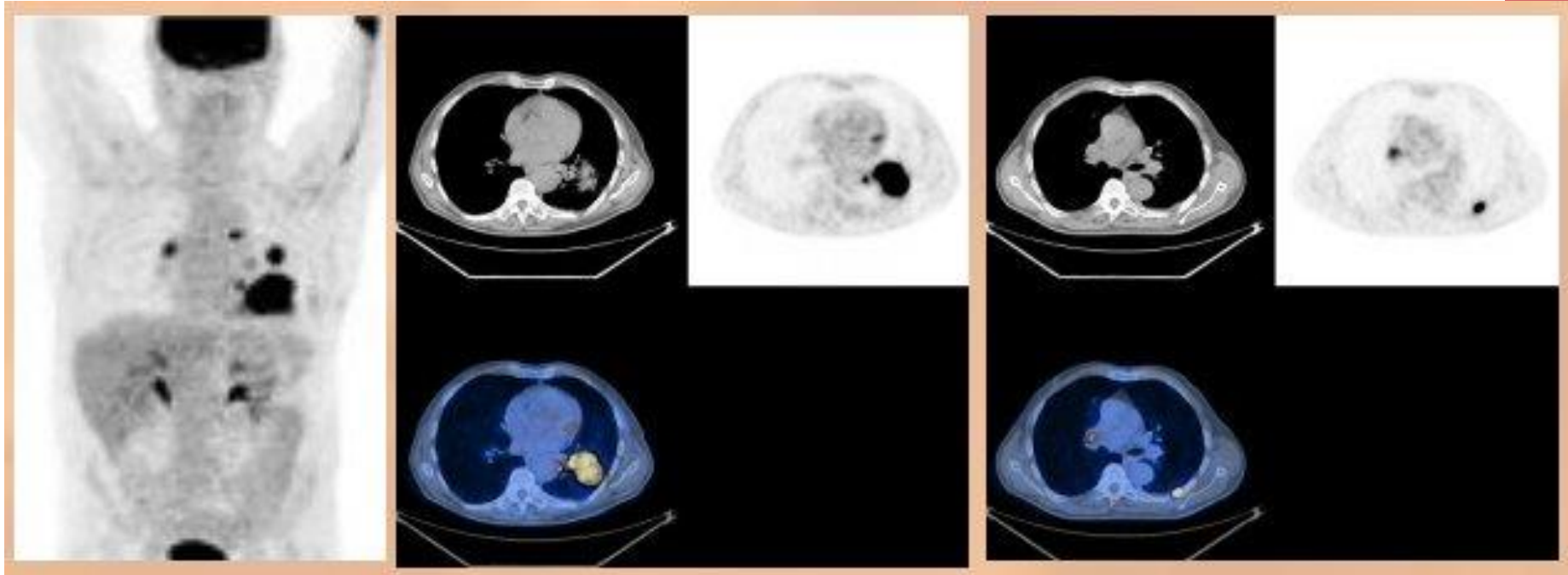
# CA POLMONE (NSCLC)



OPACITA' AL TERZO INFERIORE DEL  
POLMONE SINISTRO  
PET: AREA DI IPERMETABOLISMO CON  
ADENOPATIE OMOLATERALI  
ISTOLOGIA: ADK  
STAGING T2 N1 M0



# CA POLMONE (NSCLC)



CT/RX: ESTESA LESIONE POLMONARE  
BASALE SINISTRA  
PET-TC: VASTA AREA DI IPERMETABOLISMO  
CON ADENOPATIE OMO E CONTRO  
LATERALI E LESIONE OSSEA COSTALE  
ISTOLOGIA: ADK



Vansteenkiste JF et al.

# PET SCAN IN THE STAGING OF NON-SMALL CELL LUNG CANCER

Lung Cancer 2003

(meta-analisi di 498 pazienti)

**PET**

**SENSIBILITA' 89 %**

**SPECIFICITA' 92 %**

**TC**

**SENSIBILITA' 65 %**

**SPECIFICITA' 80 %**



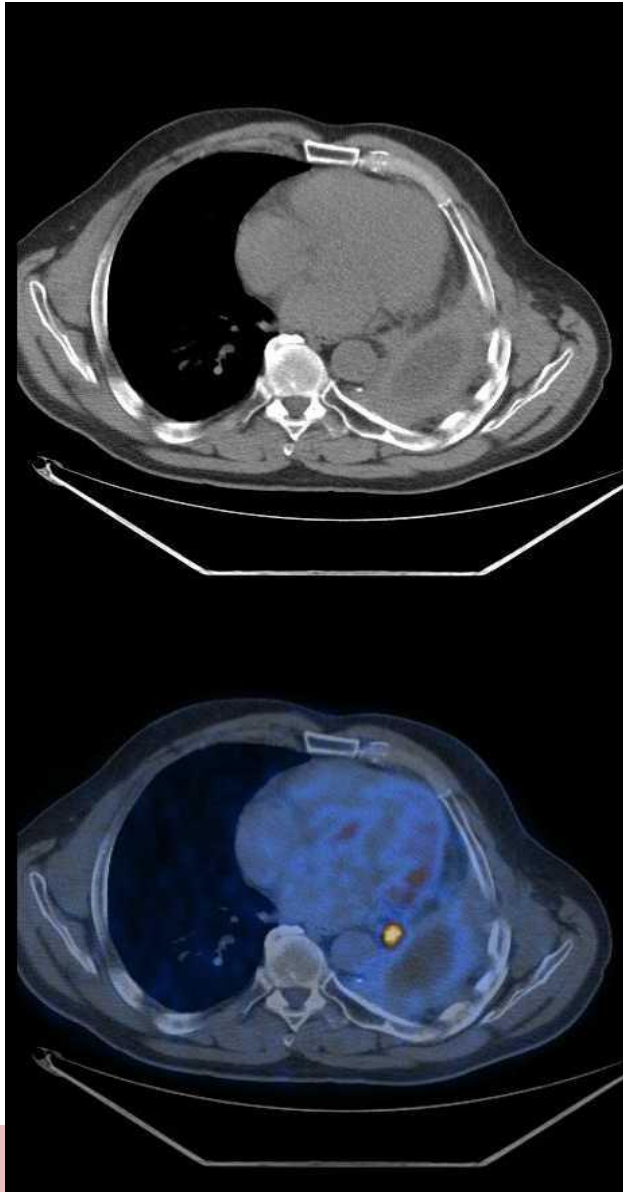
# FOLLOW-UP

SOSPETTA  
RECIDIVA



# CA POLMONE (NSCLC)

CT/RX: SOSPETTA  
RECIDIVA DI TUMORE  
POLMONARE

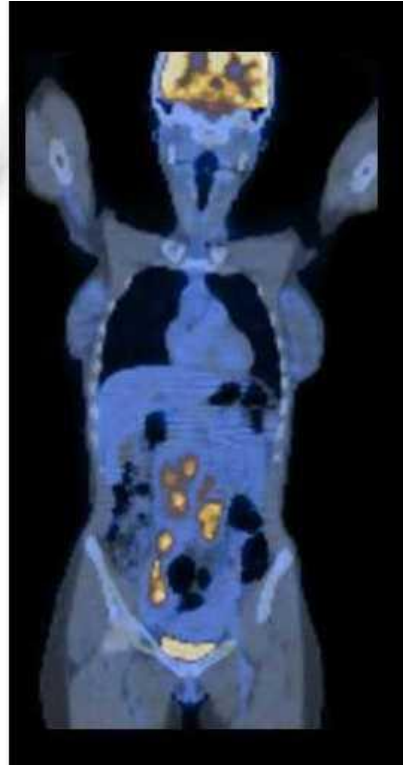


# STADIAZIONE LINFOMA





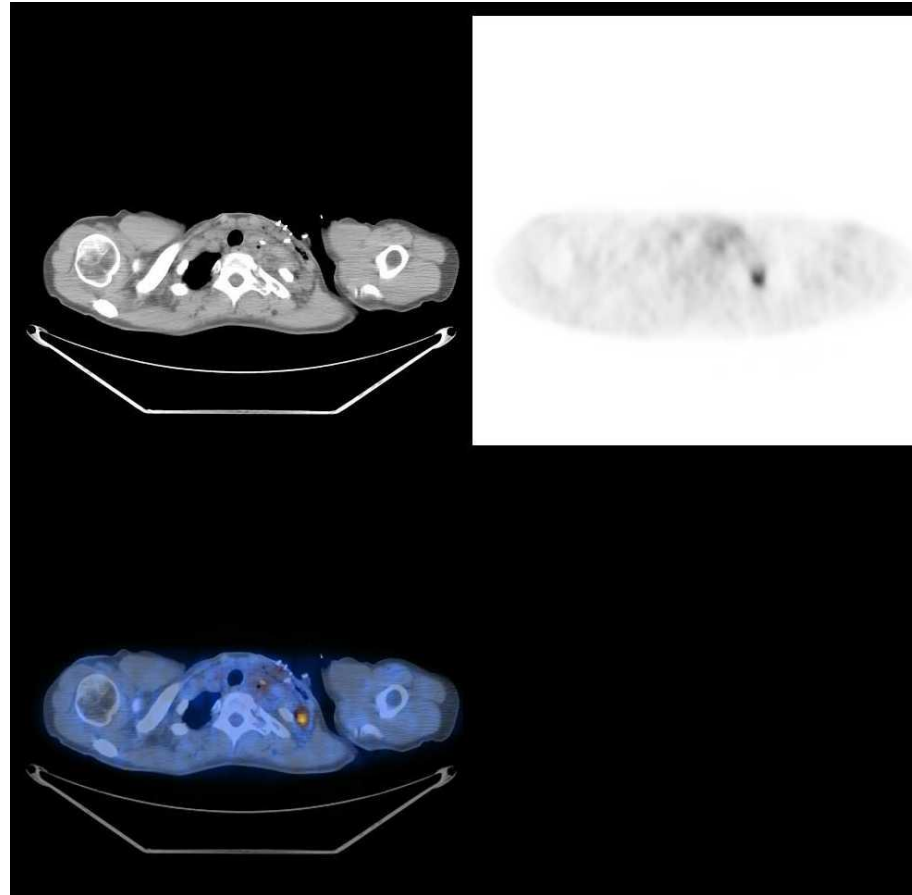
# STAGING



AGGRESSIVE NHL AT PRESENTATION



# STAGING



**AGGRESSIVE NHL AT PRESENTATION**

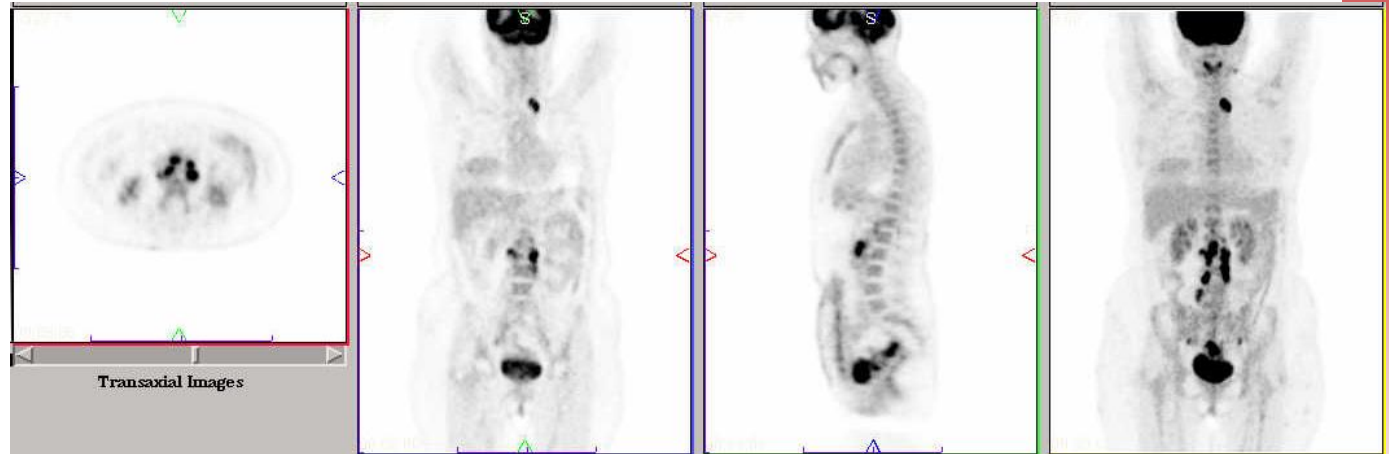


# RISPOSTA ALLA TERAPIA LINFOMA

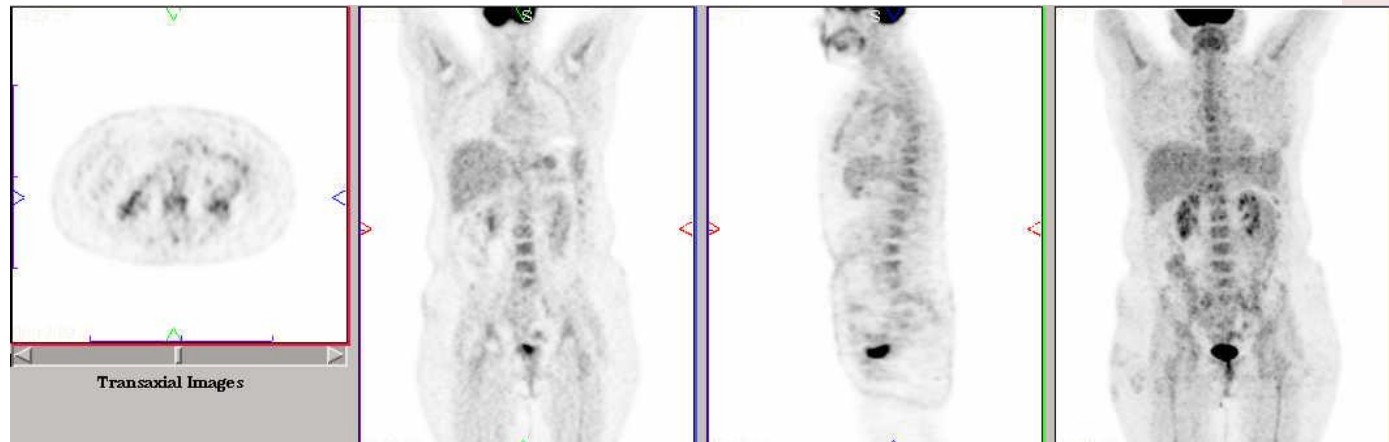


# VALUTAZIONE PRECOCE

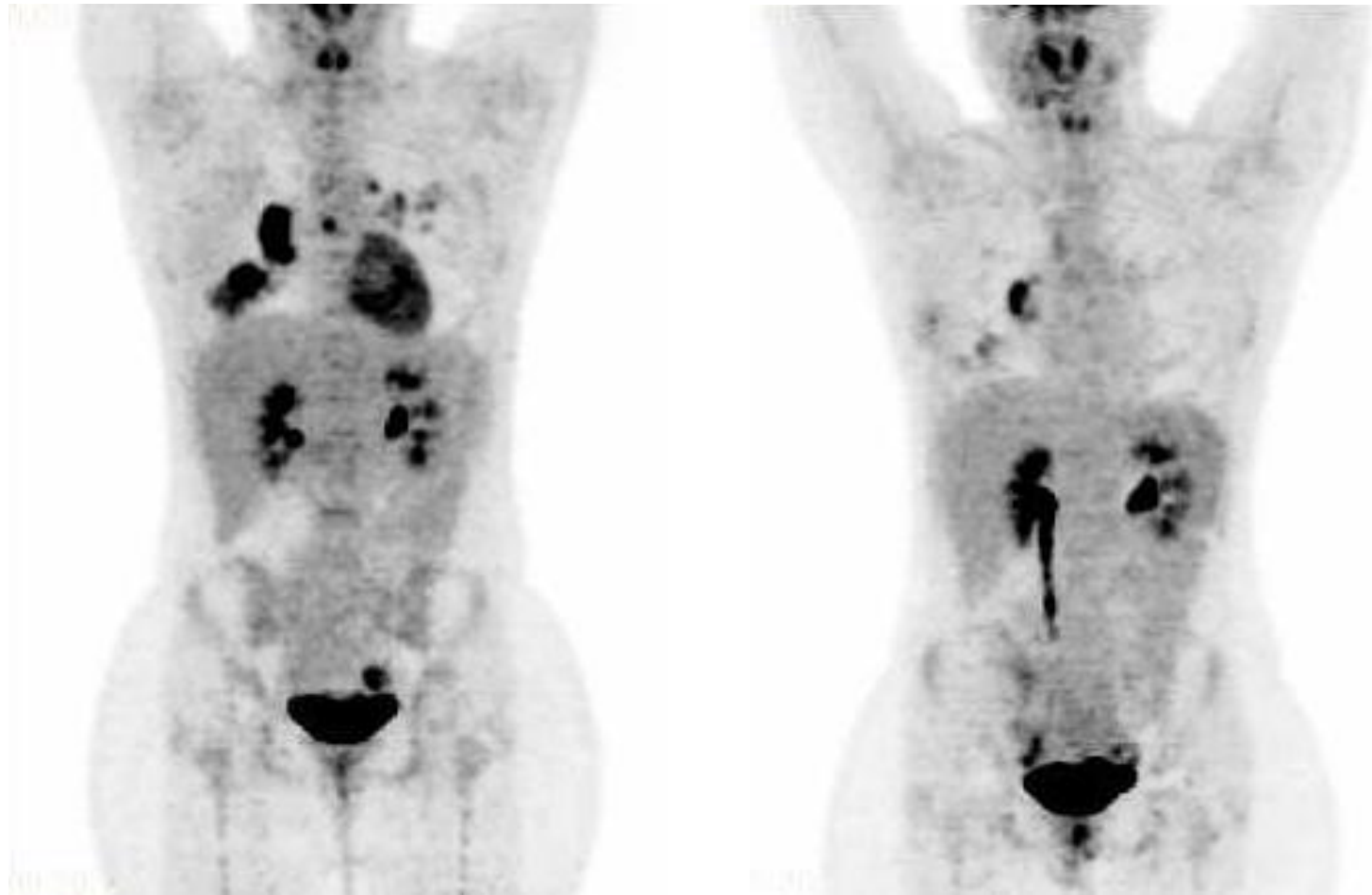
STAGING



AFTER  
2 CYCLES



# LINFOMA



ALTRI

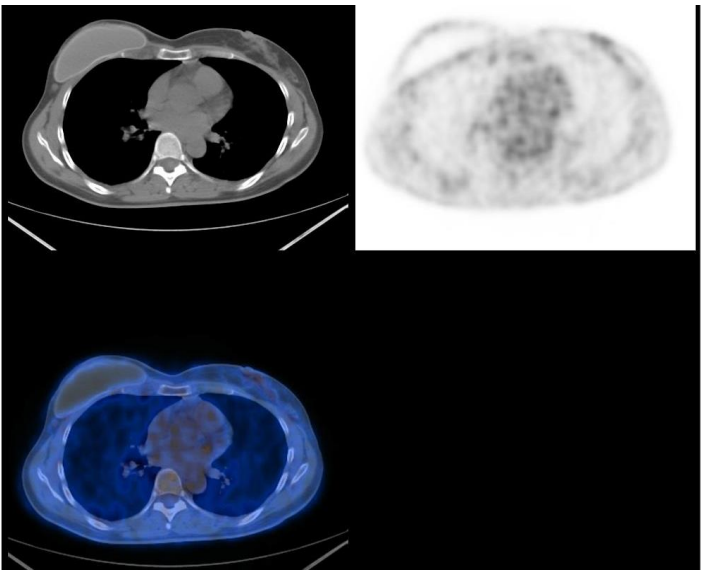




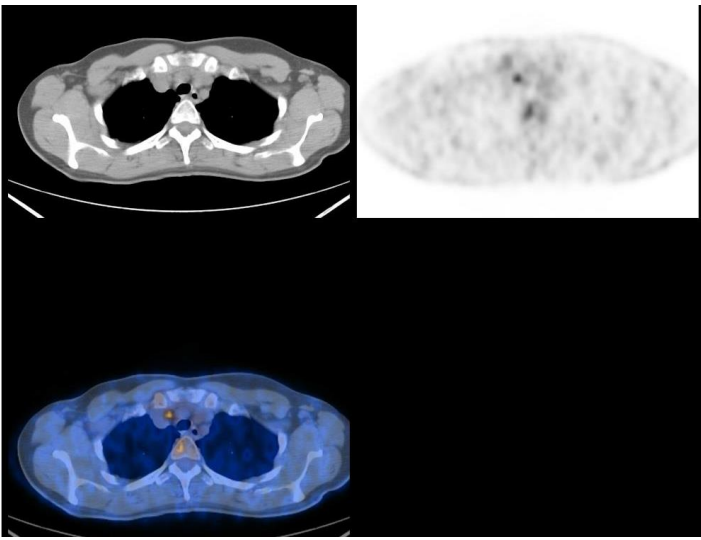
Female, 45 y.o., right mastectomy in 2002. Follow-up CT: enlargement of a right axillary lymph node.



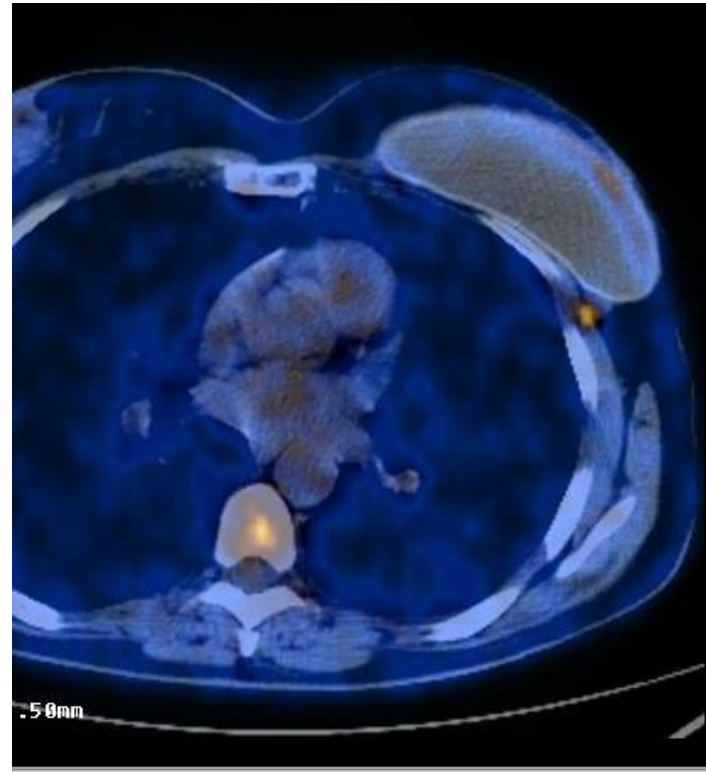
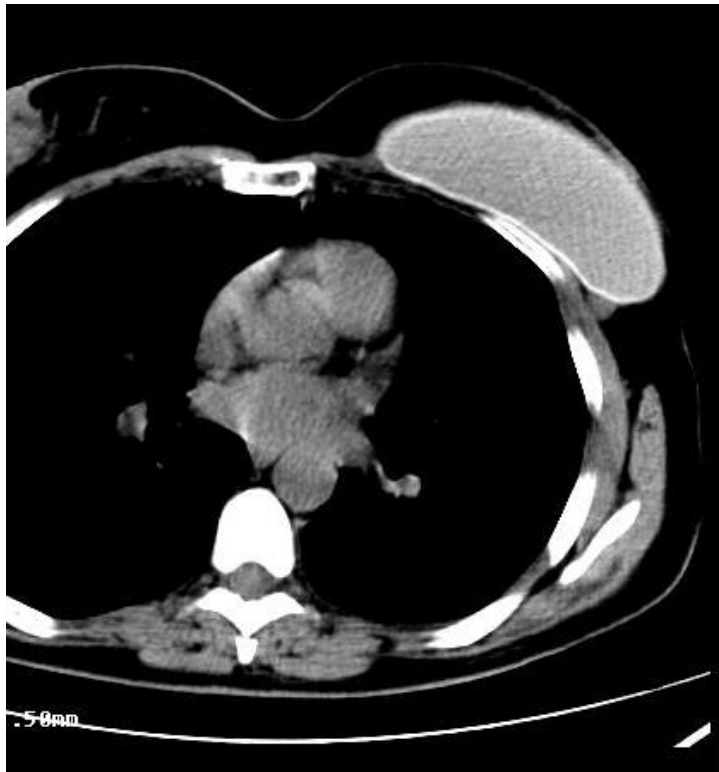
a



b

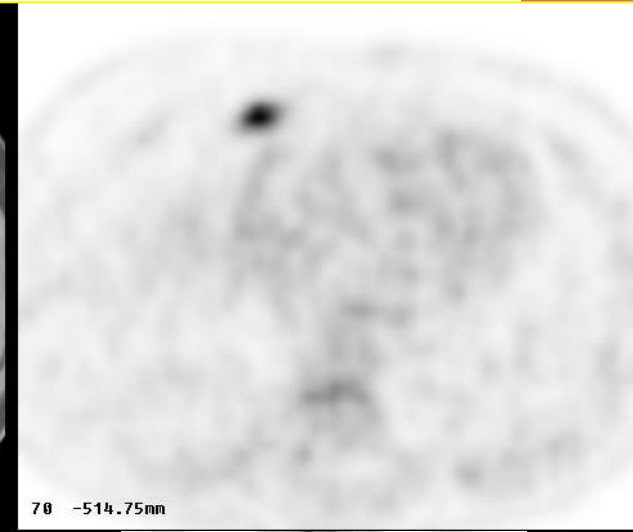
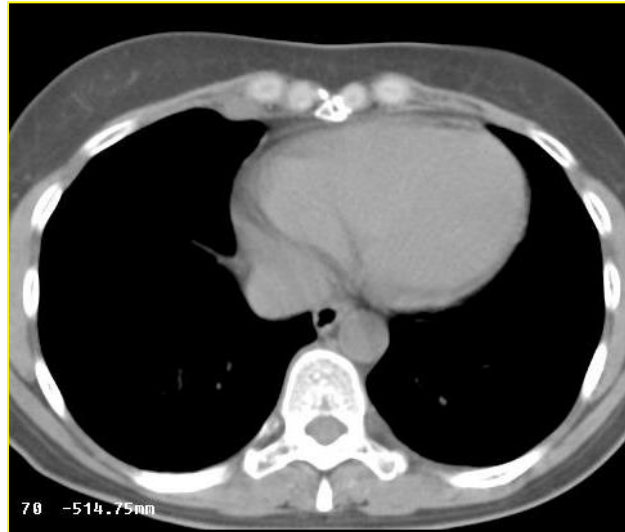


Female 44 yo. Left mastectomy for breast cancer. Follow-up CT shows a small nodule just below the prosthesis.



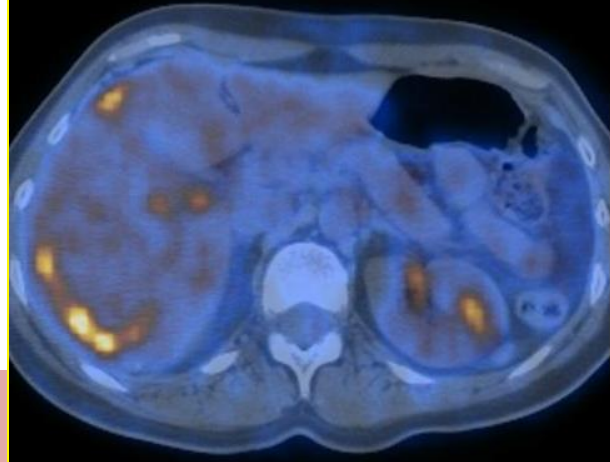
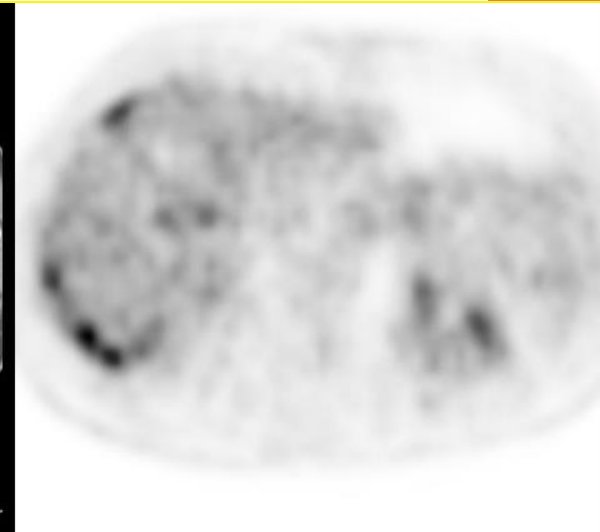
# RELAPSE

Pleural lesion in patient treated for ovarian cancer, increased markers and negative US and MR



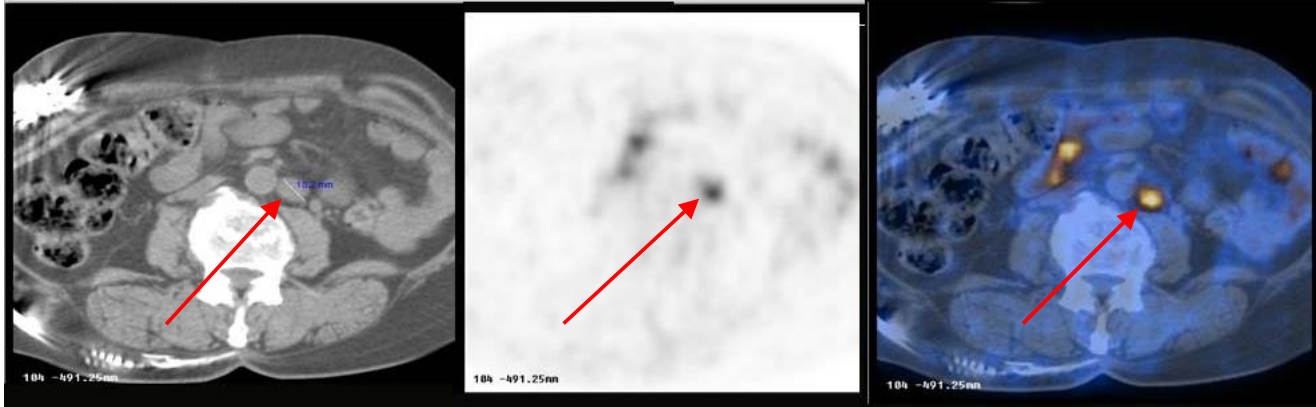
# RELAPSE

Disease diffusion to liver capsule in a patient treated for ovarian cancer, increased marker and negative CT and US

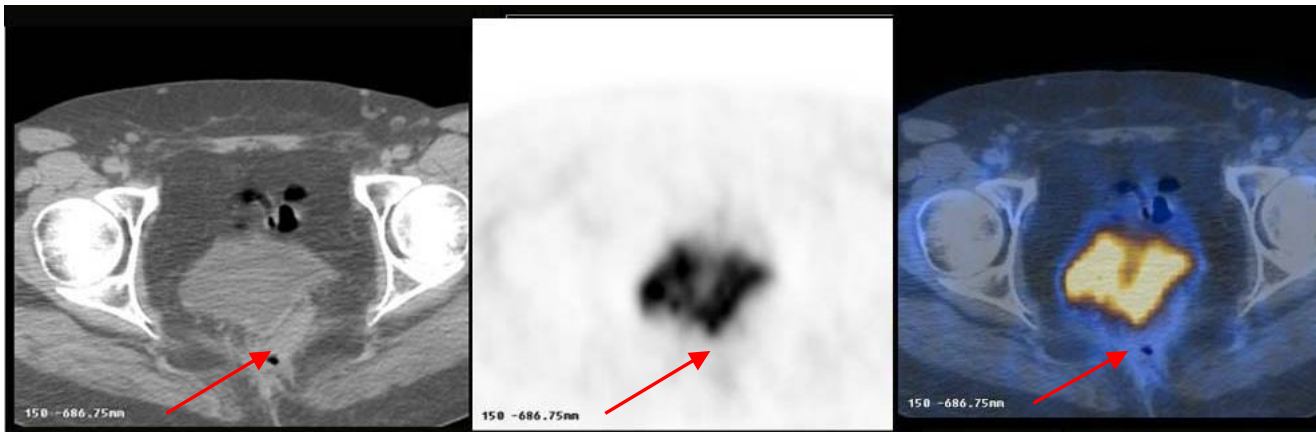




# CA COLON RETTO



Paz. femmina di 62 anni già sottoposta ad intervento chirurgico per adenocarcinoma del tratto di passaggio sigma-retto.  
CEA: 80.0 ng/ml

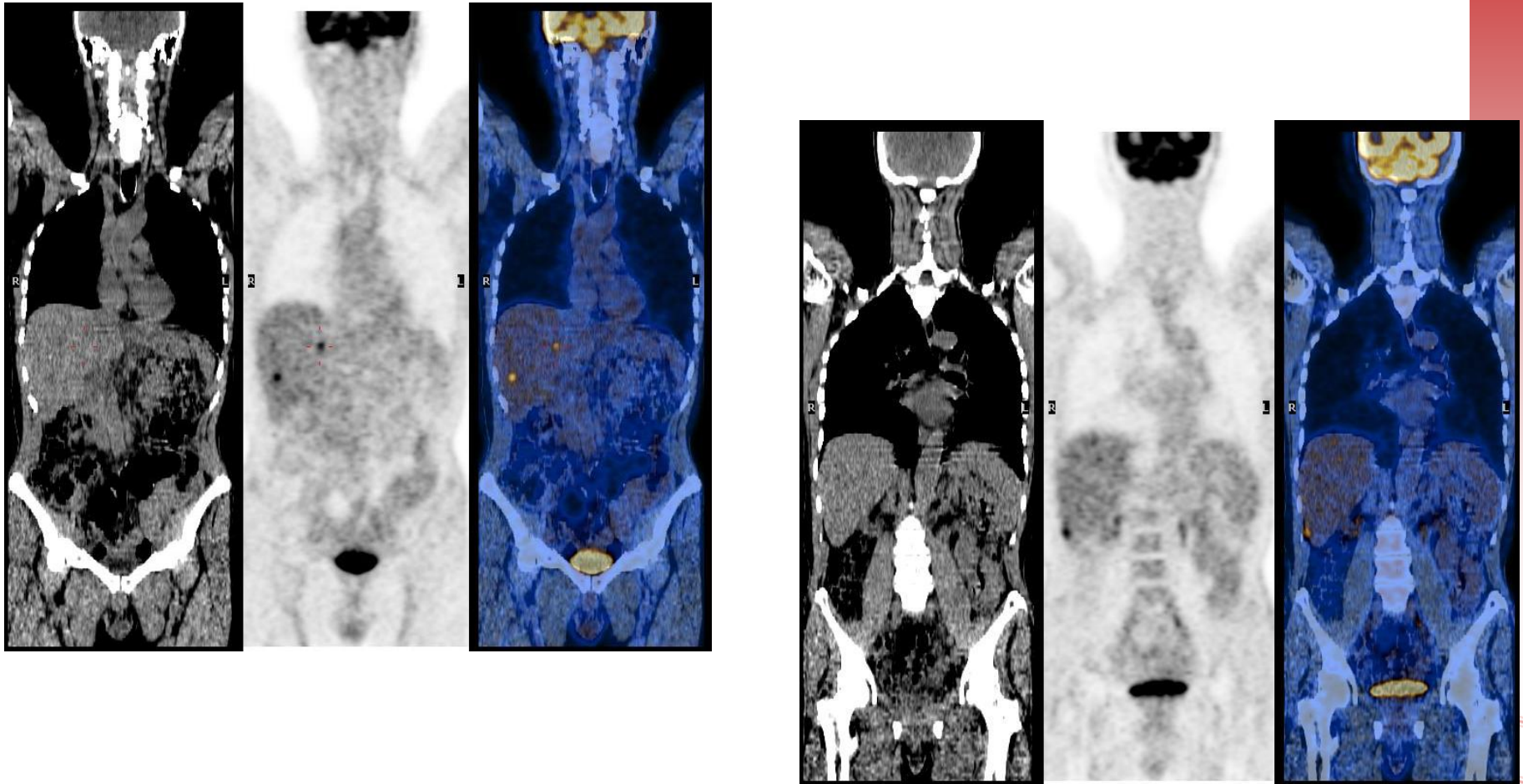


TC: sospetta ripresa di malattia in sede retro-vescicale

PET: assenza di tessuto neoplastico in sede retrovescicale. Presenza di una adenopatia metastatica in sede para-aortica.



# CA COLON RETTO



G.L: Adenocarcinoma del retto già operato.  
Rialzo dei marker.  
ECO, TC, RM negativa.

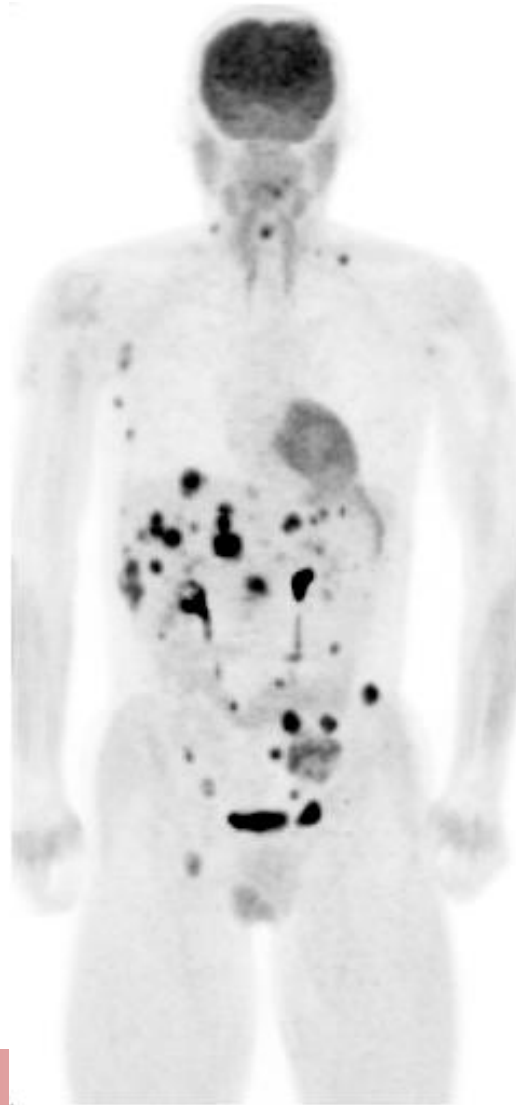
PET: piccole multiple metastasi epatiche



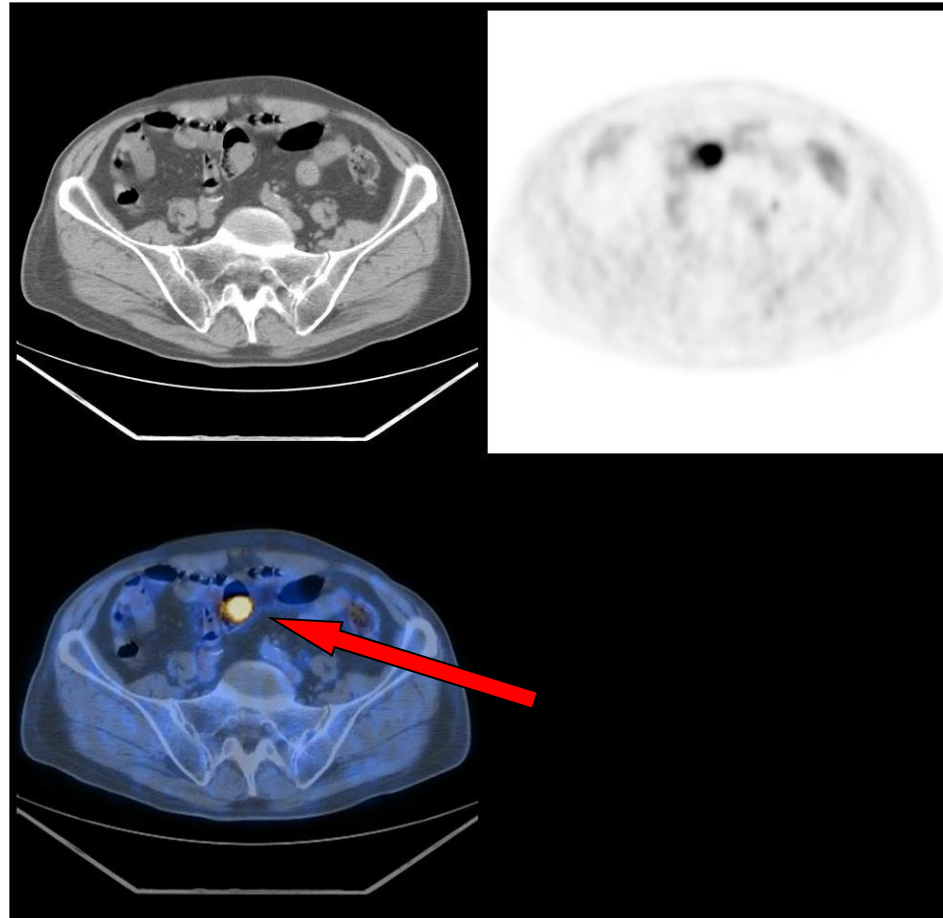


# MELANOMA

*PET FDG: melanoma con lesioni ipermetaboliche multiple.*



# NEOPLASIA OCCULTA

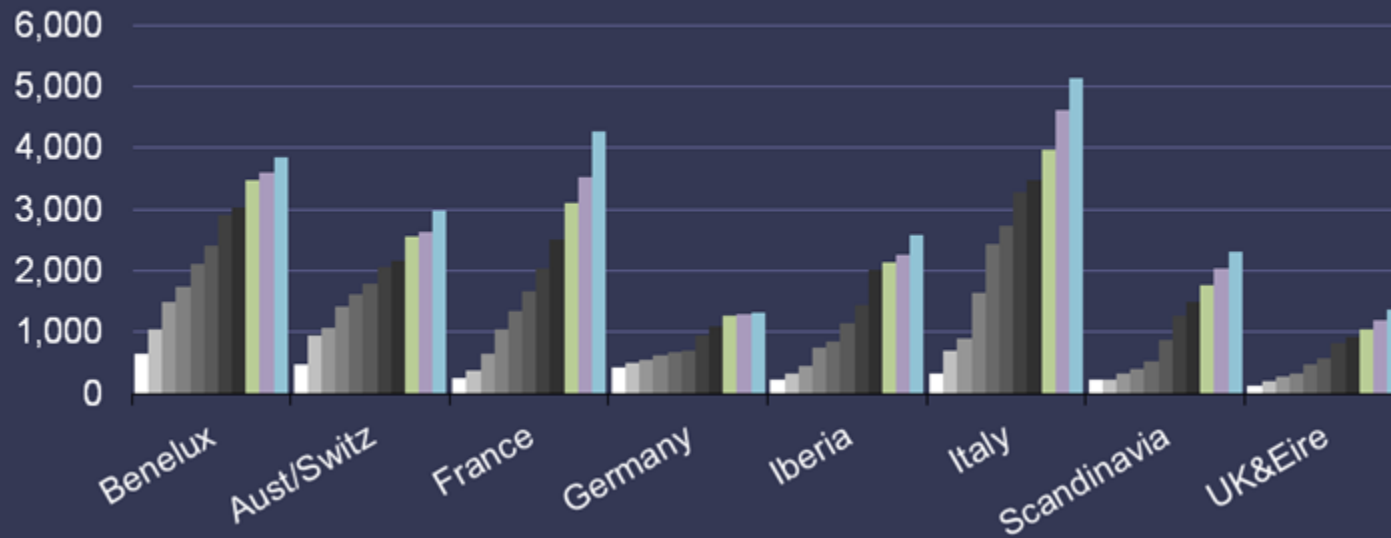


Ricerca di neoplasia primitiva occulta.

PET-TC FDG: area focale ipermetabolica a livello intestinale. Evidenza di lesione endoluminale.



## Examinations per million population 2002 -2012

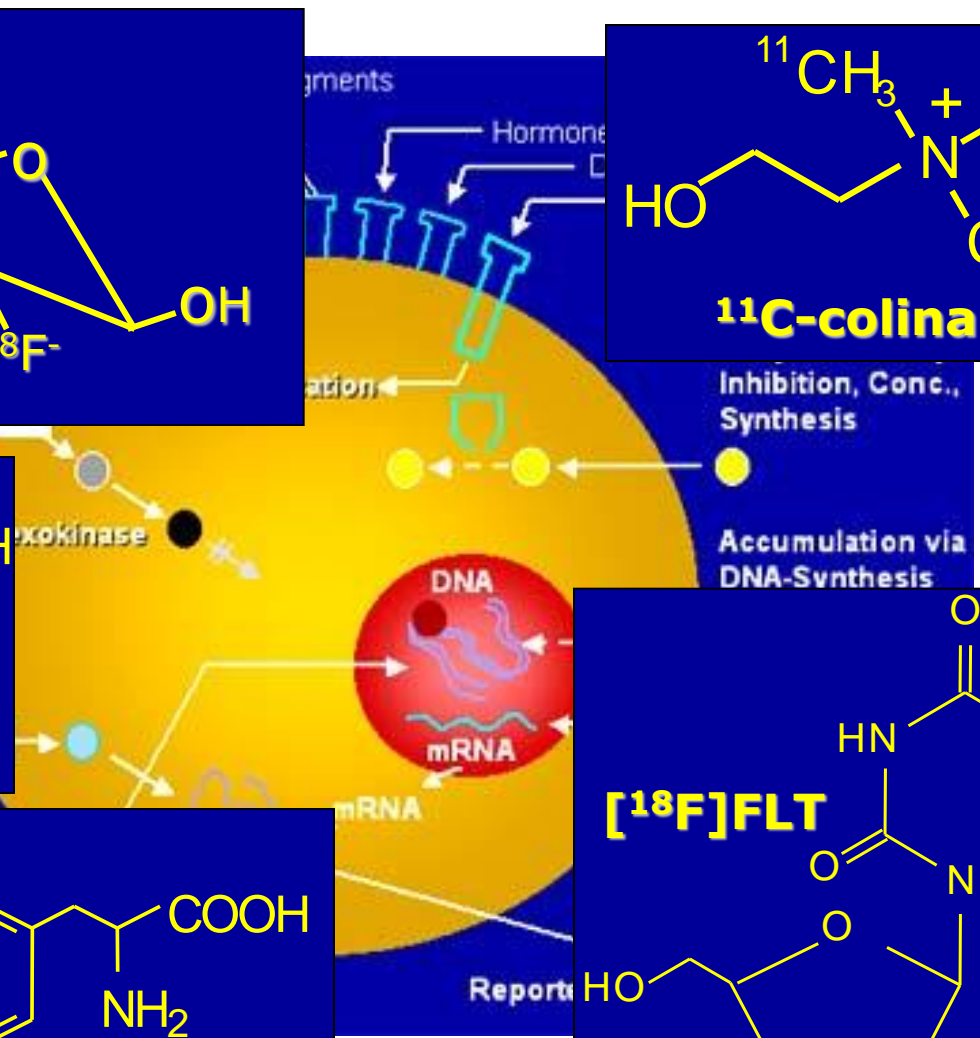
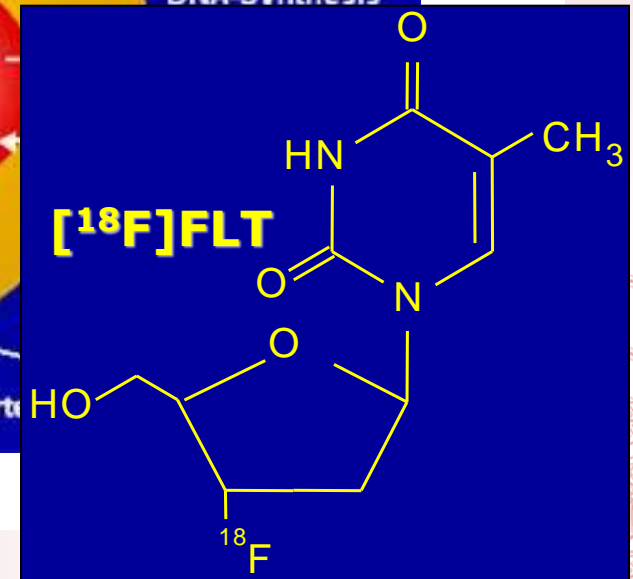
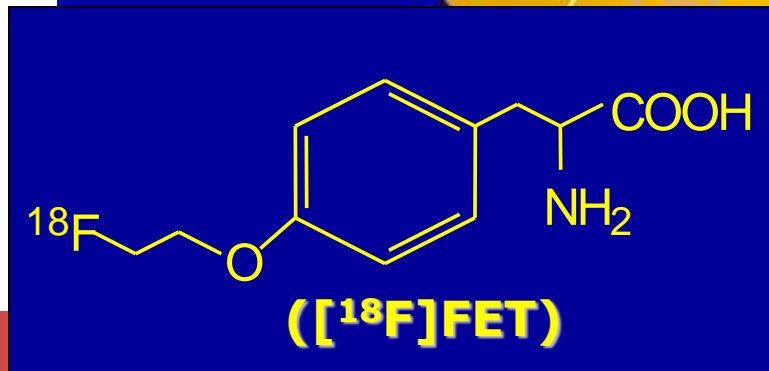
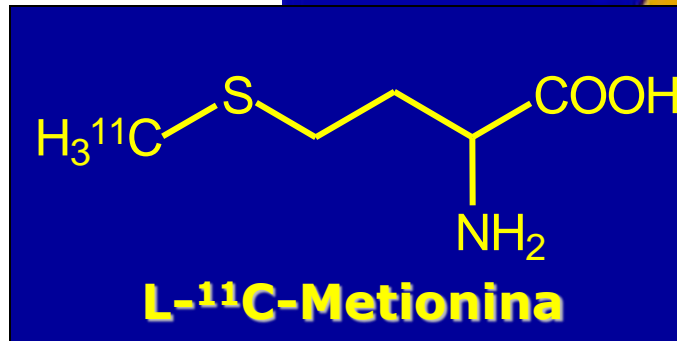
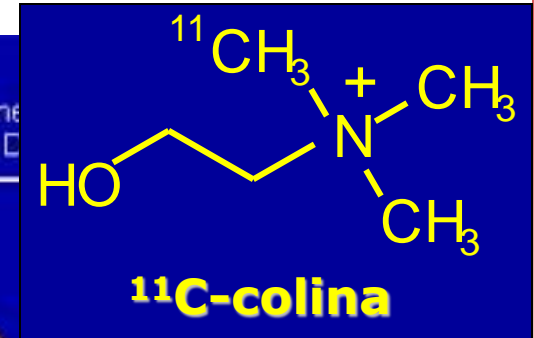
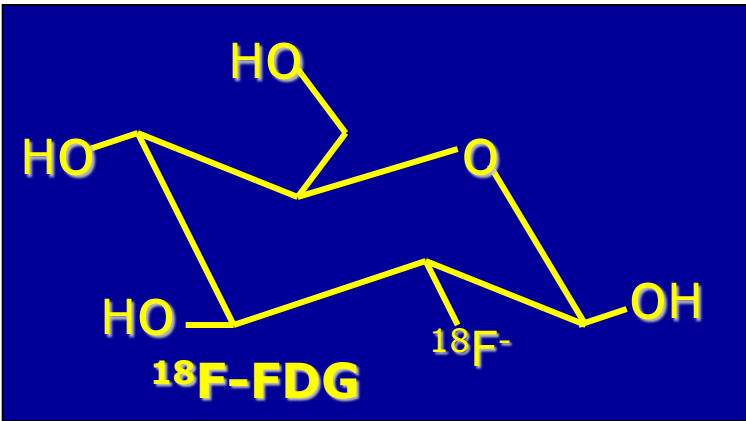


Data courtesy of:

**Anthony Stevens**  
Medical Options, London



# IMAGING METABOLICO



# Fluorinated tracers for imaging cancer with positron emission tomography

Olivier Couturier<sup>1</sup>, André Luxen<sup>2</sup>, Jean-François Chatal<sup>1</sup>, Jean-Philippe Vuillez<sup>3</sup>, Pierre Rigo<sup>4</sup>, Roland Hustinx<sup>5</sup>

$^{18}\text{F}$ -TYR

$^{18}\text{F}$ -FMT

$^{18}\text{F}$ -FET

$^{18}\text{F}$ -DOPA

$^{18}\text{F}$ -OCT

$^{18}\text{F}$ -TOCA

$^{18}\text{F}$ -FLT

$^{18}\text{F}$ -FBAU

$^{18}\text{F}$ -FMAU

$^{18}\text{F}$ -FAU

$^{18}\text{F}$ -FEC

$^{18}\text{F}$ -FBM

$^{18}\text{F}$ -FCH

$^{18}\text{F}$ -FPC

$^{18}\text{F}$ -MEC

$^{18}\text{F}$ -FES

$^{18}\text{F}$ -FMOX

$^{18}\text{F}$ -FESD

$^{18}\text{F}$ -FENP

$^{18}\text{F}$ -FMNP

$^{18}\text{F}$ -FDHT

$^{18}\text{F}$ -FMB

$^{18}\text{F}$ -MEC

$^{18}\text{F}$ -MDH

$^{18}\text{F}$ -FAMP

$^{18}\text{F}$ -MISO

$^{18}\text{F}$ -FAZA

$^{18}\text{F}$ -FETN

$^{18}\text{F}$ -FETA

$^{18}\text{F}$ -EF1

$^{18}\text{F}$ -EF5

$^{18}\text{F}$ -NaF

$^{18}\text{F}$ -FU

$^{18}\text{F}$ -SFB

$^{18}\text{F}$ -FAMP

$^{18}\text{F}$ -FHPG

$^{18}\text{F}$ -FHBG

$^{18}\text{F}$ -FIAU

$^{18}\text{F}$ -FPCV

$^{18}\text{F}$ -RGD

$^{18}\text{F}$ -TP

$^{18}\text{F}$ -FMAC

$^{18}\text{F}$ -FBG



**CHOLINE**



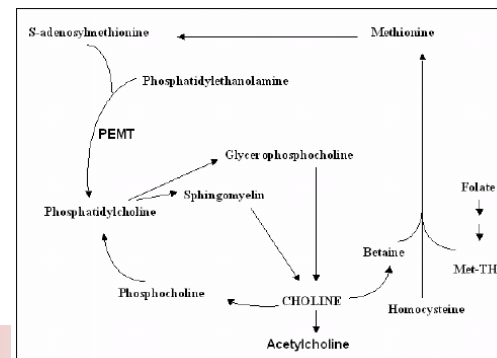
**PHOSPHOLIPID**



**TRACE  
CELLS  
MEMBRANE**

$^{11}\text{C}$ -CHOLINE

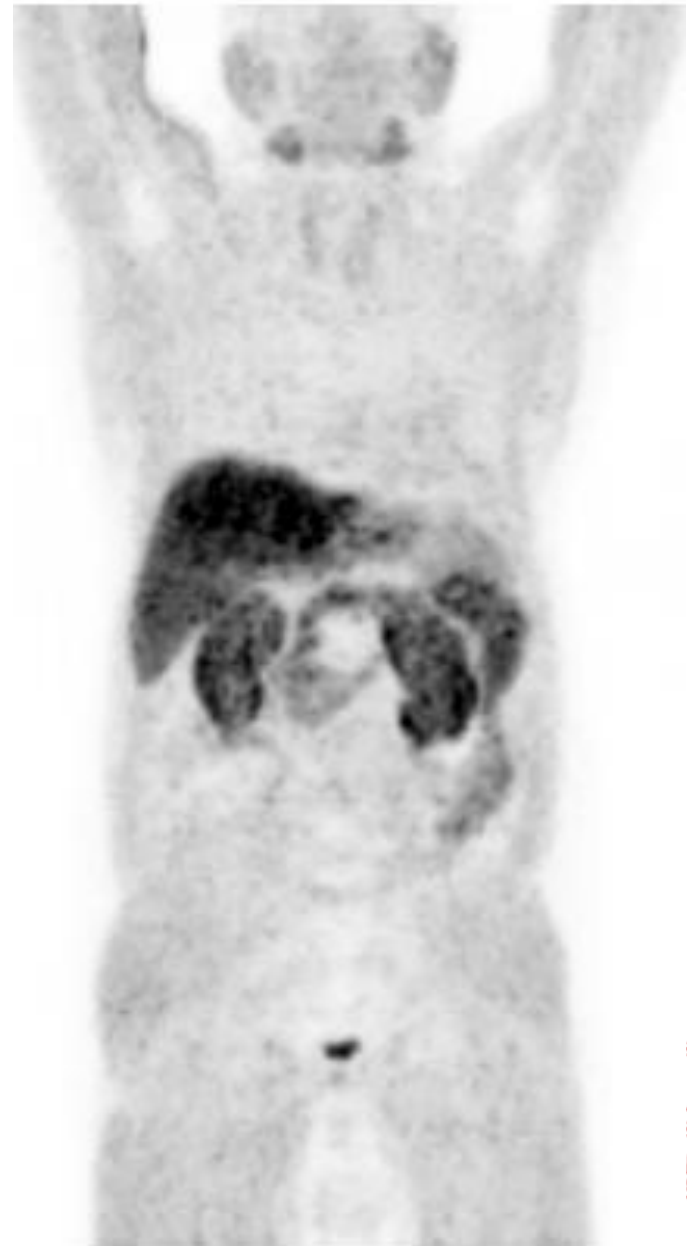
$^{18}\text{F}$ -CHOLINE







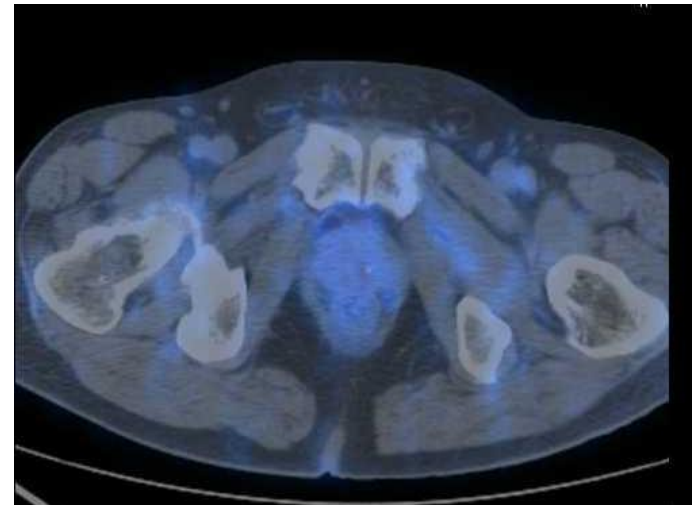
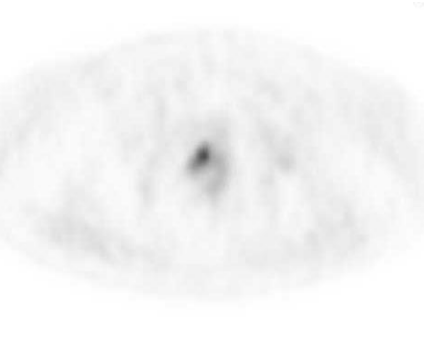
$^{18}\text{F}$ -FDG



$^{11}\text{C}$ -CHOLINE



# $^{11}\text{C}$ -CHOLINE

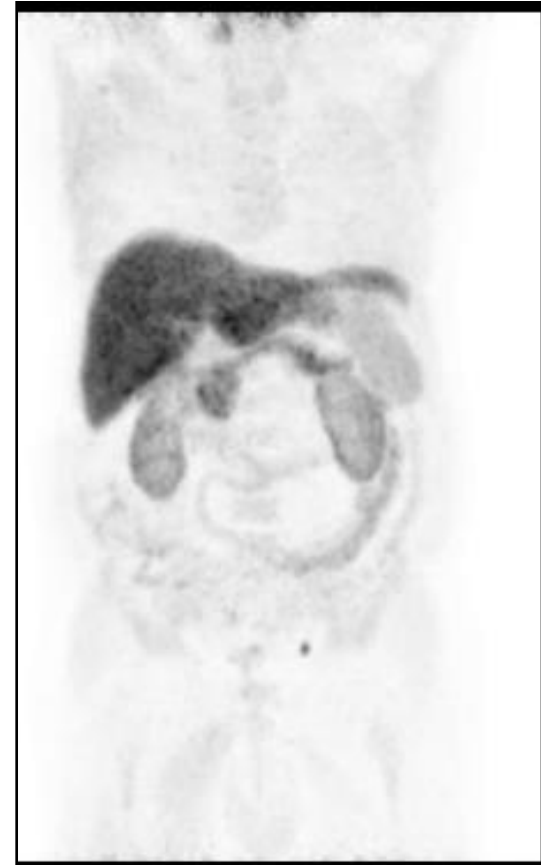
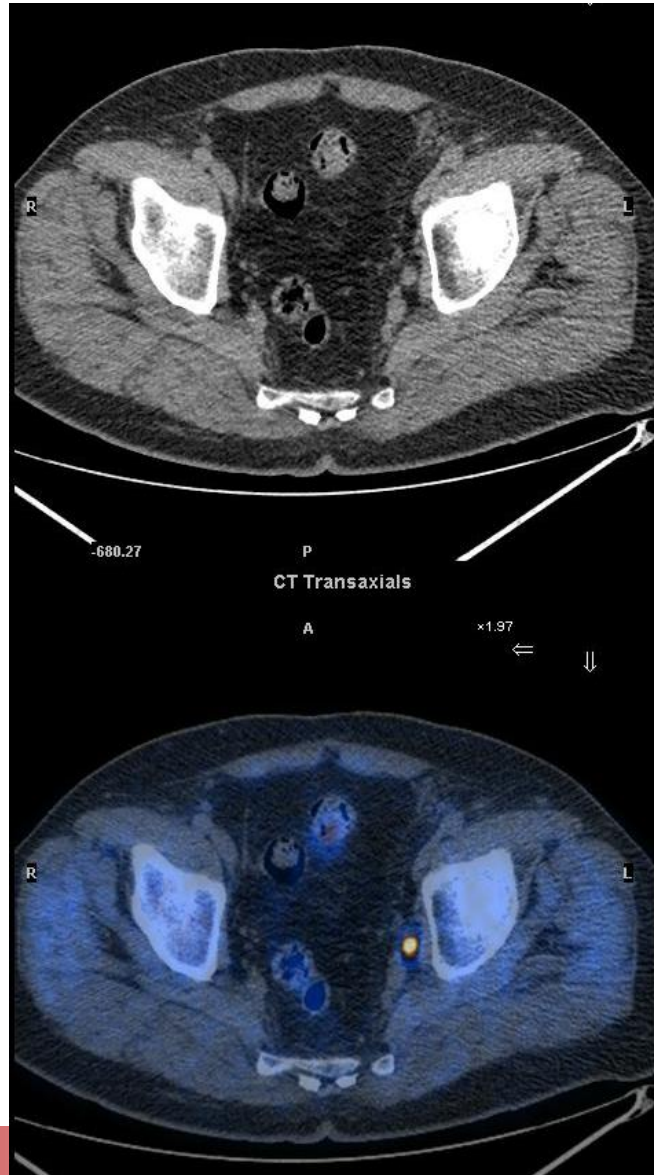


**P.V. 66 yo, treated with RT for prostate adk; recent increase of PSA (10 ng/ml).**



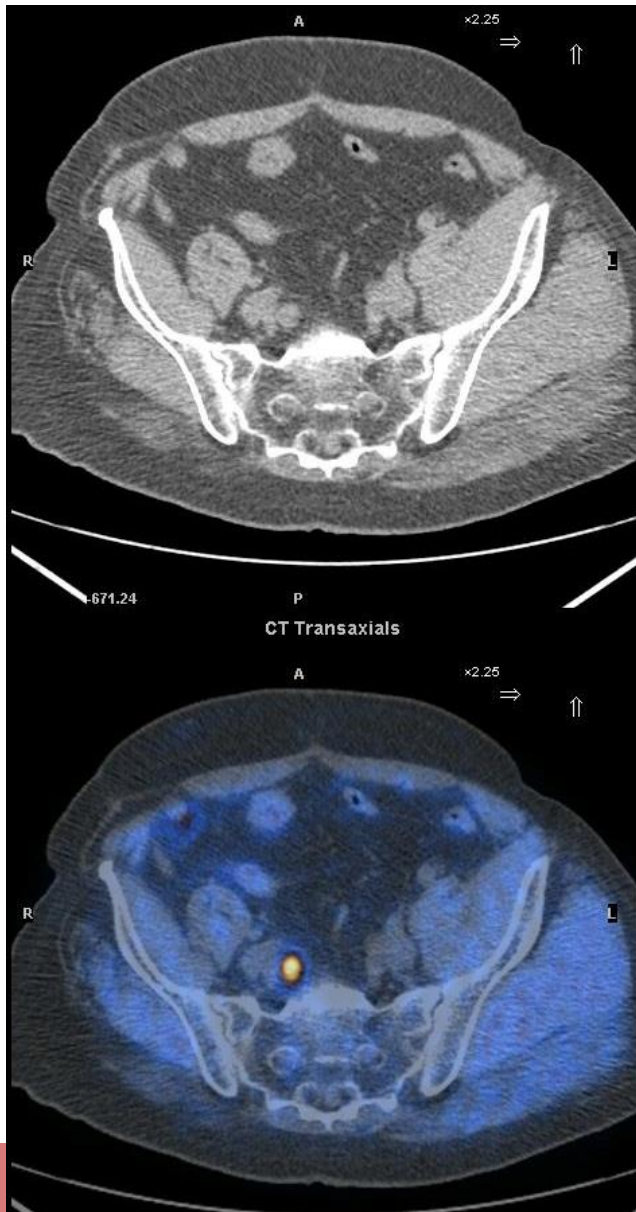
# SUSPECT OF RELAPSE

Prostatectomy  
PSA 1.3 ng/ml  
DT 3 months  
BS neg



# SUSPECT OF RELAPSE

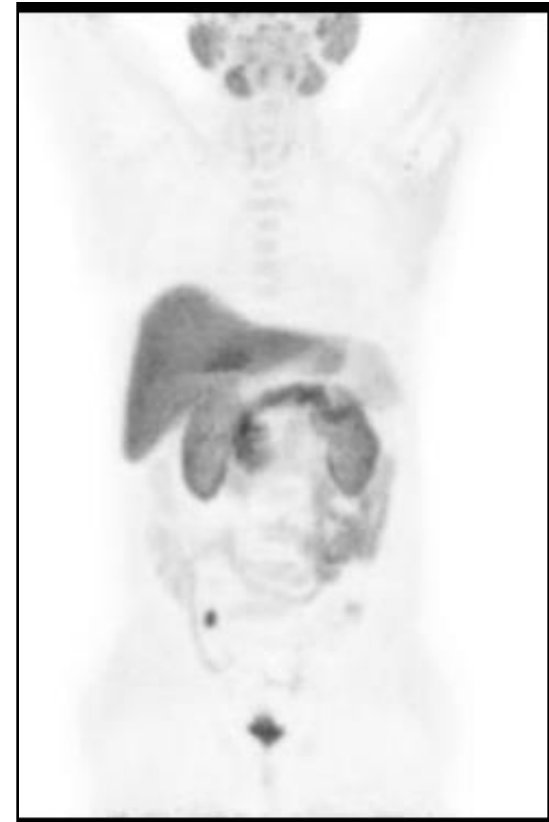
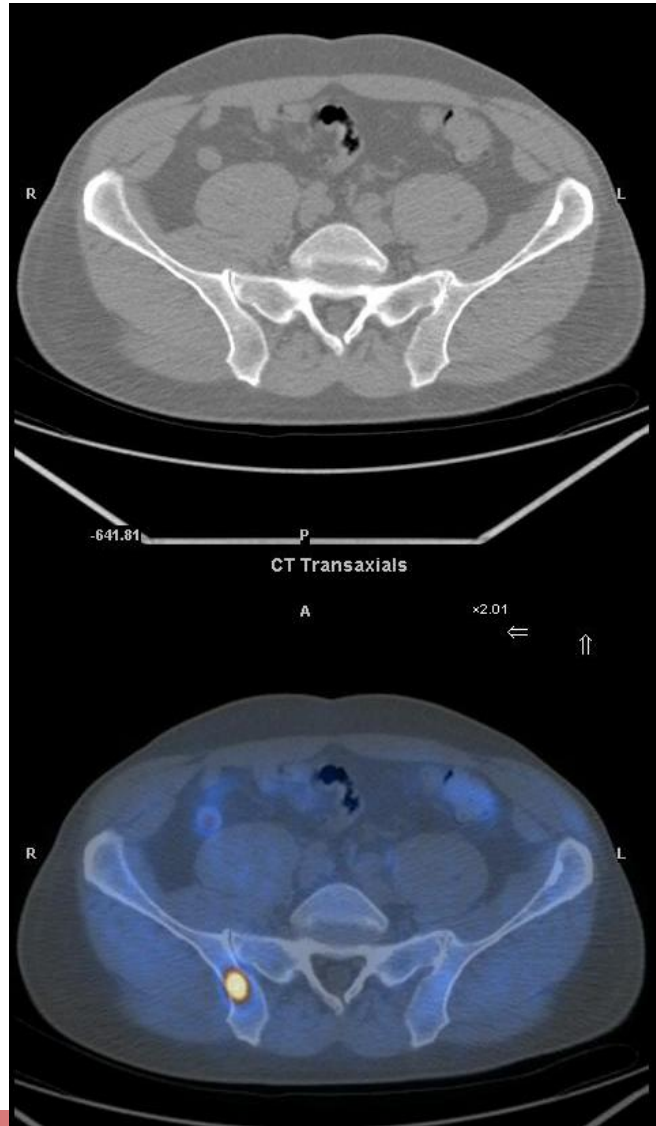
Prostatectomy  
PSA 1.1 ng/mL  
DT 4 months  
BS neg





# SUSPECT OF RELAPSE

Prostatectomy  
PSA 0.9 ng/mL  
BS neg



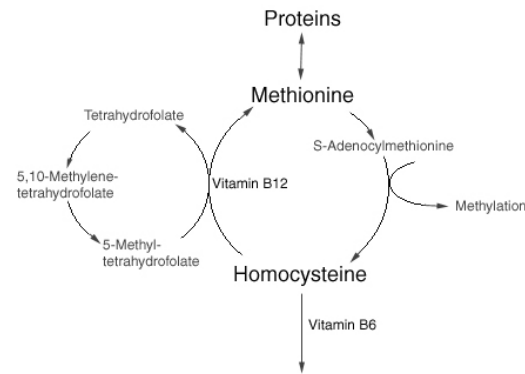
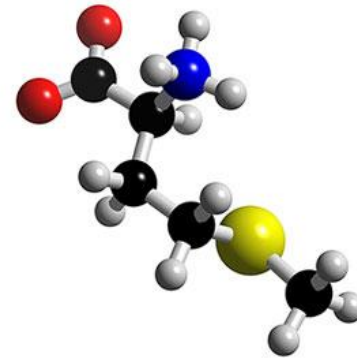
**AMINOACID**



**TRACE  
PROTIDIC  
METABOLISM**

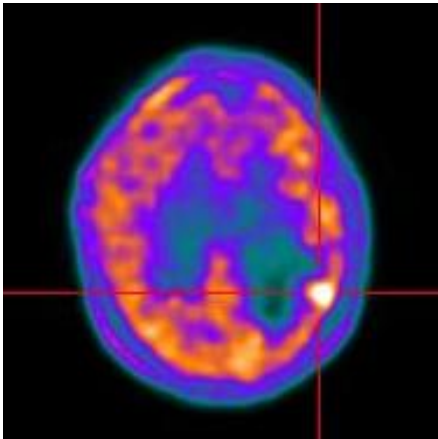
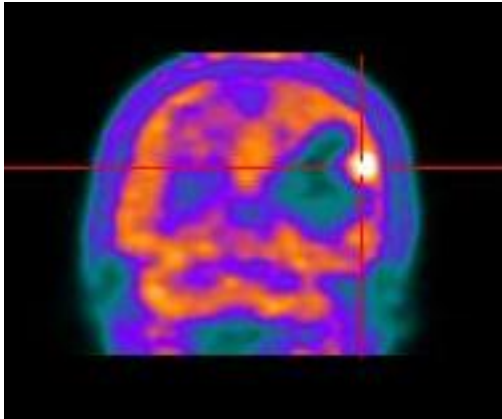
**$^{11}\text{C}$ -METHIONINE**

**$^{18}\text{F}$ -FET**

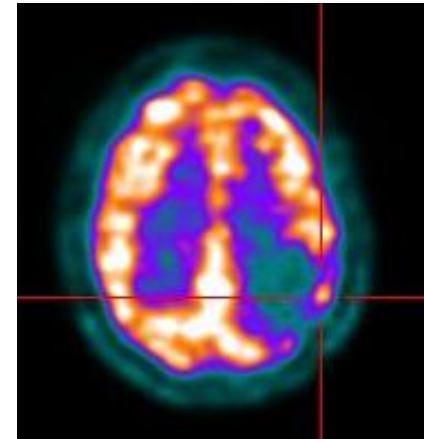
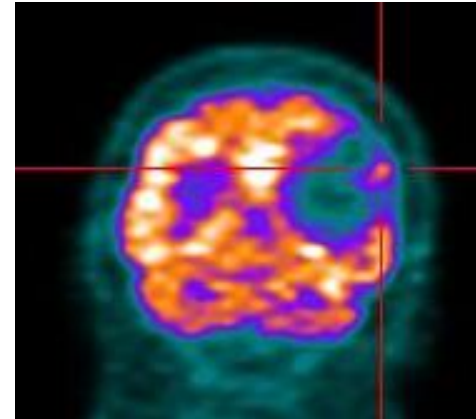




$^{11}\text{C}$ -METH



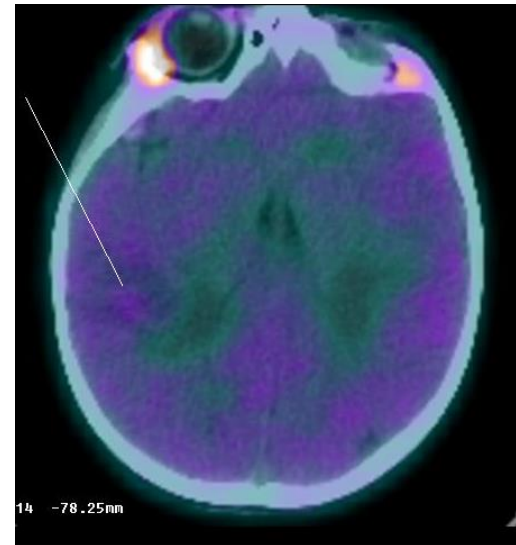
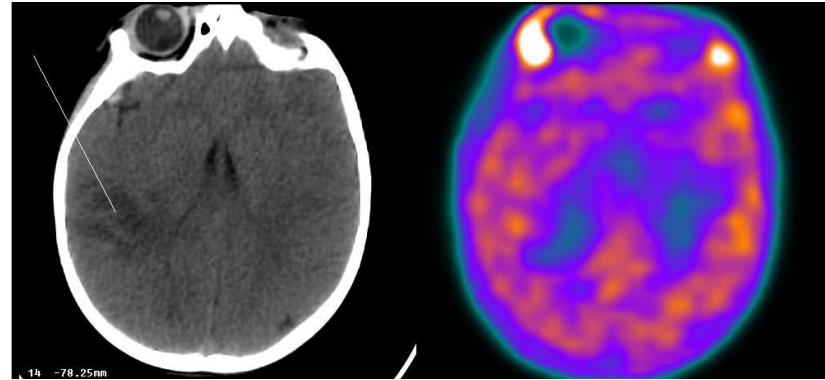
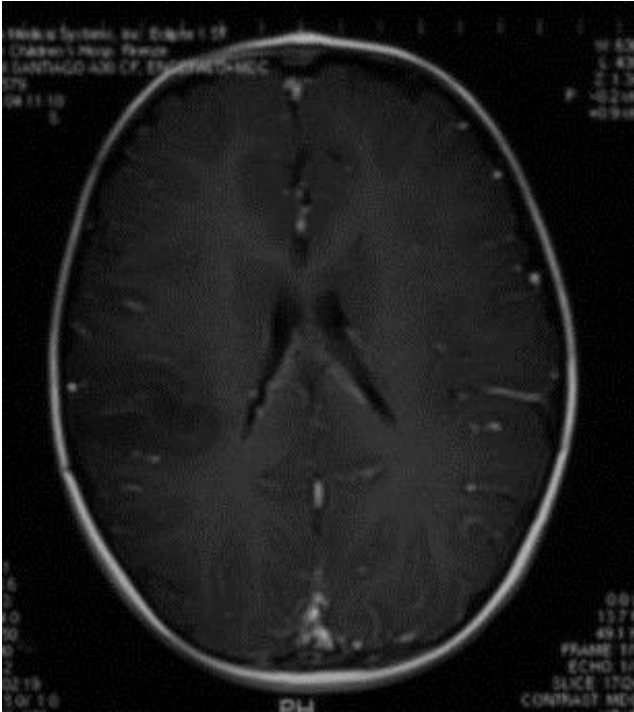
$^{18}\text{F}$ -FDG



P.L. 38 yo, treated with S + RT for glioma  
MR suspect of relapse



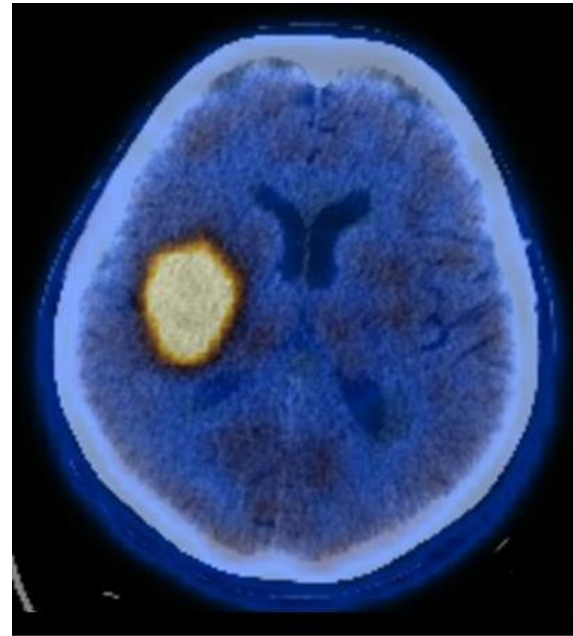
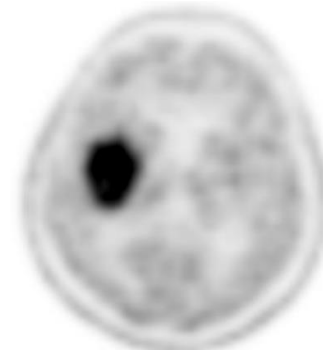
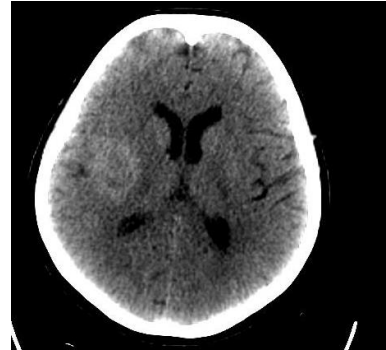
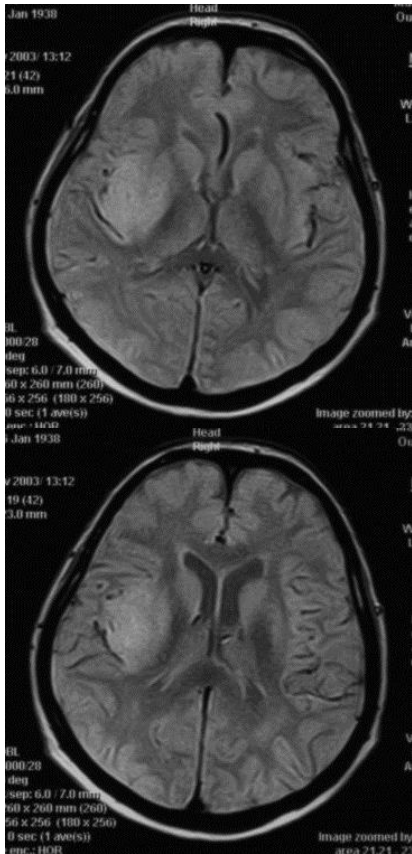
# DIAGNOSIS OF CNS TUMOURS



**MR: uncertain finding (cortical dysplasia vs lowgrade tumour)**



# DIAGNOSIS OF CNS TUMOURS



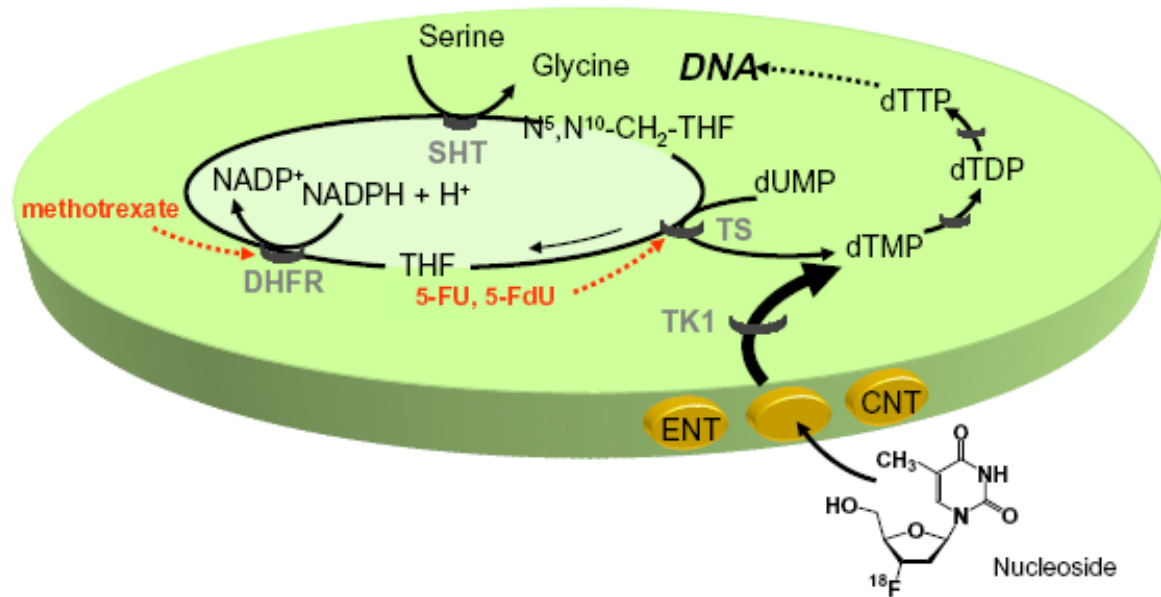
**MR: suspect lesion**



# $^{18}\text{F}$ -FLT

Molecular imaging of proliferation in vivo: Positron emission tomography with [ $^{18}\text{F}$ ]fluorothymidine

Andreas K. Buck<sup>a,\*</sup>, Ken Herrmann<sup>a</sup>, Changxian Shen<sup>c</sup>, Tobias Dechow<sup>b</sup>, Markus Schwaiger<sup>a</sup>, Hans-Jürgen Wester<sup>a</sup>



SHT: serine hydroxymethyl transferase  
 TK1: thymidine kinase  
 ENT: equilibrative nucleoside transporter

DHFR: dihydrofolate reductase  
 dUMP: deoxyuridine monophosphate  
 CNT: concentrative nucleoside transporter

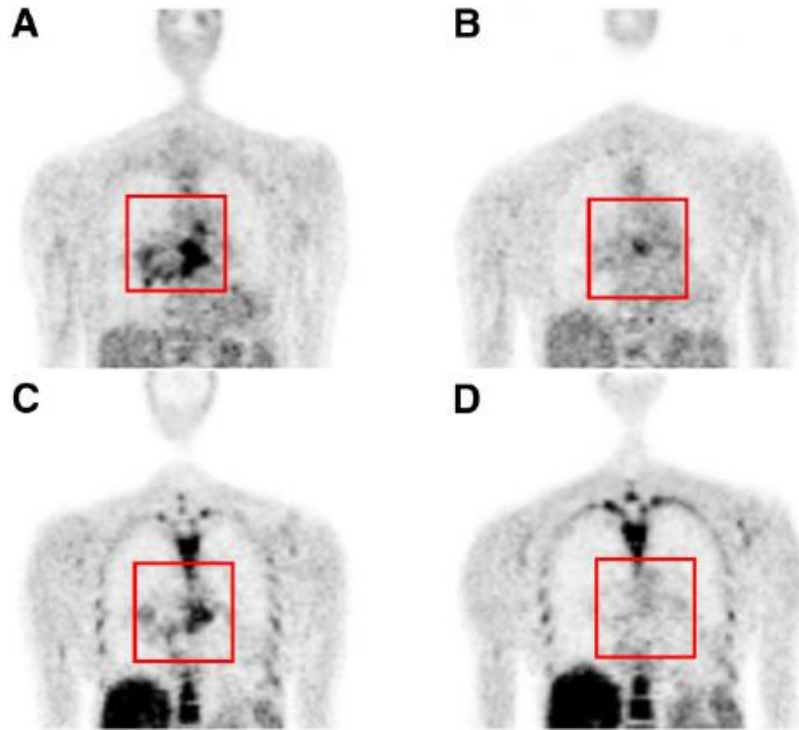
TS: thymidylate synthase  
 dTMP: deoxythymidine monophosphate (thymidylate)



# Quantitative Analysis of Response to Treatment with Erlotinib in Advanced Non-Small Cell Lung Cancer Using $^{18}\text{F}$ -FDG and $3'$ - $^{18}\text{F}$ -Fluorothymidine PET

Deniz Kahraman<sup>1,2</sup>, Matthias Scheffler<sup>2,3</sup>, Thomas Zander<sup>2,3</sup>, Lucia Nogova<sup>2,3</sup>, Adriaan A. Lammertsma<sup>4</sup>, Ronald Boellaard<sup>4</sup>, Bernd Neumaier<sup>5</sup>, Roland T. Ullrich<sup>2,3,5</sup>, Arne Holstein<sup>1,2</sup>, Markus Dietlein<sup>1,2</sup>, Jürgen Wolf<sup>2,3</sup>, and Carsten Kobe<sup>1,2</sup>

THE JOURNAL OF NUCLEAR MEDICINE • Vol. 52 • No. 12 • December 2011



**FIGURE 1.**  $^{18}\text{F}$ -FDG PET (A) and  $^{18}\text{F}$ -FLT PET (C) before start of treatment, and  $^{18}\text{F}$ -FDG PET (B) and  $^{18}\text{F}$ -FLT PET (D) after 1 wk of treatment with erlotinib.

**RESPONSE  
TO THERAPY**





**NOC-TOC**

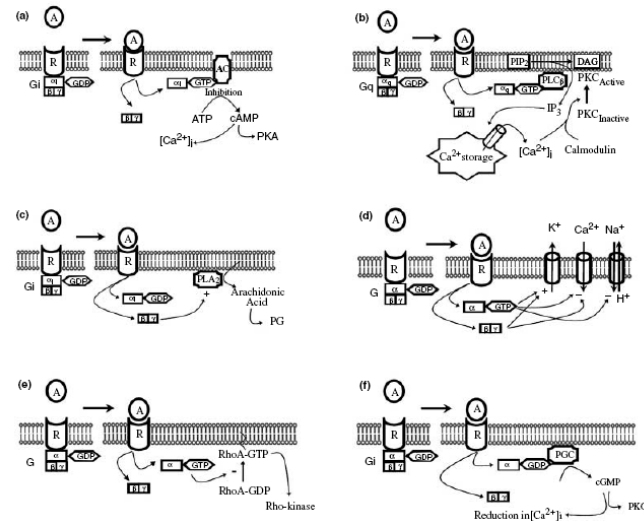
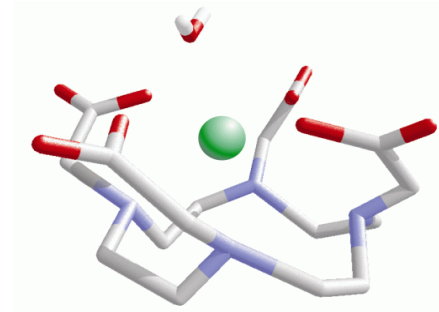


**SRS**

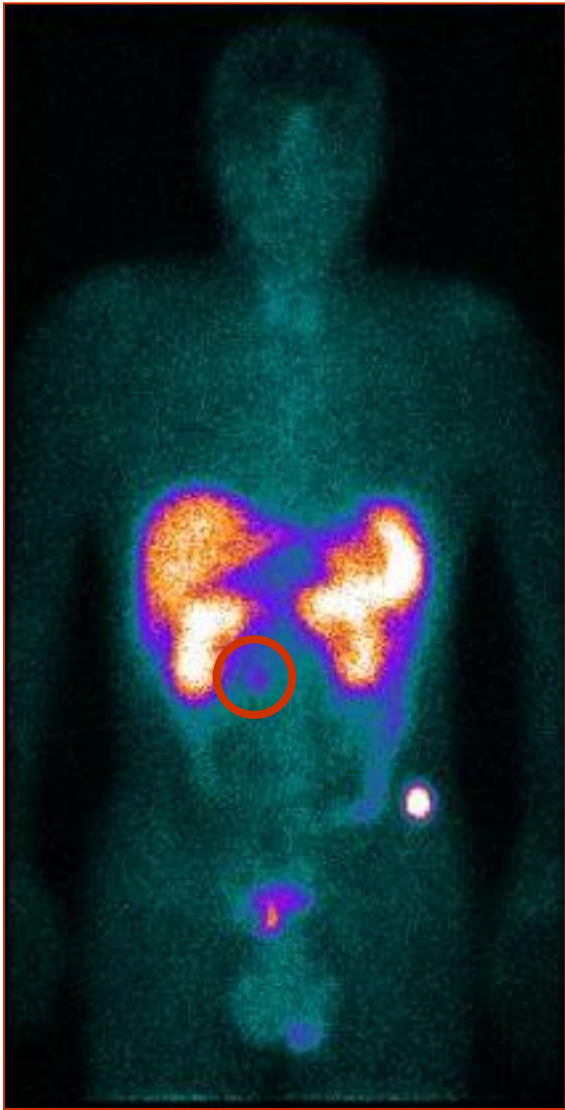


**TRACE  
SOMATOSTATIN  
RECEPTORS**

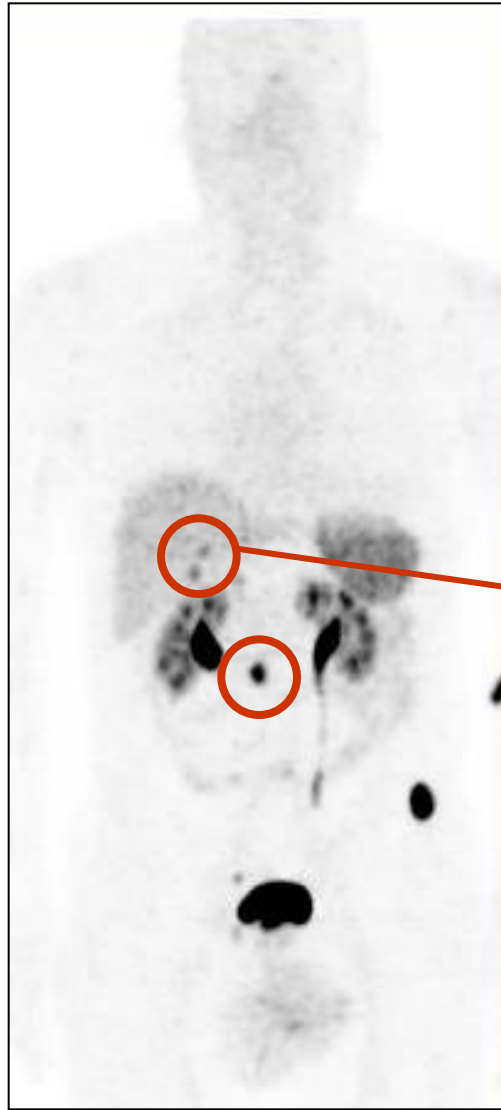
**$^{68}\text{Ga}$ -DOTA-SSA  
TOC/NOC/TATE**



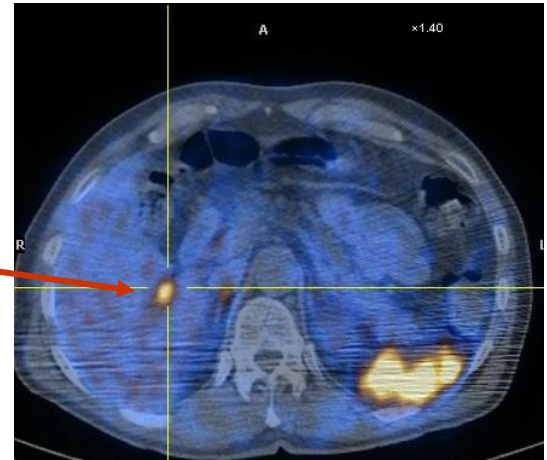


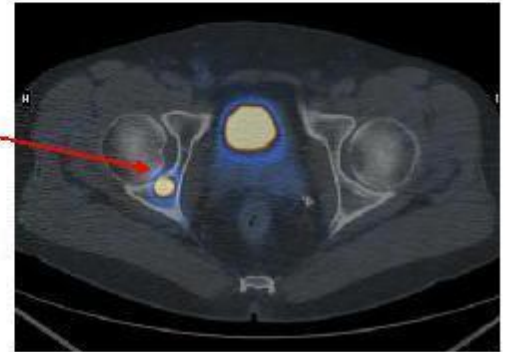
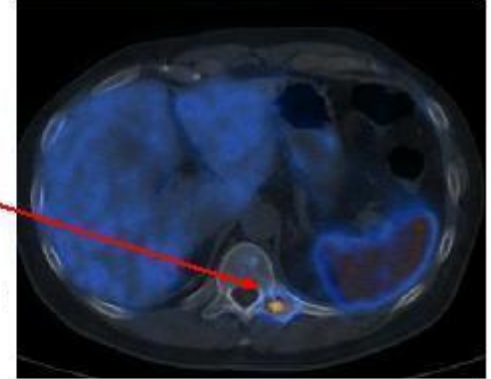
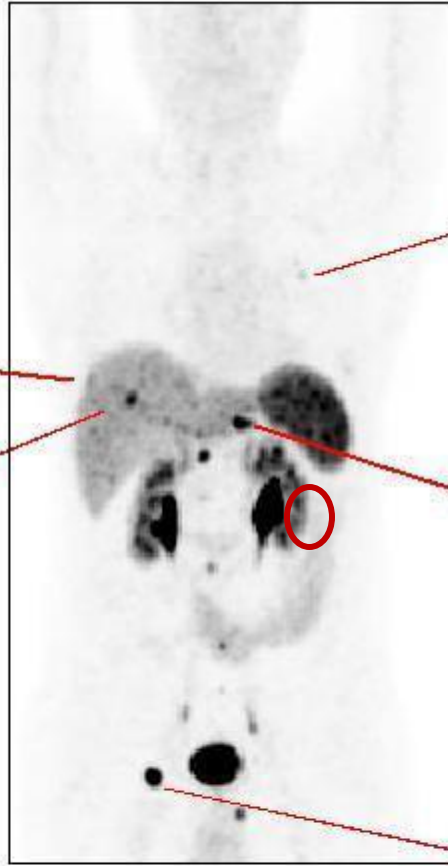
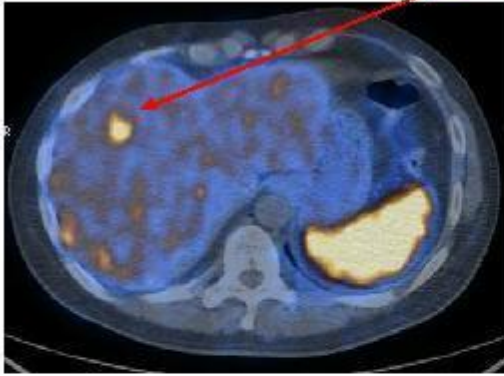
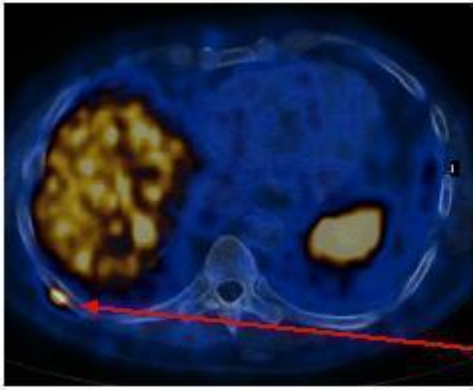


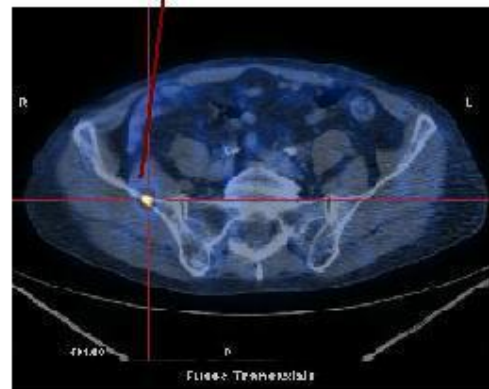
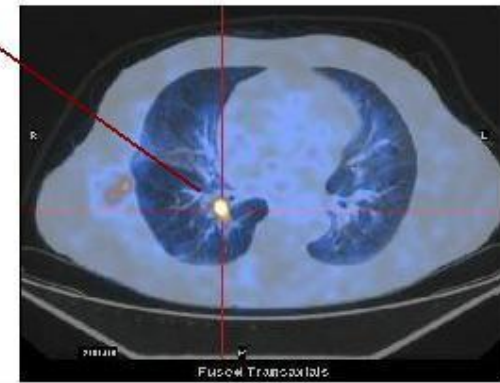
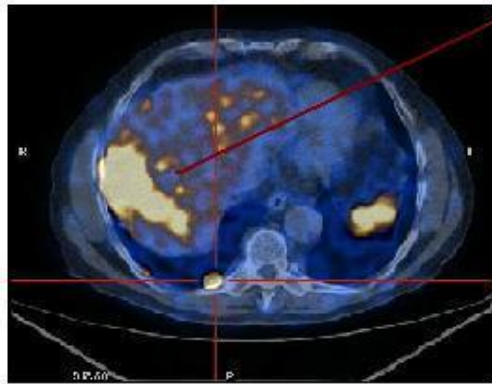
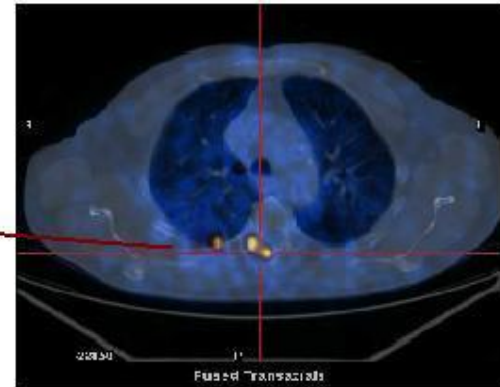
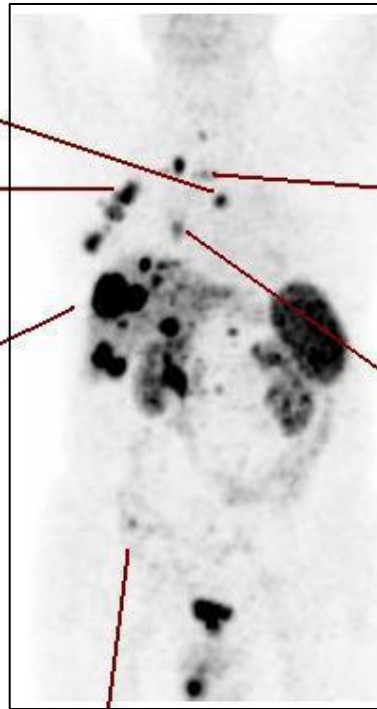
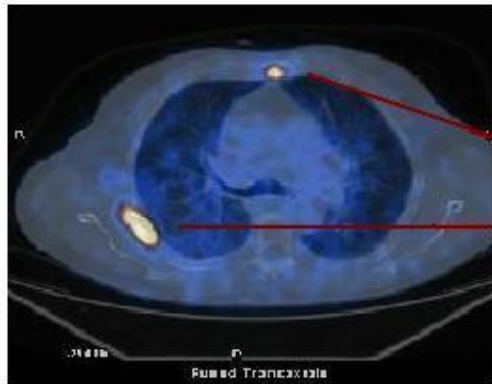
Octreoscan



Ga-DOTA-NOC

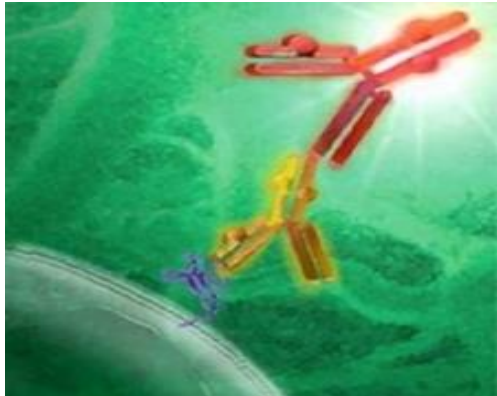






**MEDICINA NUCLEARE**

**TERAPEUTICA**



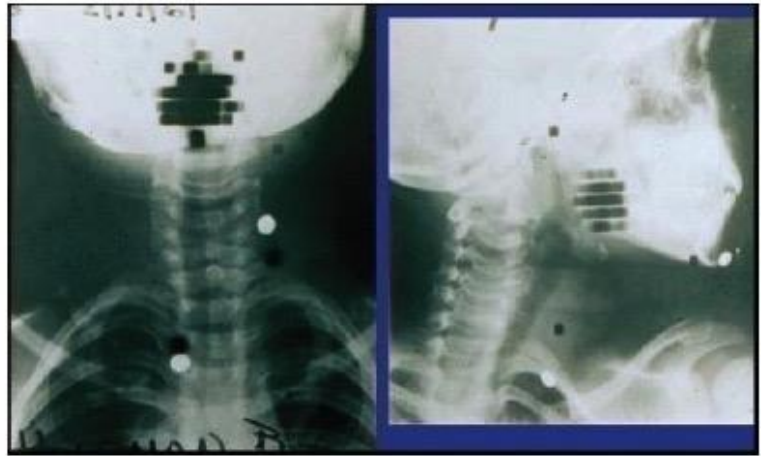
**RADIOMETABOLICA**





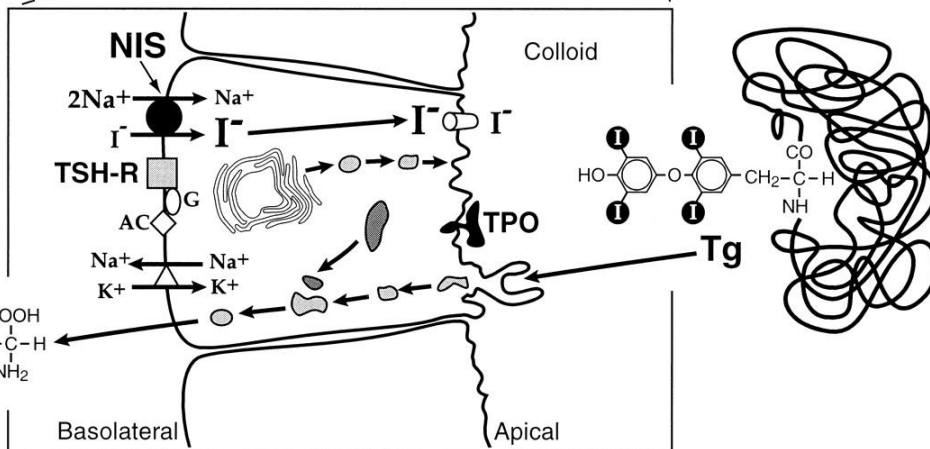
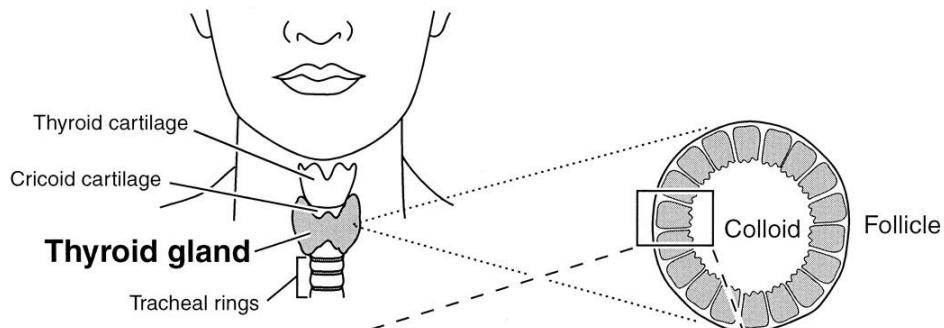


Radioiodine uptake by a Geiger counter tube  
Joseph Hamilton (1942)



# THYROID





Periodic Table by Article Value

1	2																	3					
3	4																	5	6	7	8	9	10
11	12																	13	14	15	16	17	18
19	20	21	22	23	24	25	26									33	34	35	36				
37	38	39	40	41	42	43	44									51	52	53	54				
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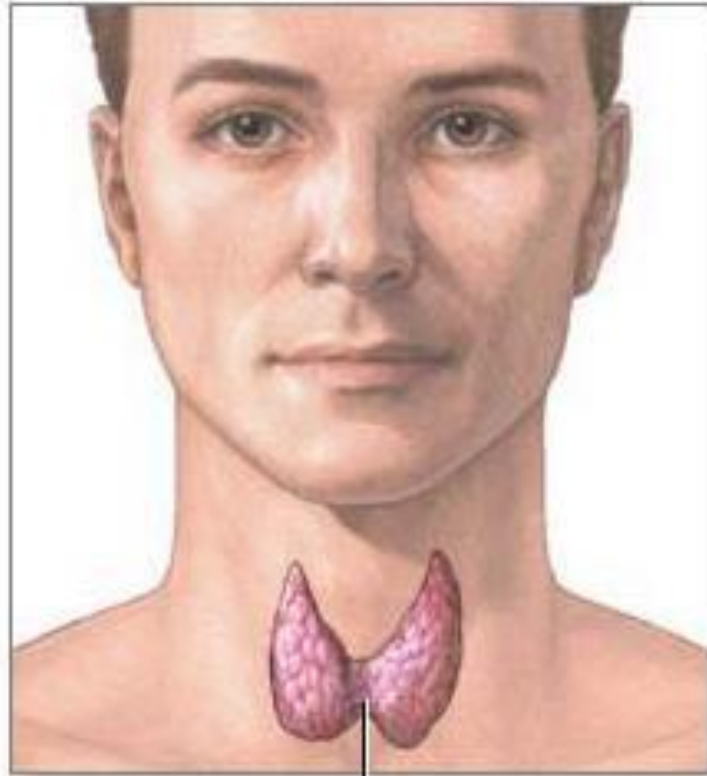
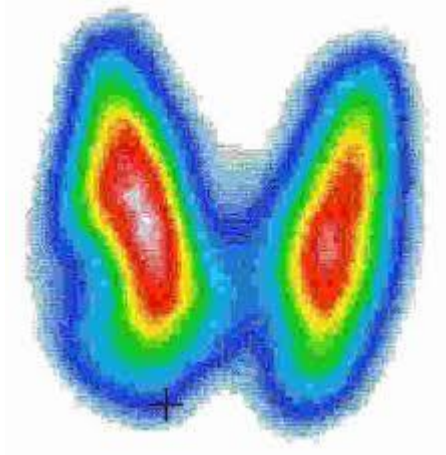
131 I

53 I

Iodine-131

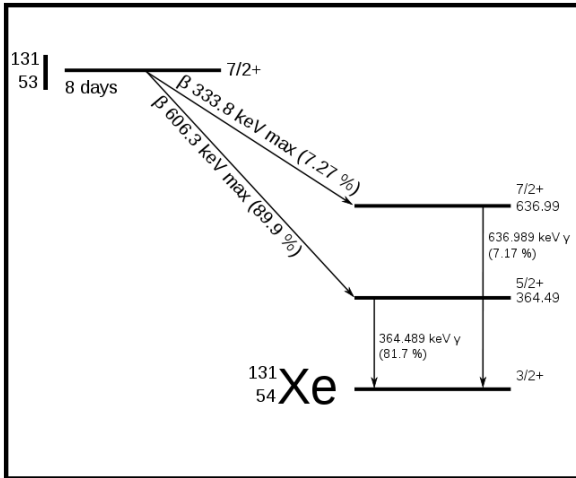




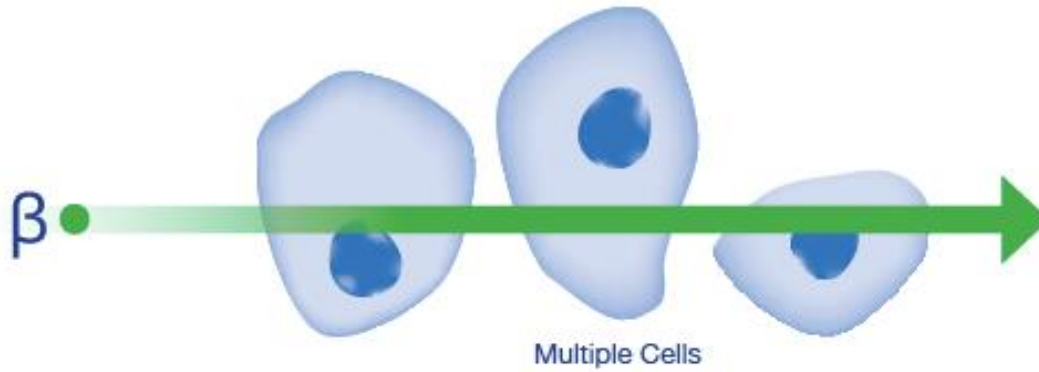


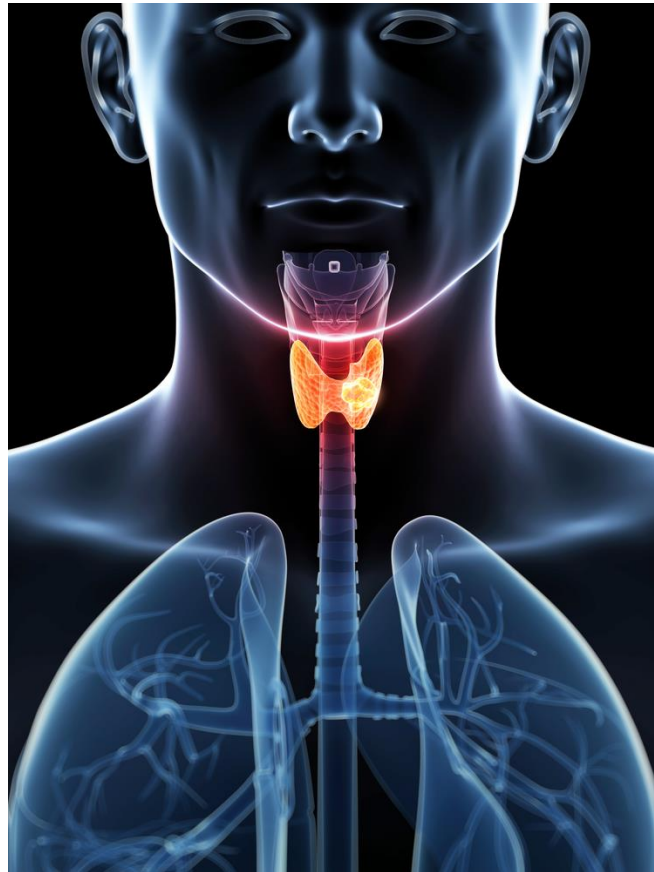
Thyroid





Path length of Beta particles of high energy (I-131 Y-90)





# THYROID CANCER





ROD STEWART



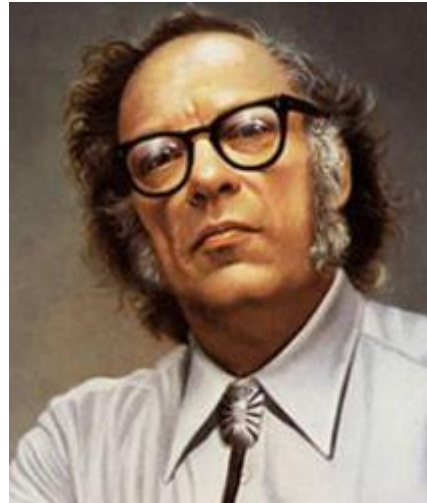
KAREN SMYERS



CRISTINA  
KIRCHNER



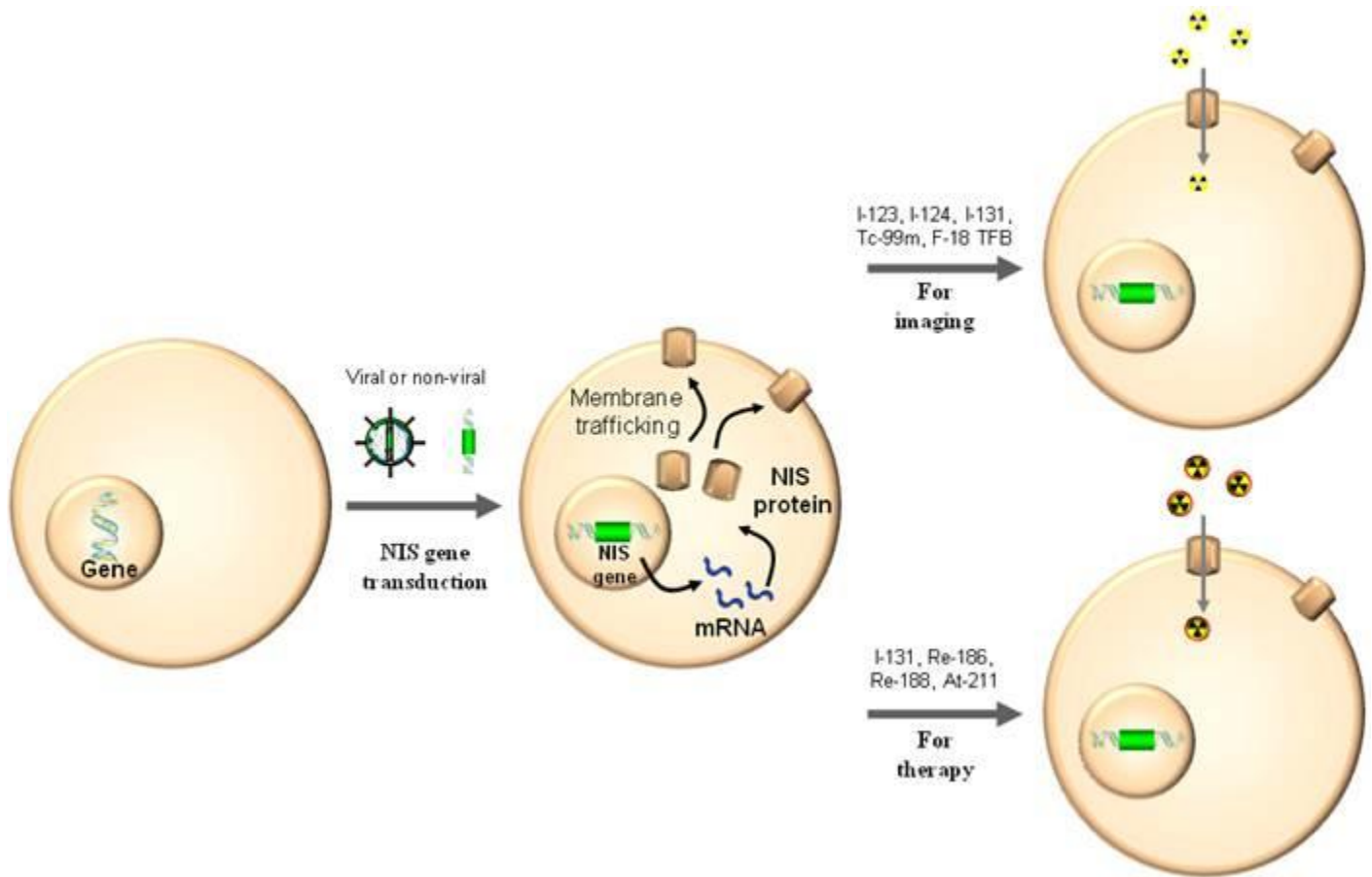
SOFIA VERGARA



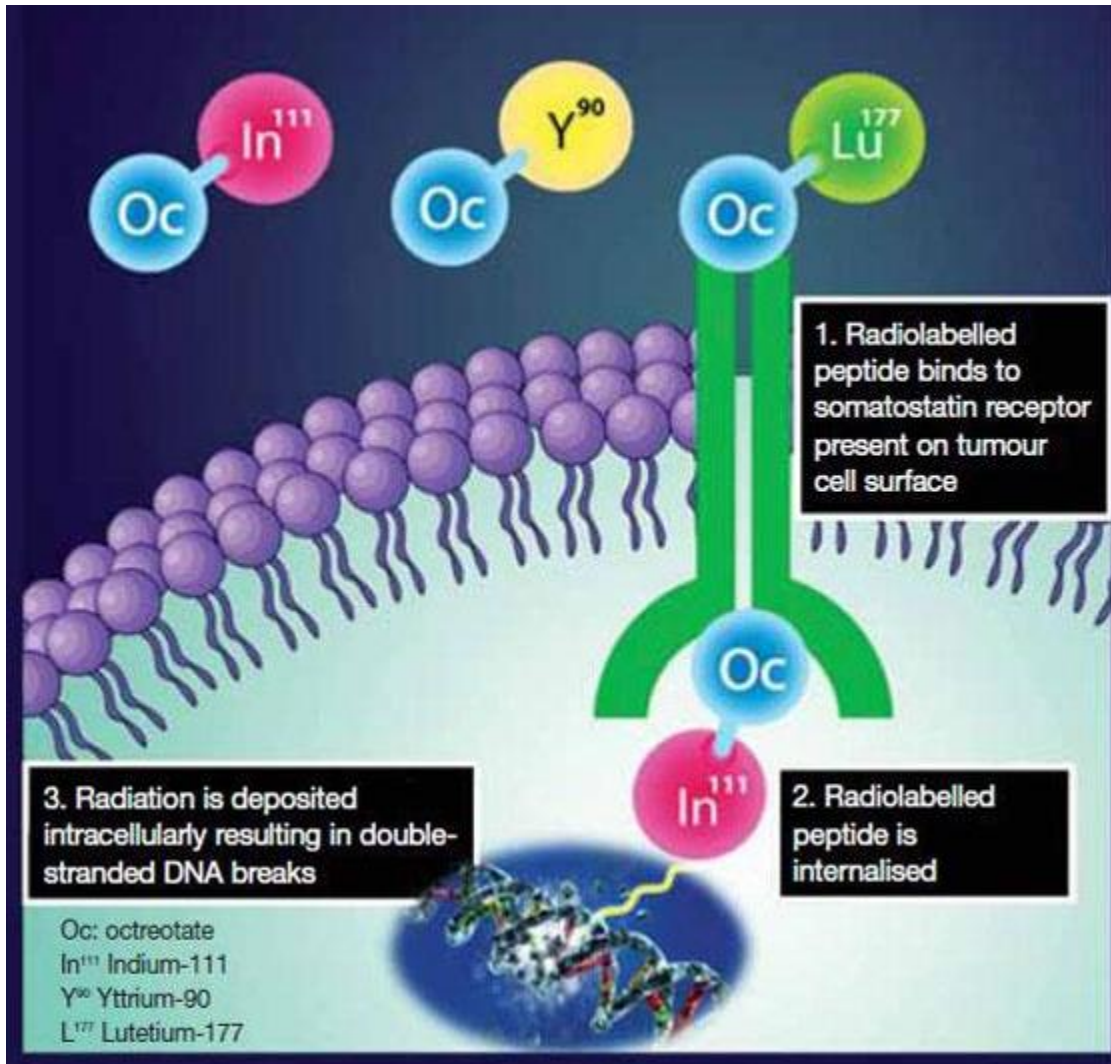
ISAAC ASIMOV



# THERANOSTIC







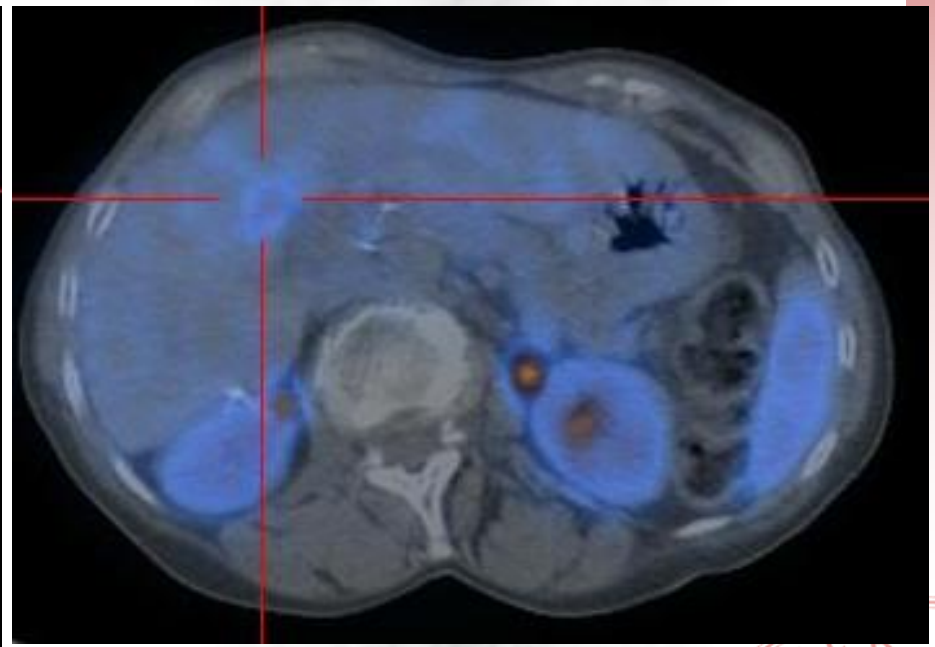
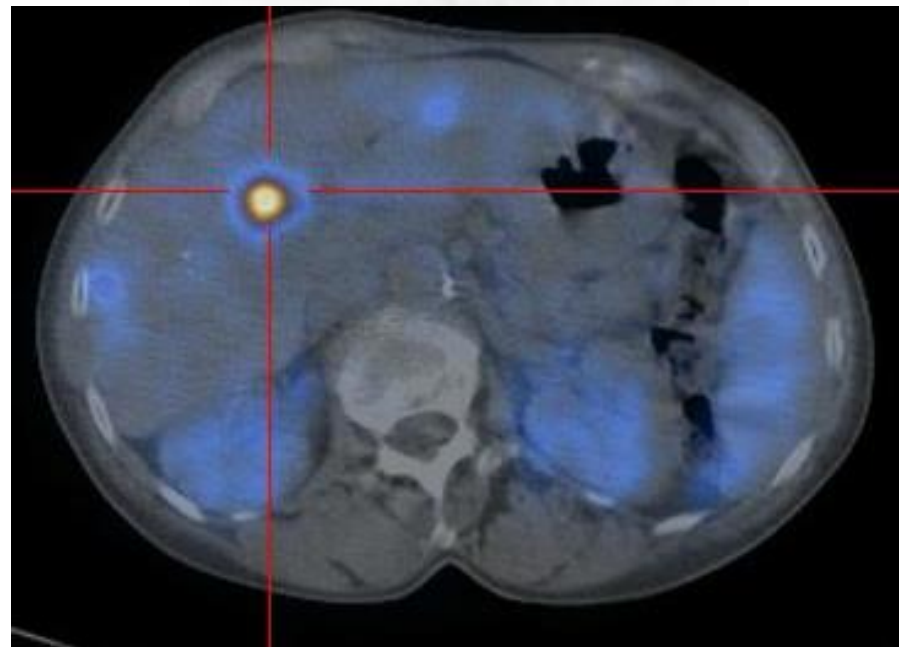


# NEUROENDOCRINE TUMOR

## NET Receptor Radionuclide Therapy:

pre-therapy

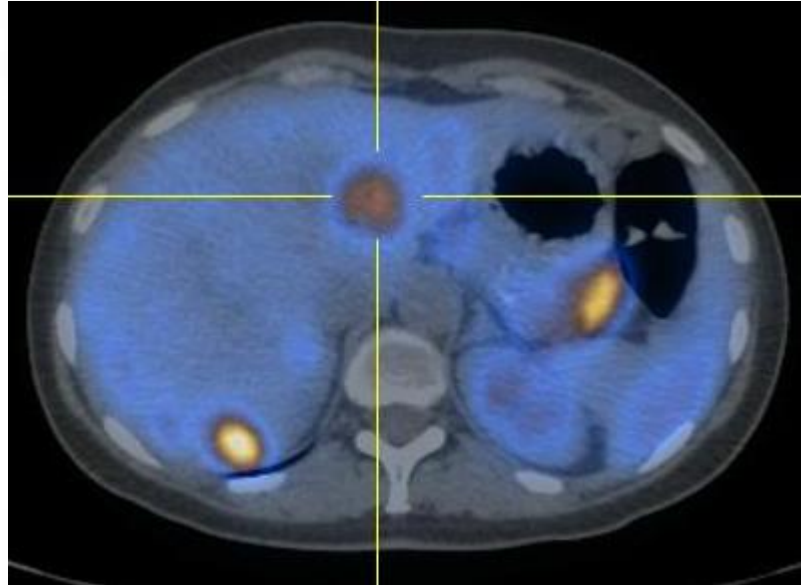
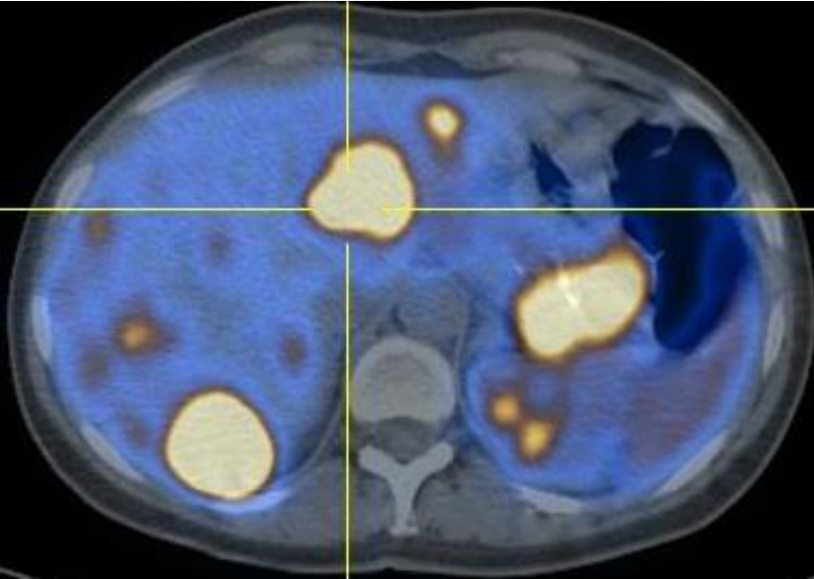
post therapy evaluation

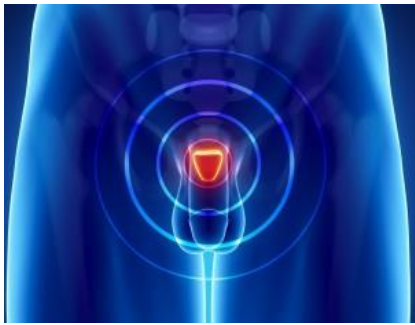


# NET Receptor Radionuclide Therapy:

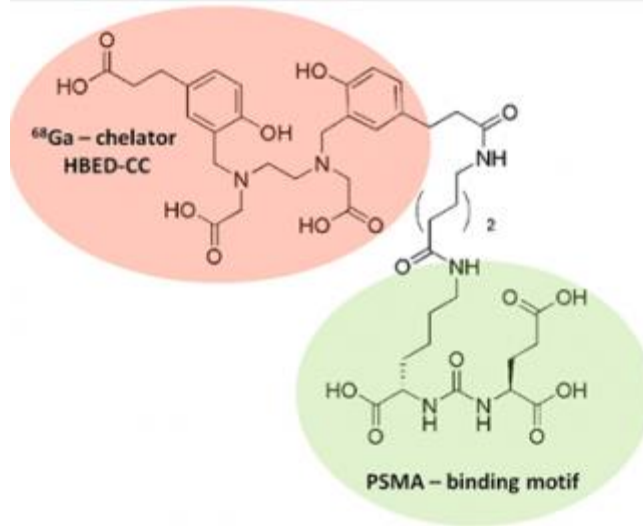
pre-therapy

post therapy evaluation



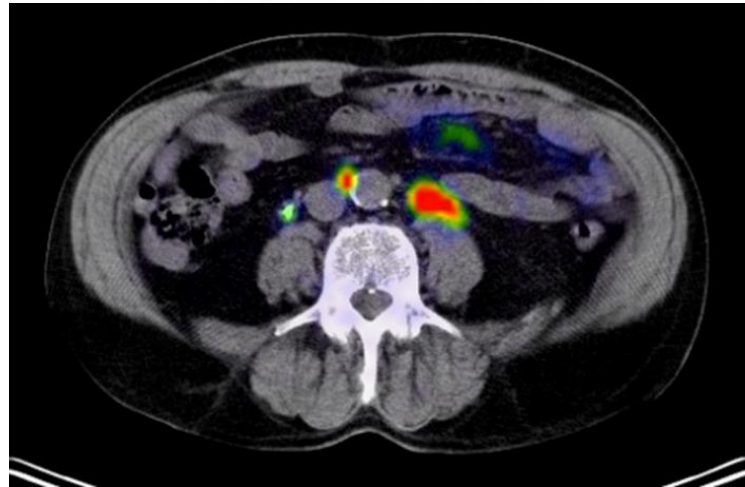


# PROSTATE CANCER



$^{68}\text{Ga}$ -PSMA





## **PROSTATE CANCER**

Image courtesy of prof Haberkorn



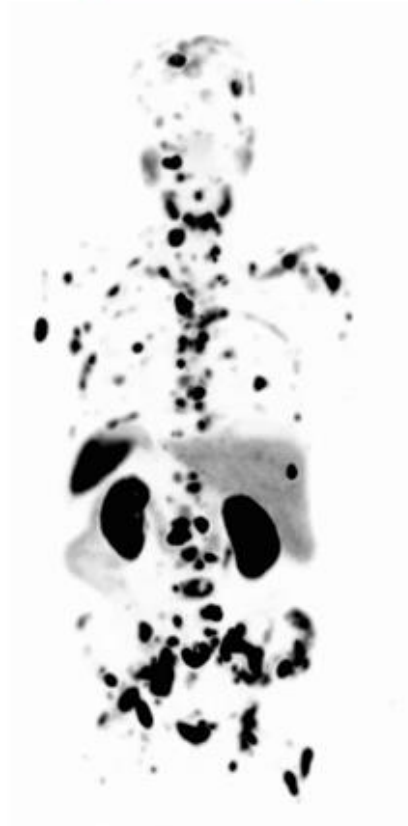
# Bone Metastases treated with $^{131}\text{I}$ -MIP-1095 Treatment

Sept 2011



Pre therapy #1

Feb 2012



Post Rx #1

May 2012

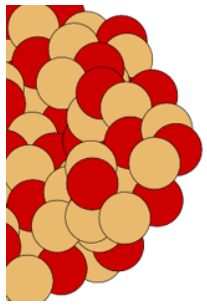


Post Rx #2

Image courtesy of prof Pichler



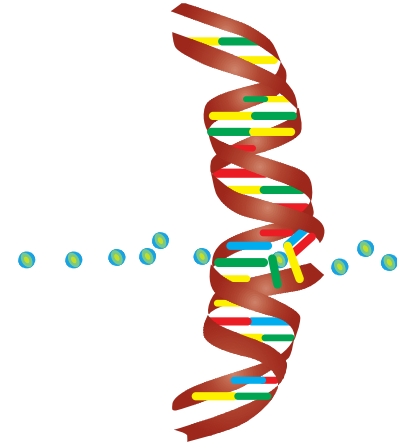




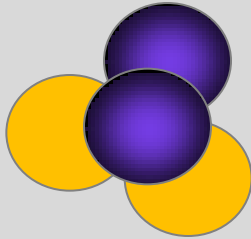

Beta Particle



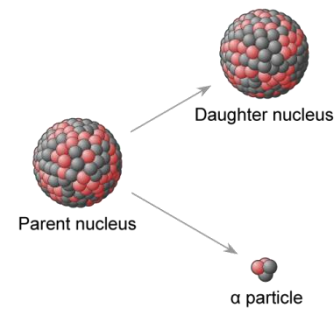
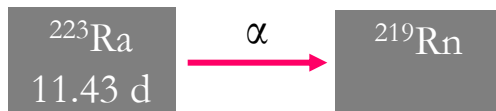
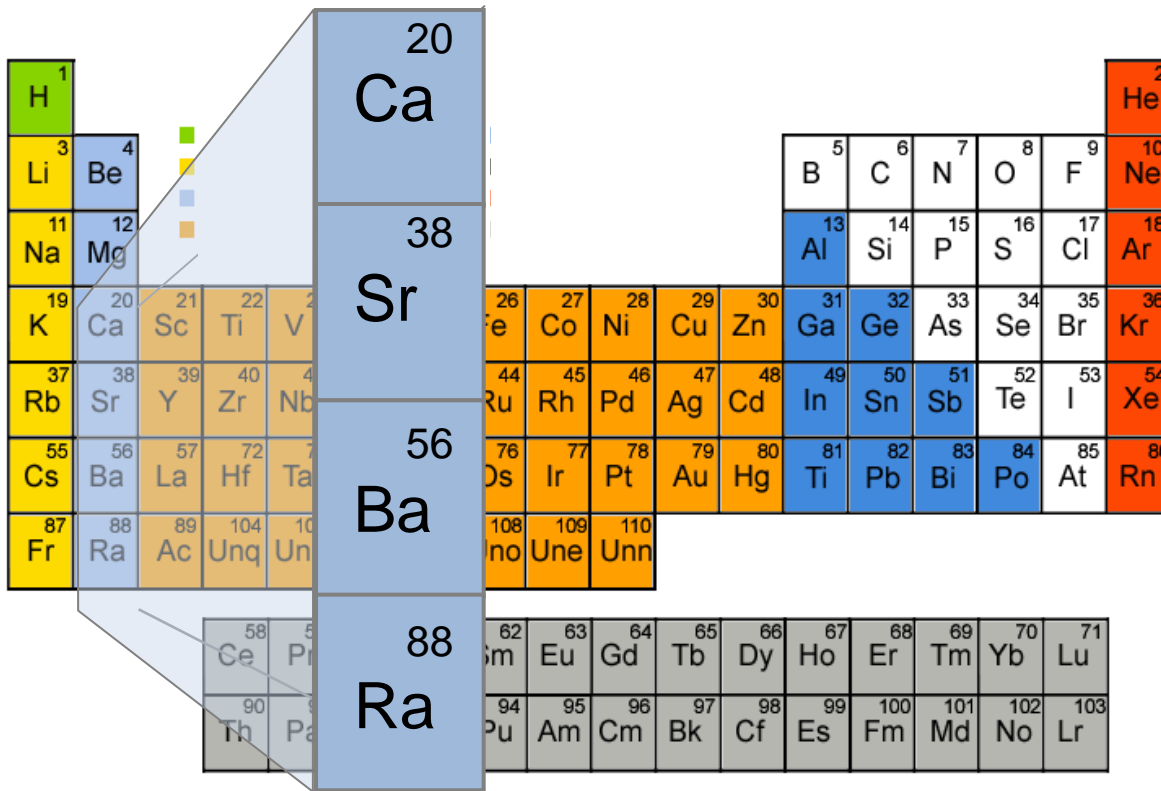
- $\beta$  particles low LET  $\rightarrow$  single chain DNA damage
- Single chain damage unlikely to kill cells

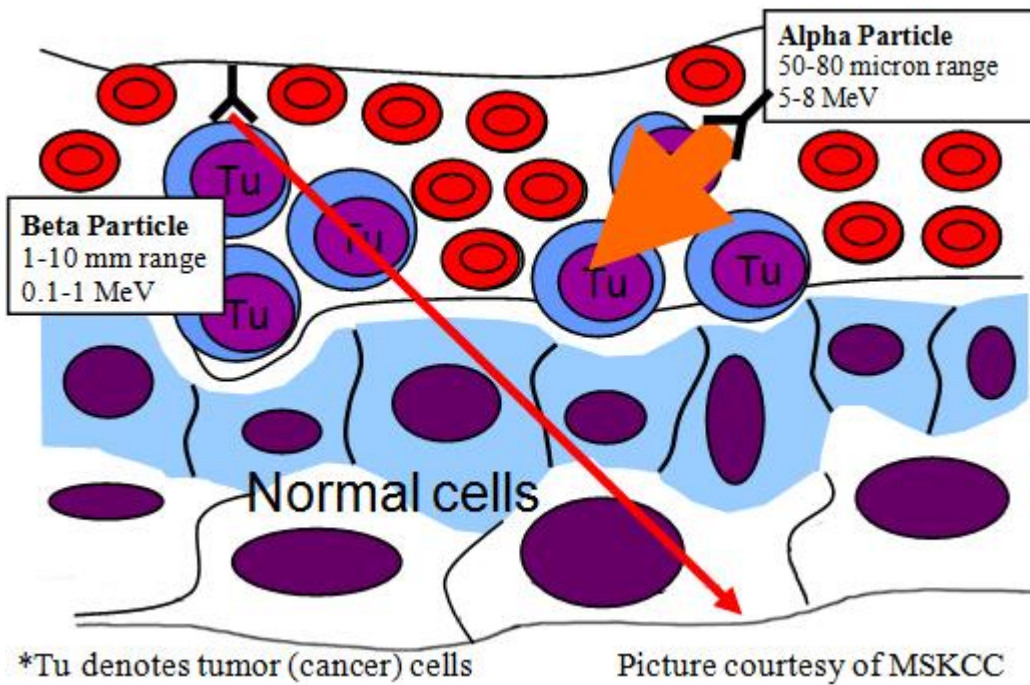




	$\alpha$	$\beta$
Size		
Mass	7000	1
Energy	5-9	0.05-2.3
Range in $\mu\text{m}$	40-100	50-12,000
LET (KeV/ $\mu\text{m}$ )	60-300	0.1-1.0
DNA hit to kill cells	1-4	> 1000







*The* **NEW ENGLAND**  
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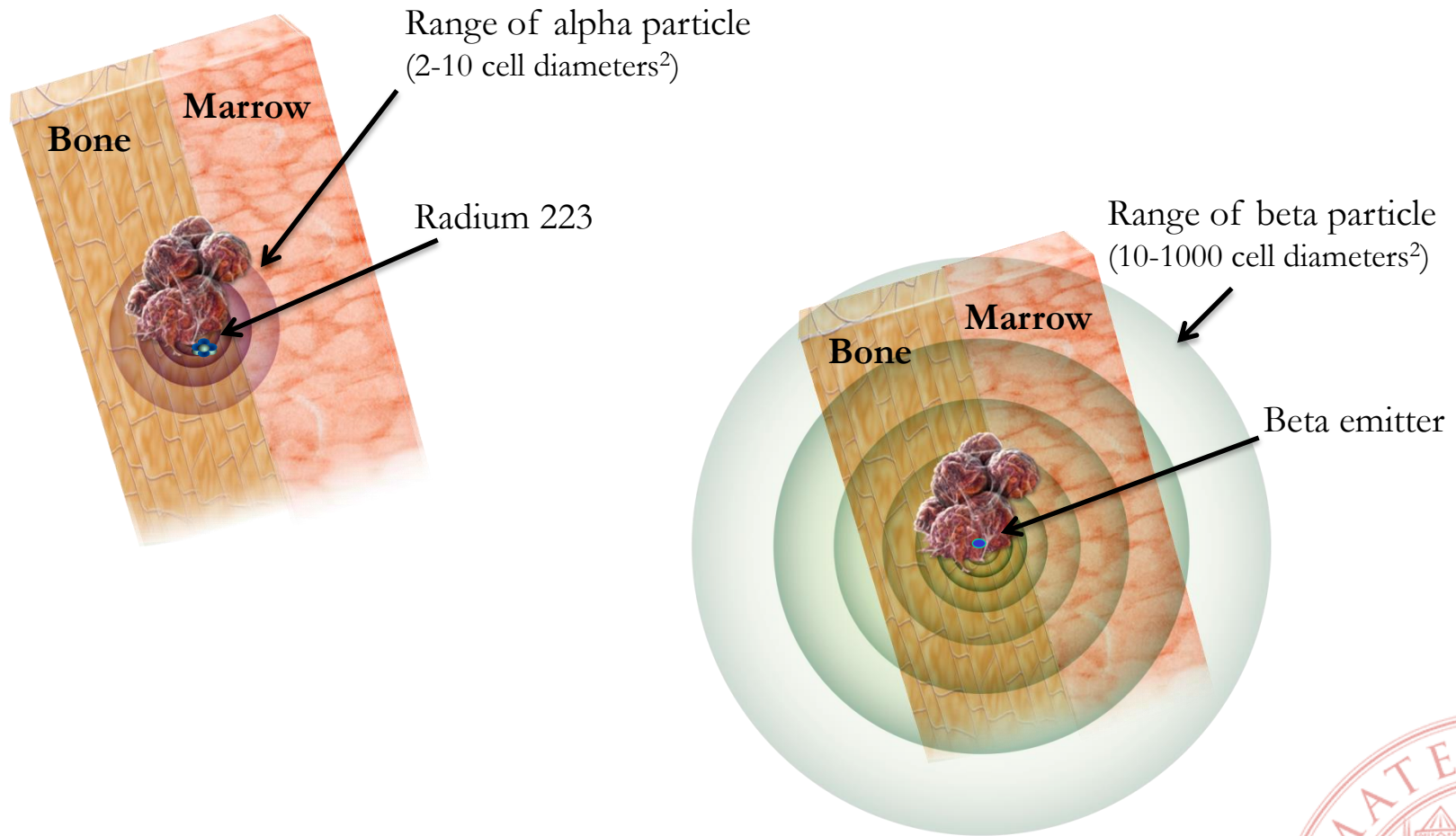
VOL. 369 NO. 3

Alpha Emitter Radium-223 and Survival  
in Metastatic Prostate Cancer

C. Parker, S. Nilsson, D. Heinrich, S.I. Helle, J.M. O'Sullivan, S.D. Fossà, A. Chodacki, P. Wiechno, J. Logue, M. Seke, A. Widmark, D.C. Johannessen, P. Hoskin, D. Bottomley, N.D. James, A. Solberg, I. Syndikus, J. Kliment, S. Wedel, S. Boehmer, M. Dall'Oglio, L. Franzén, R. Coleman, N.J. Vogelzang, C.G. O'Bryan-Tear, K. Staudacher, J. Garcia-Vargas, M. Shan, Ø.S. Bruland, and O. Sartor, for the ALSYMPCA Investigators\*



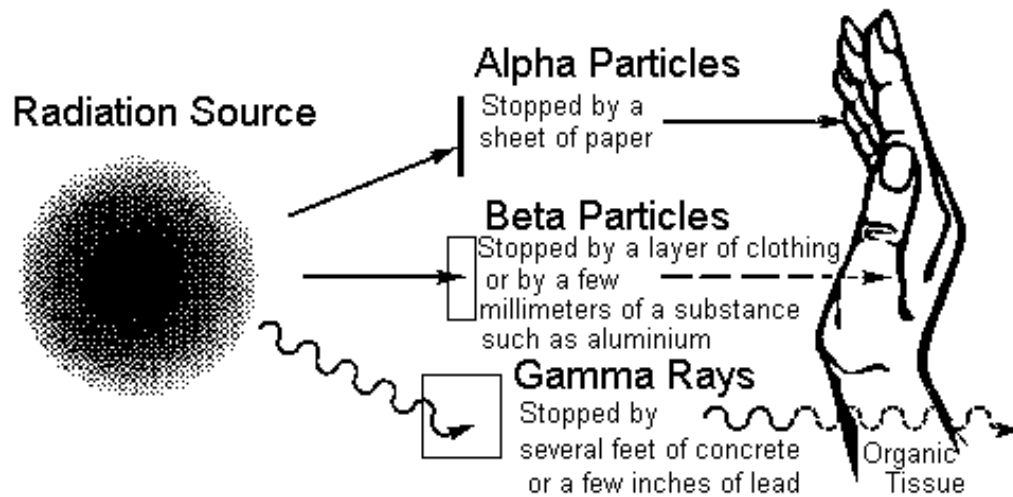
# Short range of alpha-emitters reduces bone marrow exposure



Brechbiel M. Dalton Trans. 2007;43:4918-4928.

Bruland ØS et al. Clin Cancer Res 2006;12:6250s-7s; Henriksen G et al. Cancer Res 2002;62:3120-5











**KEEP  
CALM  
AND ENJOY THE  
RADIATION**





**THANK YOU**

