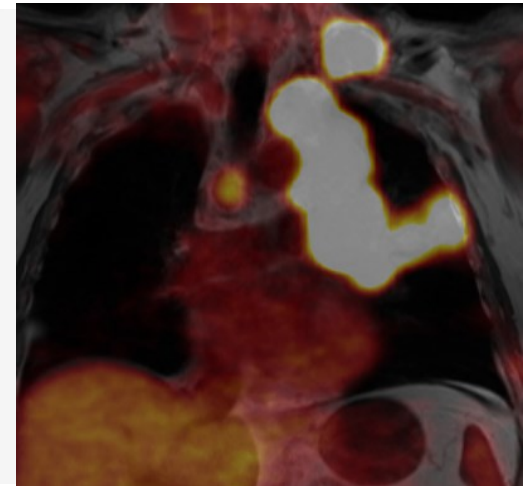
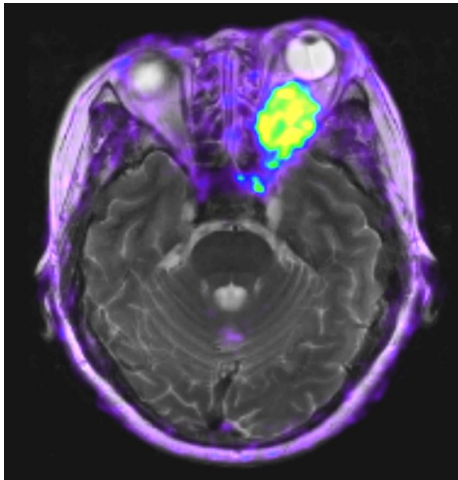




PET/MRI-Theory and clinical applications

Sergios Gatidis

November 06, 2017

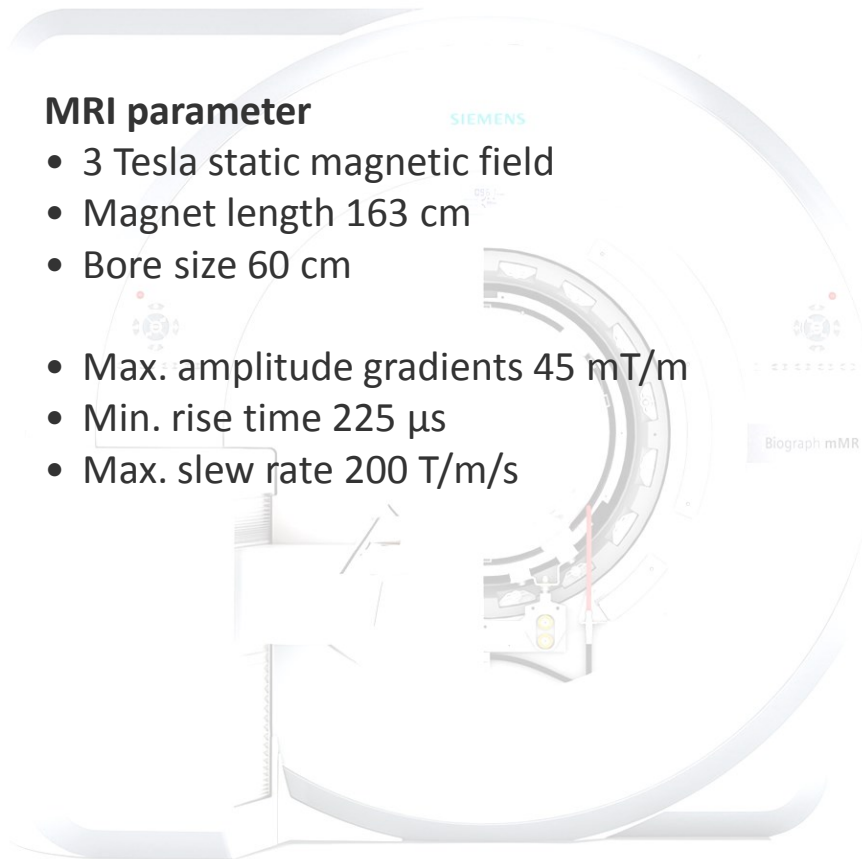
February 2011: Installation of the PET/MR scanner



- BrainPET/MR since 2008
- Whole body MR-PET Biograph mMR



Technical concepts mMR



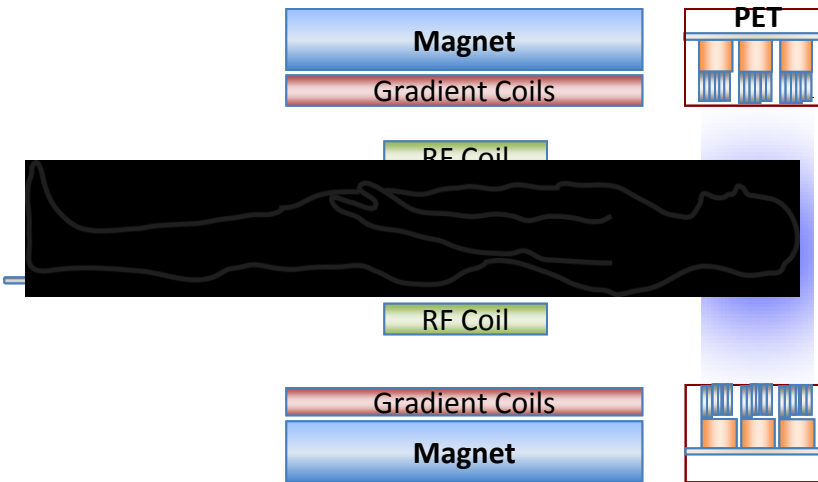
MRI parameter

- 3 Tesla static magnetic field
- Magnet length 163 cm
- Bore size 60 cm
- Max. amplitude gradients 45 mT/m
- Min. rise time 225 μ s
- Max. slew rate 200 T/m/s

PET-Detector

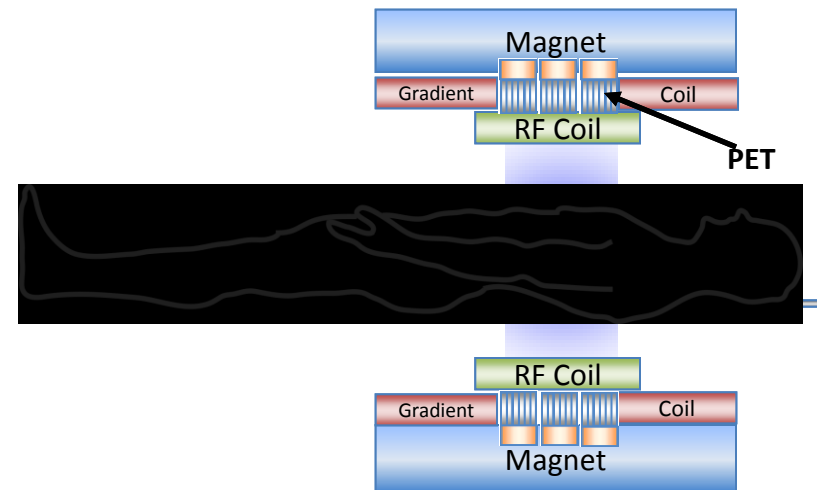
- Crystal material: LSO
- Crystal element dimension:
 $4 \times 4 \times 20 \text{ mm}^3$
- Crystal elements per block 64
- Avalanche Photodiodes (APDs):
9 per block
- Blocks per detector ring: 56
- Crystal elements per ring: 448
- Number of detector element rings: 64
- Total detector blocks: 448
- Total number of crystal elements: 28 672
- Transaxial FoV: 594 mm
- Axial FoV: 25.8 cm
- Detector ring diameter: 656 mm

sequential PET/MR



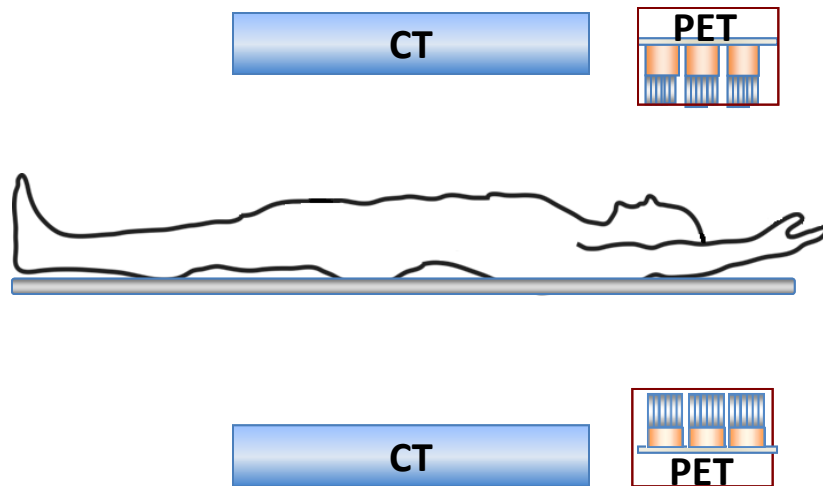
- + Interference easier to avoid
- + Use largely existing hardware
- + Lower costs

simultaneous PET/MR



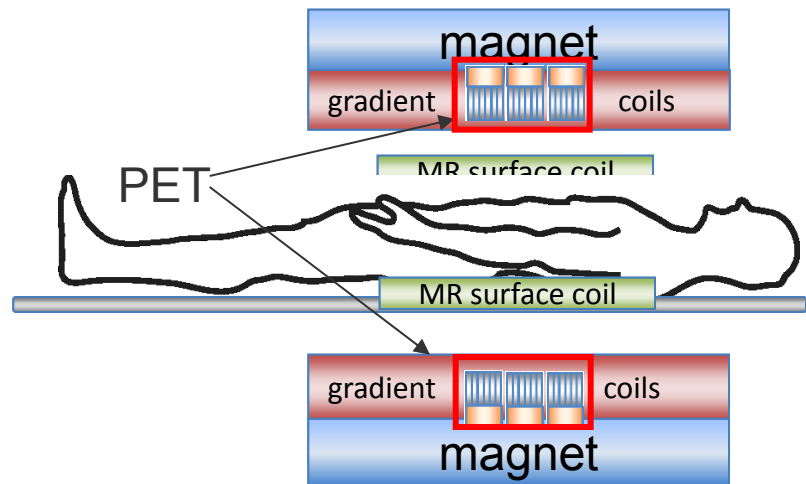
- + Simultaneous functional imaging
- + Higher throughput
- + Best image registration

PET/CT



Sequential acquisition of PET and CT

PET/MRI



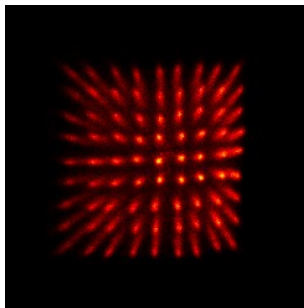
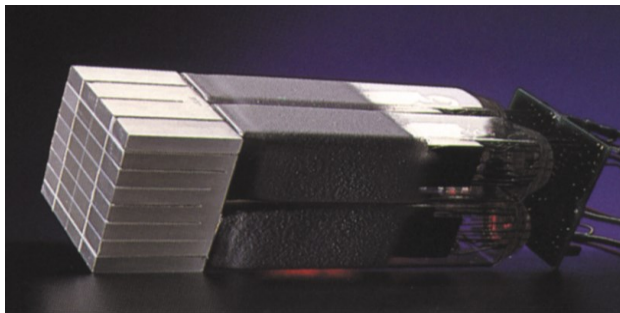
Simultaneous acquisition of PET and MRI



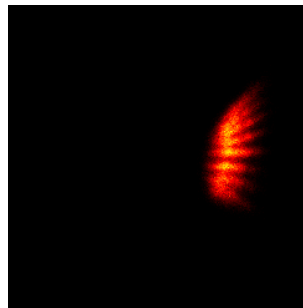
	CT	MRI
acquisition time	+	-
radiation exposure	-	+
soft tissue contrast	-	+
functional imaging	(+)	++
robustness	+	(-)

Technical concepts

Conventional PET-Detectors
Photomultiplier tubes (PMTs)

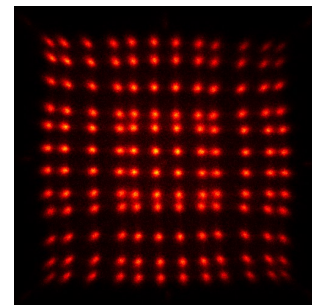
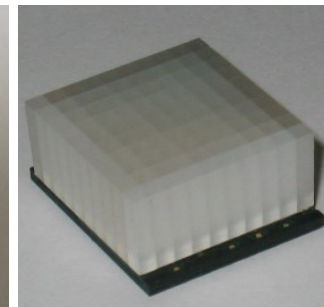
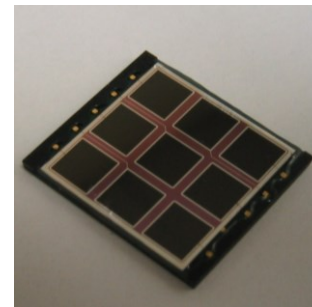


$B=0$

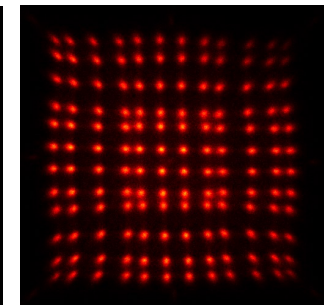


$B \neq 0$

MRI-PET Detectors
semiconductor based (APD)

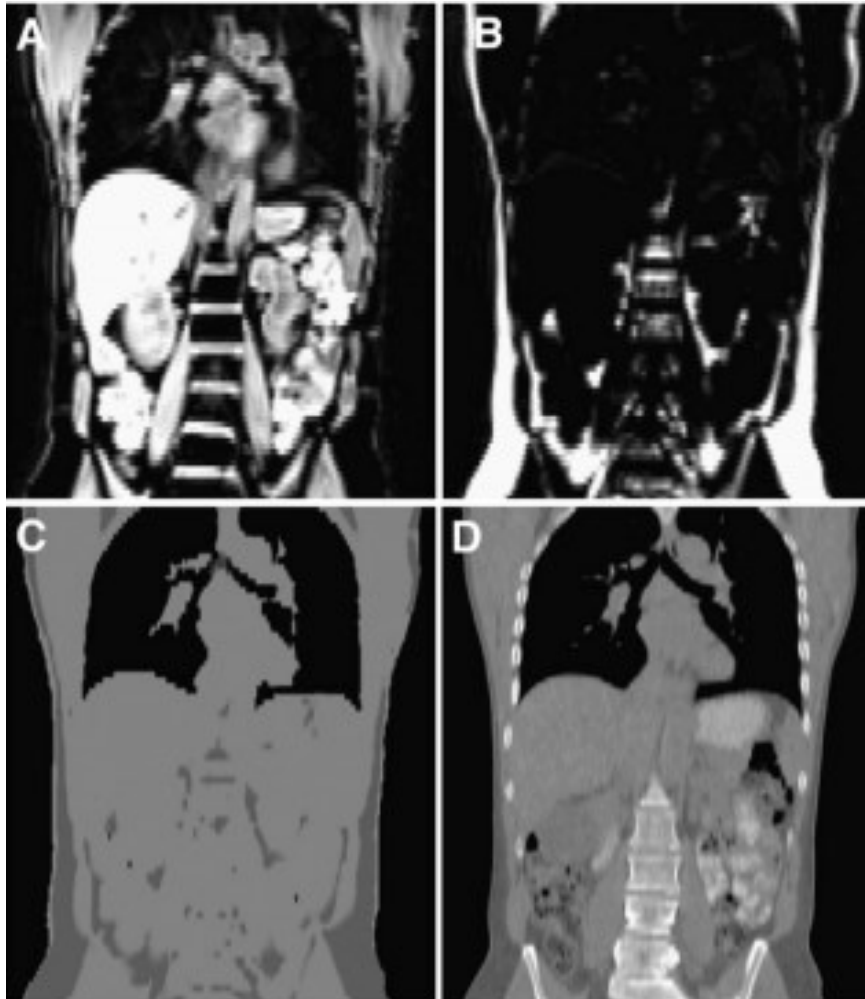


$B=0$



$B \neq 0$

AC: segmentation-based



The method involves the segmentation of an attenuation map into 4 classes: background, lungs, fat, and soft tissue.

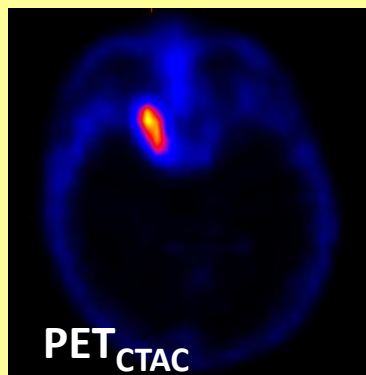
tissue
segmentation



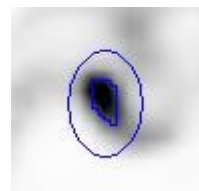
MR-based attenuation map

Martinez-Möller et al. JNM 2009

AC: atlas-based



Max	7.27 SUV
Min	3.67 SUV
Avg	4.81 SUV



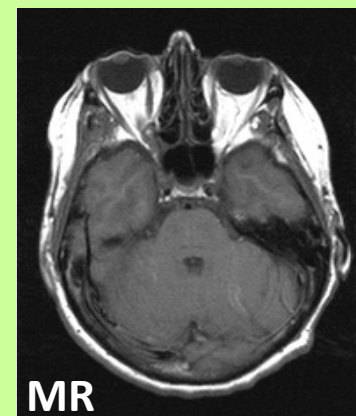
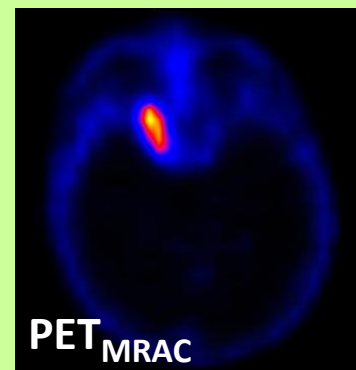
Max	7.32 SUV
Min	3.67 SUV
Avg	4.84 SUV

**Visual Impression of PET_{MRAC} and
PET_{CTAC} almost identical**

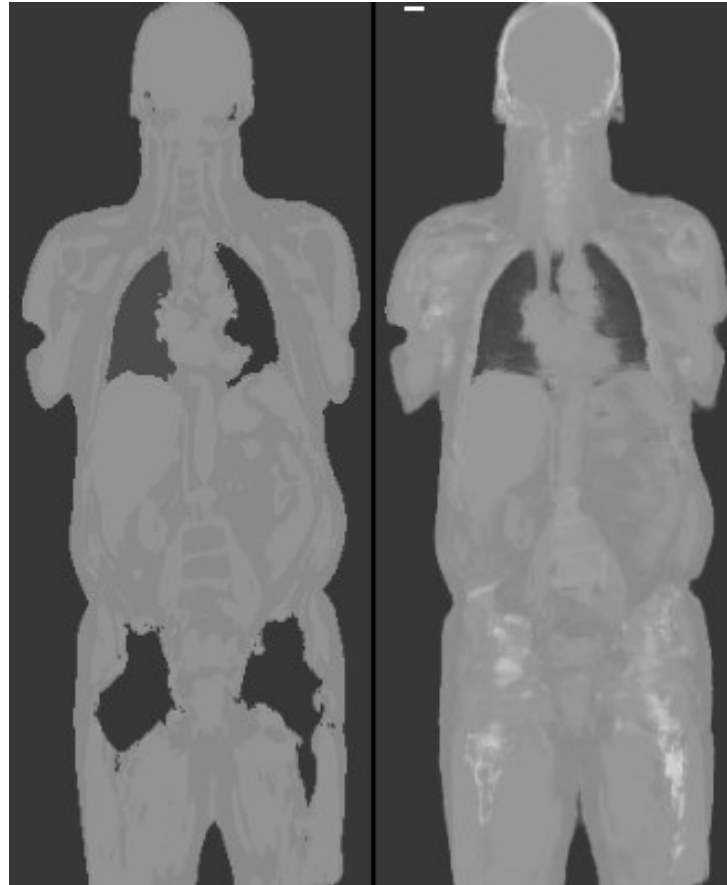
Quantification Error below 1%

Tracer: [⁶⁸Ga]DOTA-TOC

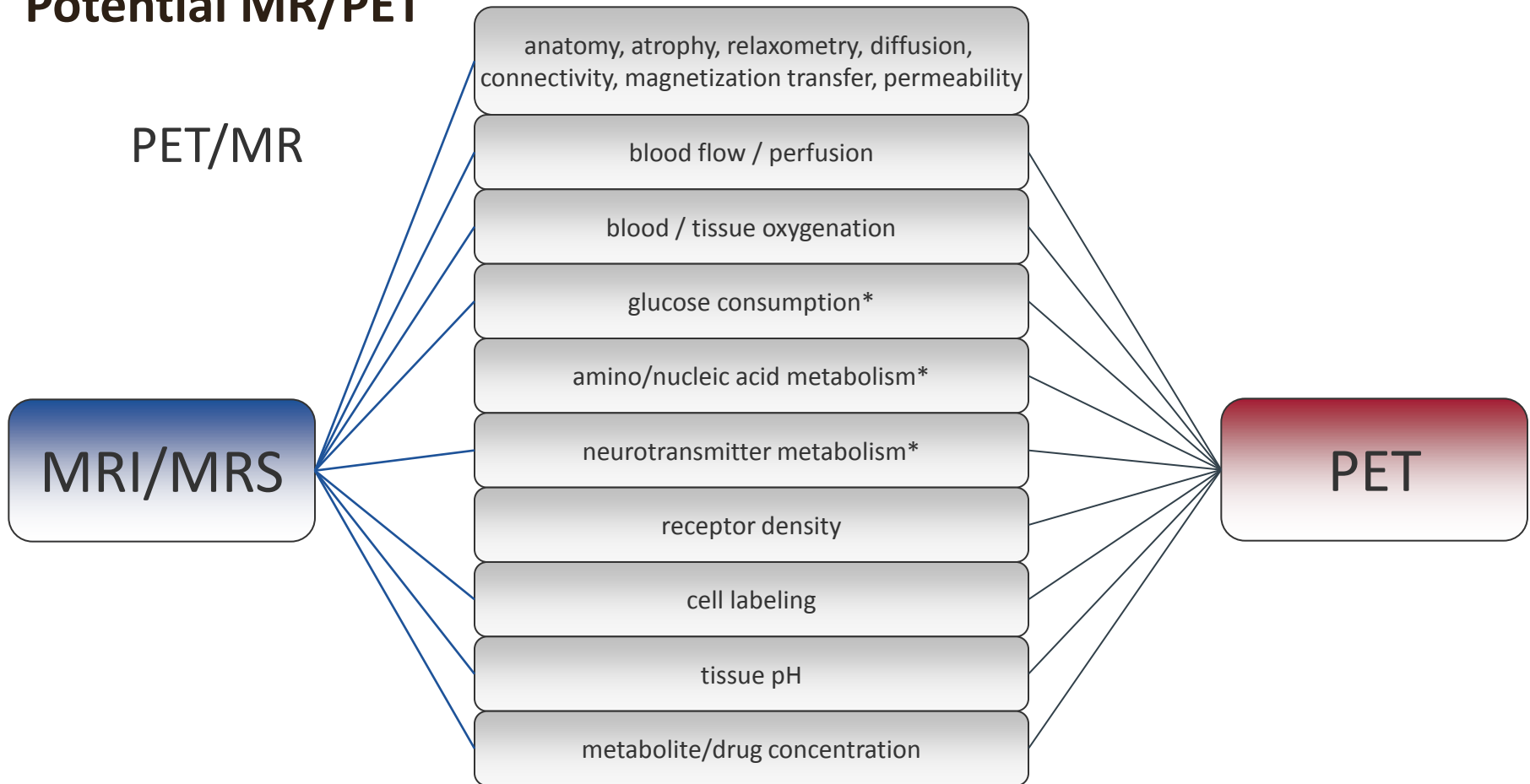
Reconstruction performed on PET/CT Scanner, using
Image Size 128x128, OSEM Reconstruction with 4
Iterations, 8 Subsets;
Gaussian Filter FWHM 5 mm



segmentation versus atlas-based AC



Potential MR/PET



* MRS = concentration, PET = turnover

→ correlate, cross calibrate, monitor on different stages: Multi-functional Imaging

Workflow: preparation

referral form:

UNIVERSITÄTS KLINIKUM TÜBINGEN
MR-PET-Zentrum
Abt. für Nuklearmedizin und Abt. für Diagnostische und Interventionelle Radiologie
Ottfried-Müller-Str. 12 • 72076 Tübingen
Tel.: 07071 / 29-80544
Fax: 07071 / 29-49280

Anforderung einer MR-PET-Untersuchung

Bitte beachten:
- NÜCHTERNHEIT: BEI BESTIMMTEN UNTERSUCHUNGEN (FDG)
- AUSREICHENDE HYDRATION (UNGESÜSSTER TEE, WASSER)

Studienpatient: ☐ ja, Name der Studie: _____
Diagnose und Fragestellung, ggf. Histologie: _____

Operation: ☐ ja, wann Lokalisation: _____ ☐ nein
Chemo- / Hormontherapie: ☐ ja _____ ☐ nein
Tag der letzten Gabe: _____ Nächste Gabe geplant am: _____
Radiation: ☐ ja, wann beendet: _____ ☐ nein
Voruntersuchungen: ☐ ja, Modalität/wann/wie: _____ ☐ nein

Patient: Ist zum Untersuchungzeitpunkt: ☐ ambulant - Kasse: _____ ☐ stationär - Kasse: _____
☐ privat ☐ GKV: Verordnung von: _____ ☐ GKV
Der Name der gesetzlichen- und privaten Krankenkassen ist: _____
Krankenhausbehandlung: _____
ausnahmlos erforderlich: _____
Selbstzahler/GKV: _____

Aktueller Kreatinin-Wert: _____ mg/dl (Normbereich: _____)
GFR-MDRD: _____ ml/min (Normbereich: _____) Größe/Gewicht: _____ cm / _____ kg

Diabetes mellitus: ☐ ja ☐ Typ 1 ☐ Typ 2 ☐ nein
Schwangerschaft: ☐ ja ☐ nein
Metallimplantate/Metalleile im Körper: ☐ ja ☐ keine Prothesen/implantierbare Metallteile ☐ nein
Herzschrittmacher/Defibrillator: ☐ ja ☐ MR-tauglich ☐ ja ☐ nein
Künstliche Herzklappen: ☐ ja ☐ MR-tauglich ☐ ja ☐ nein
Neurostimulator: ☐ ja ☐ MR-tauglich ☐ ja ☐ nein
OP am Herzen oder am Kopf: ☐ ja ☐ nein
Allergien/Überempfindlichkeiten: ☐ ja ☐ nein
Leidet der Pat. an Klaustrophobie? ☐ ja ☐ nein
Beruhigungsmittel ausreichend: ☐ ja ☐ nein
Kurzanästhe notwendig: ☐ ja ☐ nein

Wunschtermin: - eventuelle Alternative: _____
Name, Telefon, Funk- und Fax des Überwachers: _____ Datum, Unterschrift: _____

Vorformalen PET-Befunden, abgelesen und hiermit beschrieben:

Indikationsstellung Nuklearmedizin: _____
Tracer: _____ Radioaktivität: _____ MBq
Datum: _____ Arzt: _____
Termin: _____ Datum: _____ Uhrzeit: _____

Information provided by the referring physician

patient history:

- indication/diagnose/question
- preceding treatment
- available examinations (PET, CT, MRI)

detailed questionnaire:

- lab data (creatinine, GFR)
- diabetes
- pregnancy
- known contrast media allergies
- claustrophobia (sedation?)
- metallic implants

decision for examination:

approval by radiologist/nuclear medicine physician; definition of tracer and activity

Workflow: documentation

Etikett
(Name, Vorname, Geb.-Datum)

Anamnese
UND
Untersuchungsprotokoll
MR-PET

Anamnese:

Messbereich:

Radiopharmakon

2. ANAMNESEBLATT

Akt. Blutzucker: mg/dl
Nüchtern seit: Stunden

Injektionsort: MBq Datum: Uhrzeit: Unterschrift:

Rückmessung: MBq Datum: Uhrzeit: Unterschrift:

Appl. Dosis: MBq Datum: Uhrzeit: Unterschrift:

Messprotokolle

MRAC-PET
T2_tirm_cor
Ep2d_advdiff_spar_tra_b50_800

Kontrastierung

	Menge (ml)	Fluss (ml/s)	i.v. Medikation	
Gadoviste			Buscopan	mg
			Solu-Dacortin 250mg	mg
			Fenistil 4mg	mg
			Dormicum (i.v.)	mg Uhrzeit
Sonstige			Tavor	mg
			Lasix 20mg	mg

Unters.zeit MRAC: Unters.zeit MR-Sequenzen:

PET-Beds (Anzahl): Zeit pro Bed (min):

Raumbelegung: KM-Zwischenfall: → nicht: g

Arzt (Nuklearmedizin) → Arzt (Radiologie)

patient history

range of examination, protocol advise

tracer used, blood glucose level

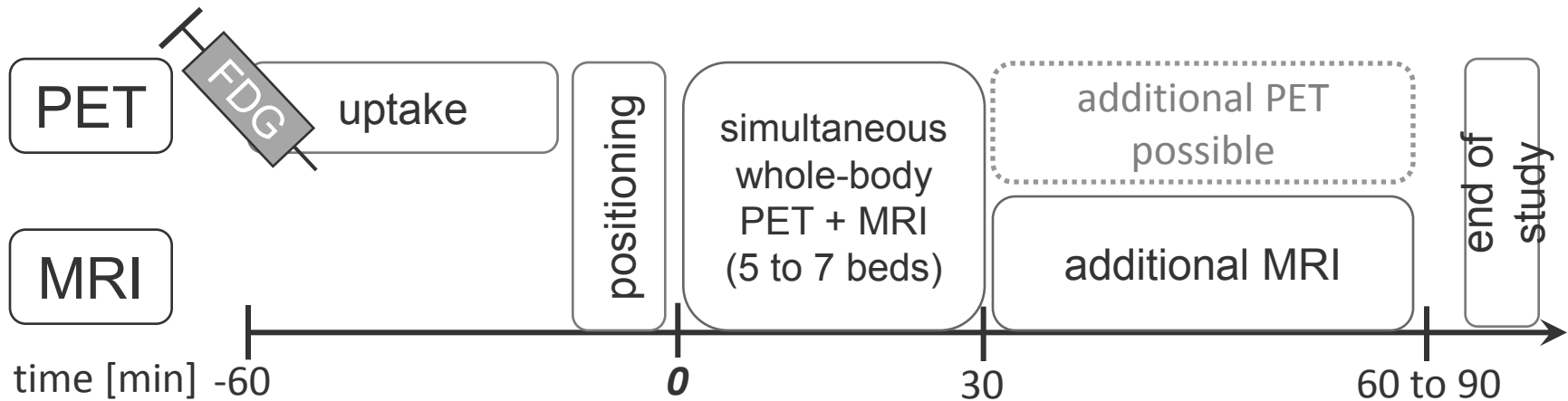
physician

technician

Workflow: examination

A) patient information and informed consent (15-30 min)

B) tracer uptake + examination





Indications and Applications

- primary staging
- therapy monitoring
- follow-up

especially in

- prostate cancer
 - neuroendocrine tumors
 - gynecologic malignancies
 - lymphoma
 - pediatric oncology
 - neurooncology (other presentation)
-



General aspects

Whole body staging: **protocol**

basic module

whole body staging

axial T2 HASTE

coronal STIR

DWI

} + PET (multiple beds)

whole body T1 flash-3D fs post contrast

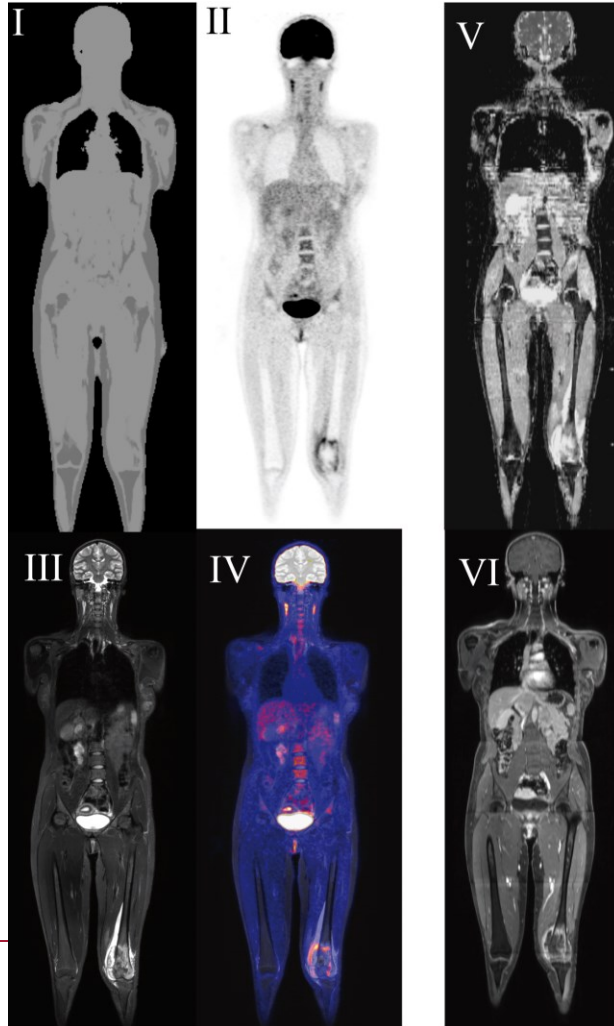
**additional local
imaging**

transverse T2 fs / STIR (neck, thorax, abdomen)

local DCE MRI (e.g. liver, prostate)

local staging using high resolution MR sequences

PET/MRI protocol



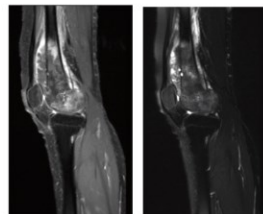
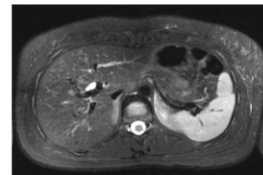
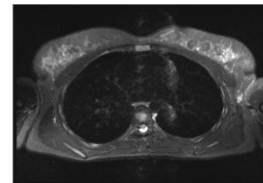
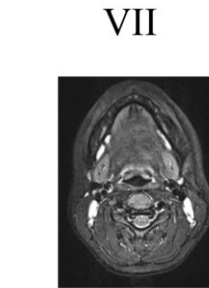
I) Attenuation Correction
III) coronal STIR
V) DWI
VI) contrast-enhanced VIBE

} + II) PET

basic module

+

VII) local imaging



17 year-old girl with
osteosarcoma of the left femur



General aspects: lung imaging

Is MRI sufficient for the detection of pulmonary metastases?

- PET in PET/MR equivalent to PET in PET/CT for FDG-avid nodules
- specific sequences necessary (navigated T2 / 3D Flash) for lung staging
- detection rate of nodules <1 cm in MRI limited

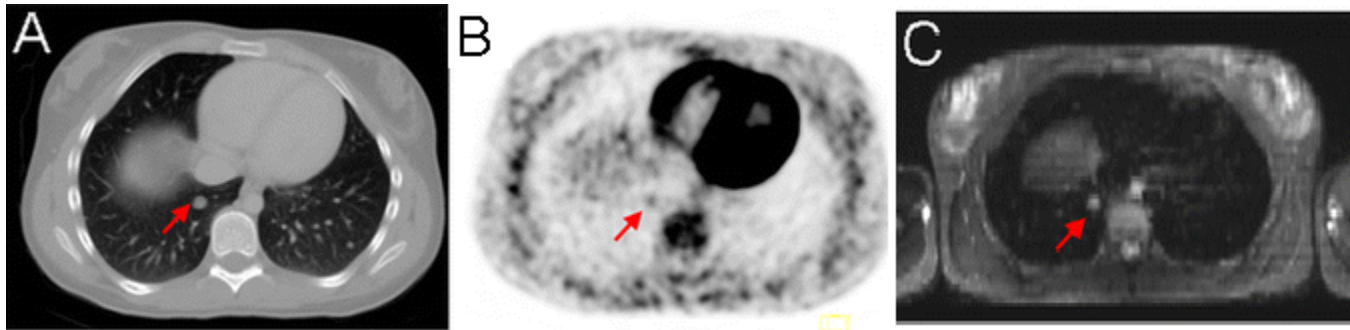
(Schwenzer et al. Radiology 2012; Rauscher et al. JNM 2014)

However:

- most lung lesions missed in PET/MR are benign
- PET/MR equivalent to PET/CT on patient base for lung staging

(Raad et al. 2016)

Lung nodules in PET/MRI



13-year-old patient with alveolar soft part sarcoma.



General aspects: bone imaging

Bone is (still) neglected in MR-based attenuation

→ SUV of bone lesions can be underestimated (*Samarin et al. 2016*)

However:

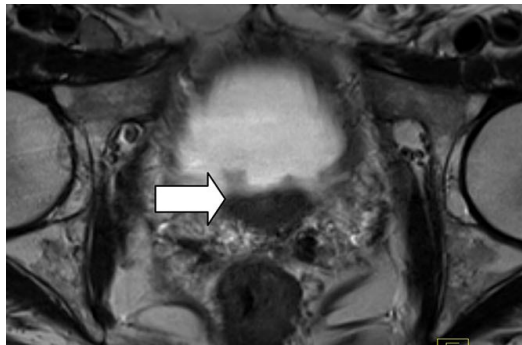
MR allows for better morphologic detection of bone lesions (coronal STIR)

-> higher diagnostic confidence (*Eiber et al. 2014*)

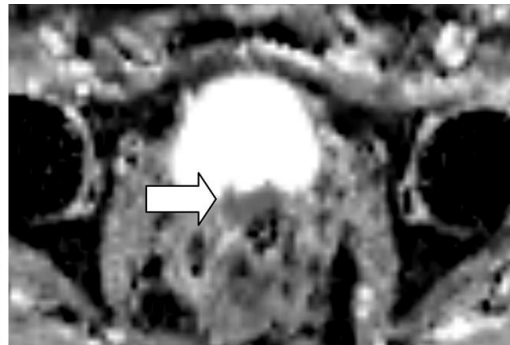


Clinical applications

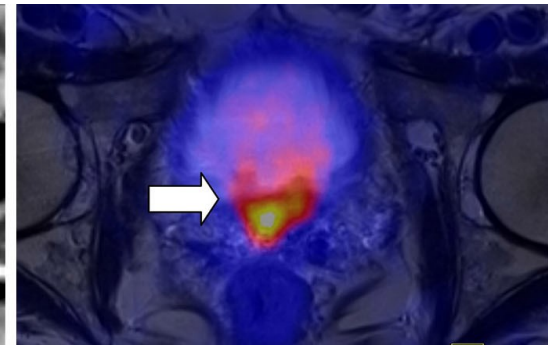
Prostate cancer



T2 TSE



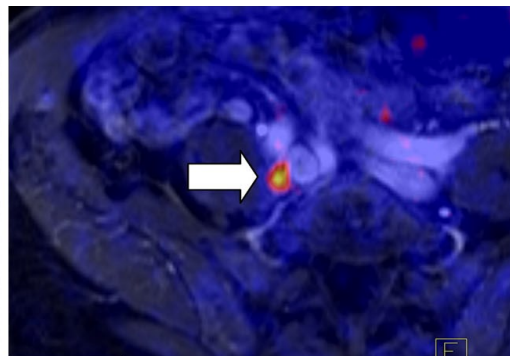
ADC



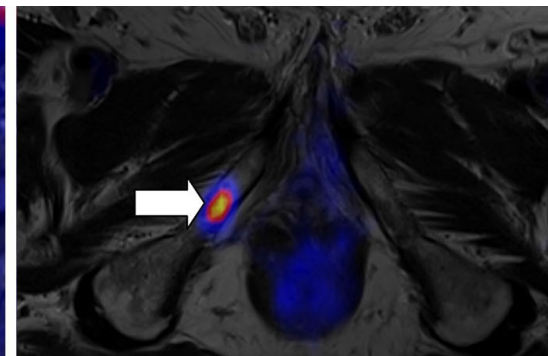
T2+PET



STIR ax



STIR + PET



T2 +PET

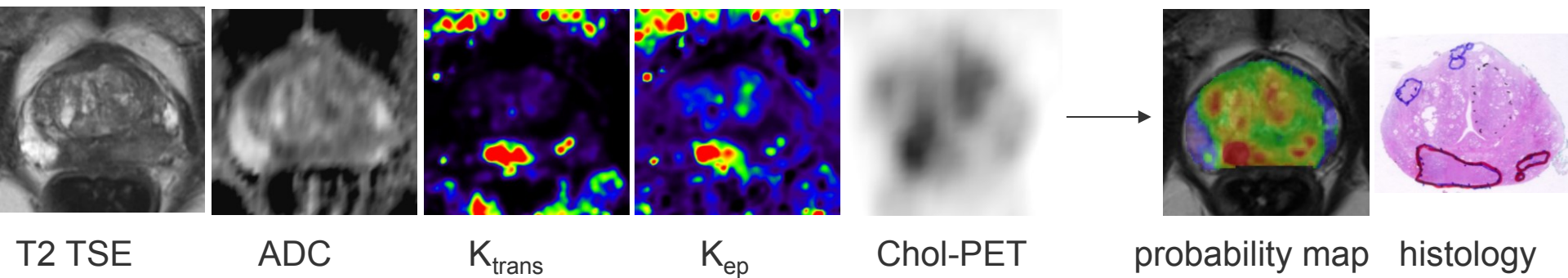
74-year-old patient with biochemical relapse of prostate cancer after prostatectomy
Ga68 PSMA PET/PET/MR reveals local recurrence as well as nodal and osseous metastases

Prostate cancer: literature

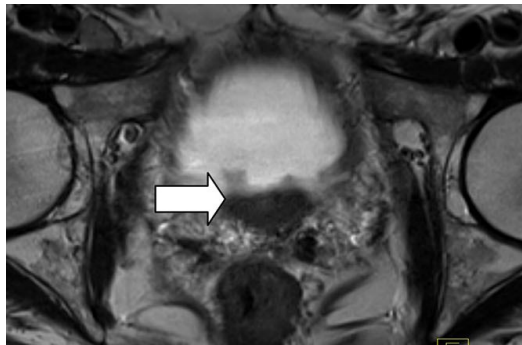
-PSMA-PET/MR can improve localization of primary prostate cancer compared to MRI
(*Eiber et al. European Radiology 2016*)

-possible benefit of Choline PET/MR over PET/CT for staging of prostate cancer thanks to better anatomical allocation of lesions
(*Souvatzoglu et al. 2013*)

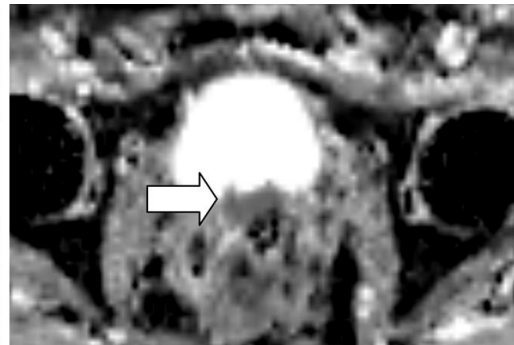
-PET/MR allows for multiparametric characterization of primary prostate cancer
(*Gatidis et al. NMR Biomed 2015*)



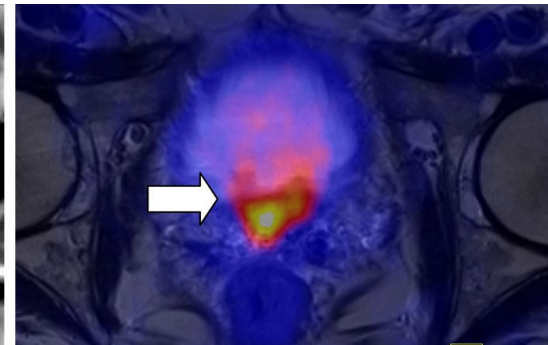
Prostate cancer in PET/MRI



T2 TSE



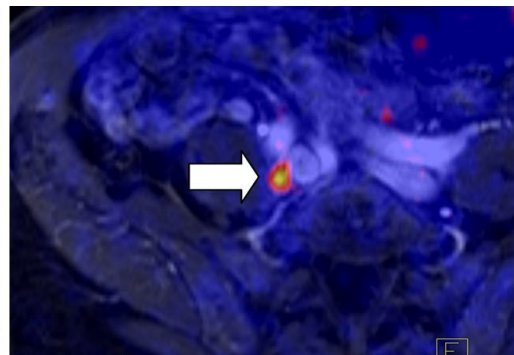
ADC



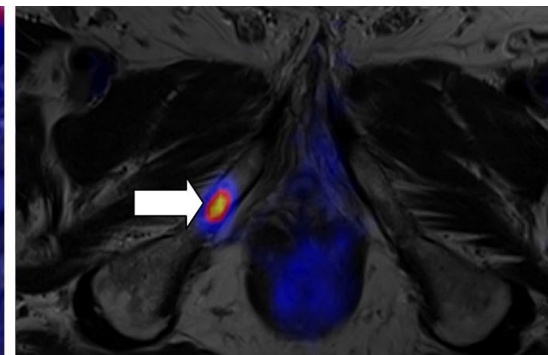
T2+PET



STIR ax



STIR + PET



T2 + PET

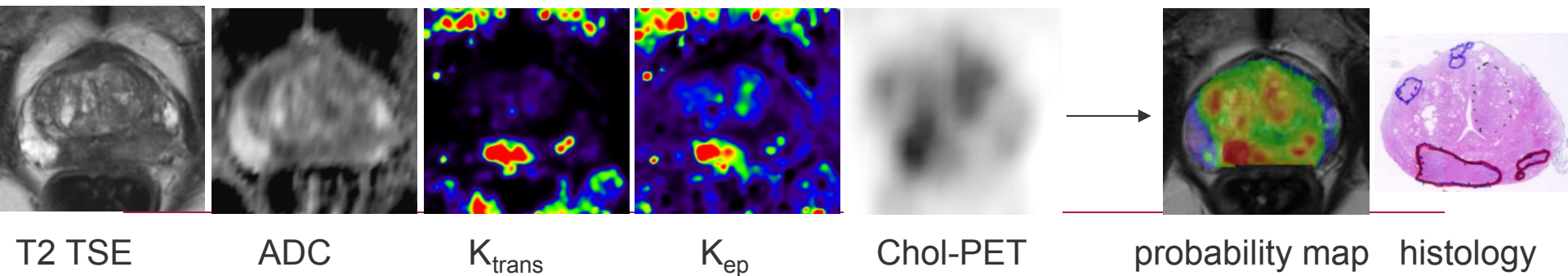
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Prostate cancer: literature

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(Souvatzoglou et al. 2013)

-PET/MR allows for multiparametric characterization of primary prostate cancer
(Gatidis et al. *NMR Biomed* 2015)





PET/MRI vs. PET/CT in children

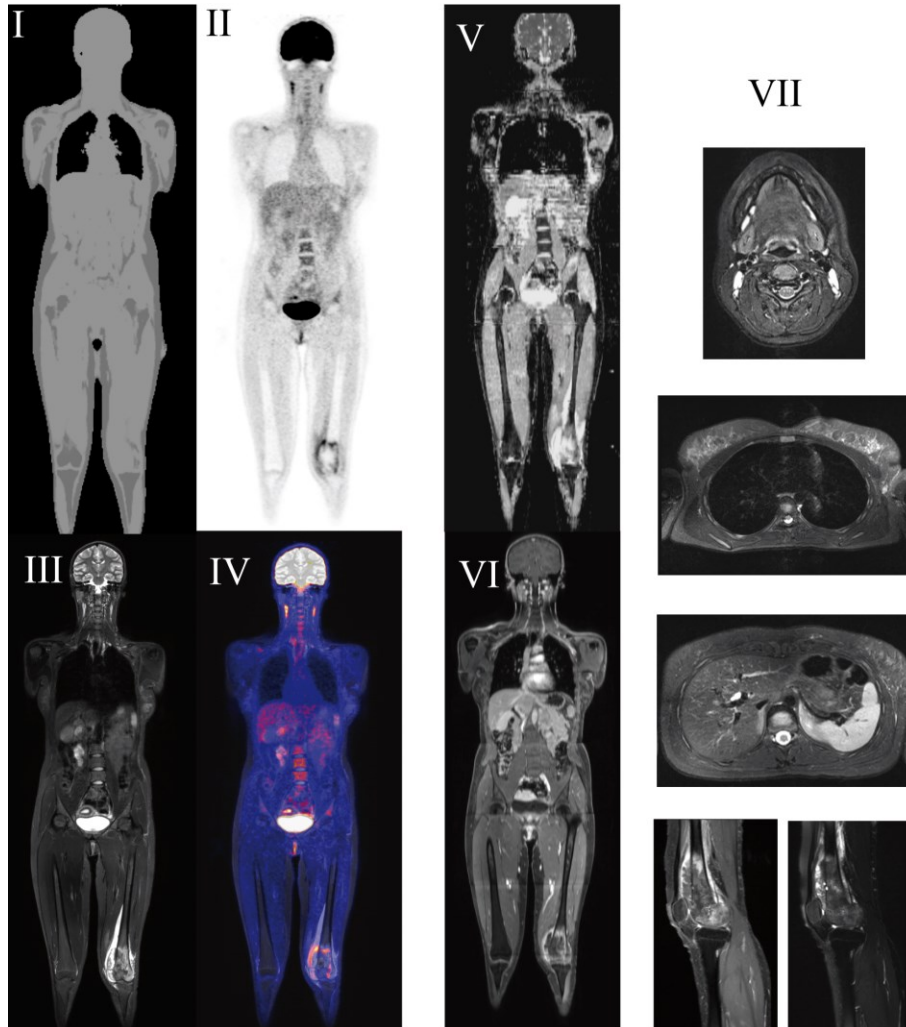
Advantages of PET/MRI

- high soft-tissue contrast of MRI
 - simultaneous local and whole body staging (reducing total number of examinations)
 - Better anatomical characterization of soft-tissue and bone marrow lesions (better detection of morphologic PET correlates)
- Multiparametric tumor characterization (PET + functional MRI: DWI, DCE, ...)
- Reduced radiation exposure (by up to 70 %)

Disadvantages of PET/MRI

- longer examination times per single examination
- possible limitations in detecting lung metastases

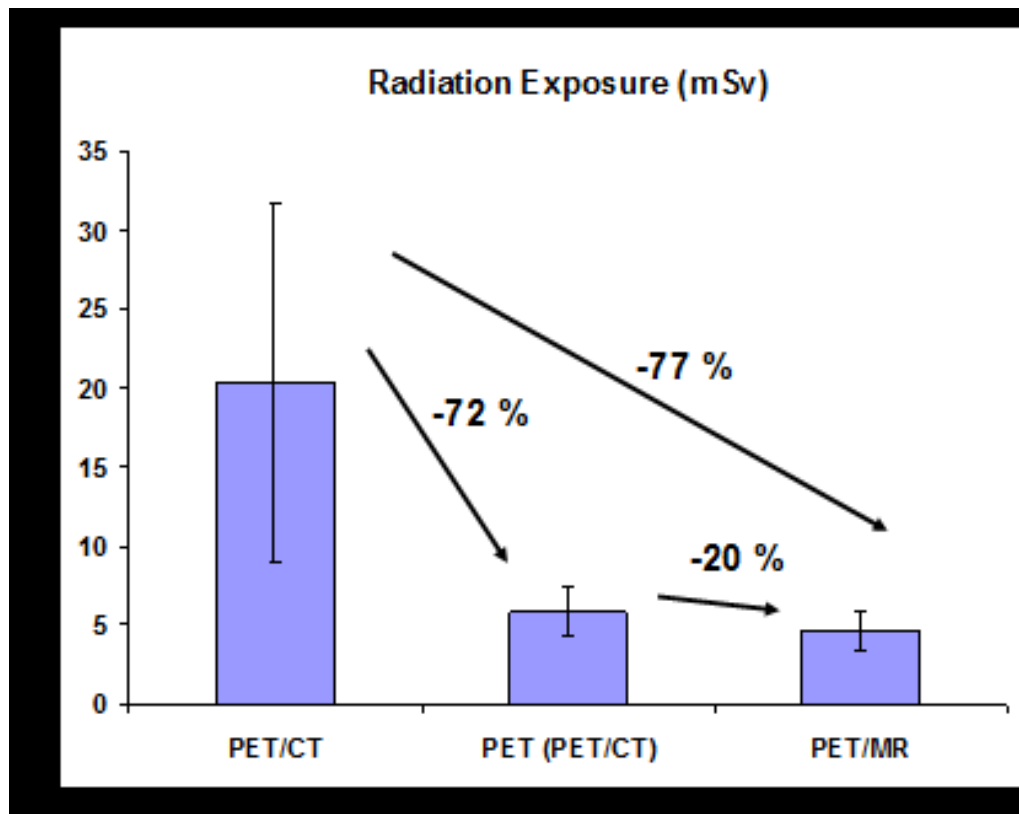
PET/MRI protocol in children



- I) Attenuation Correction
 - III) coronal STIR
 - V) DWI
 - VI) contrast-enhanced VIBE
 - VII) local imaging
- + II) PET

17 year-old girl with
osteosarcoma of the left femur

Dose aspects





PET/MRI in pediatric oncology: literature

-PET/MR at least equivalent to PET/CT for staging and follow-up of solid malignancies in children

-advantages of PET/MR in the detection and characterization of soft-tissue lesions

-reduction of total number of examinations and thus sedations (local and whole body imaging in one exam)

-significantly reduced radiation exposure compared to PET/CT

(Schäfer et al., Radiology 2014, Gatidis et al. Invest Radiol 2015)



Summary:

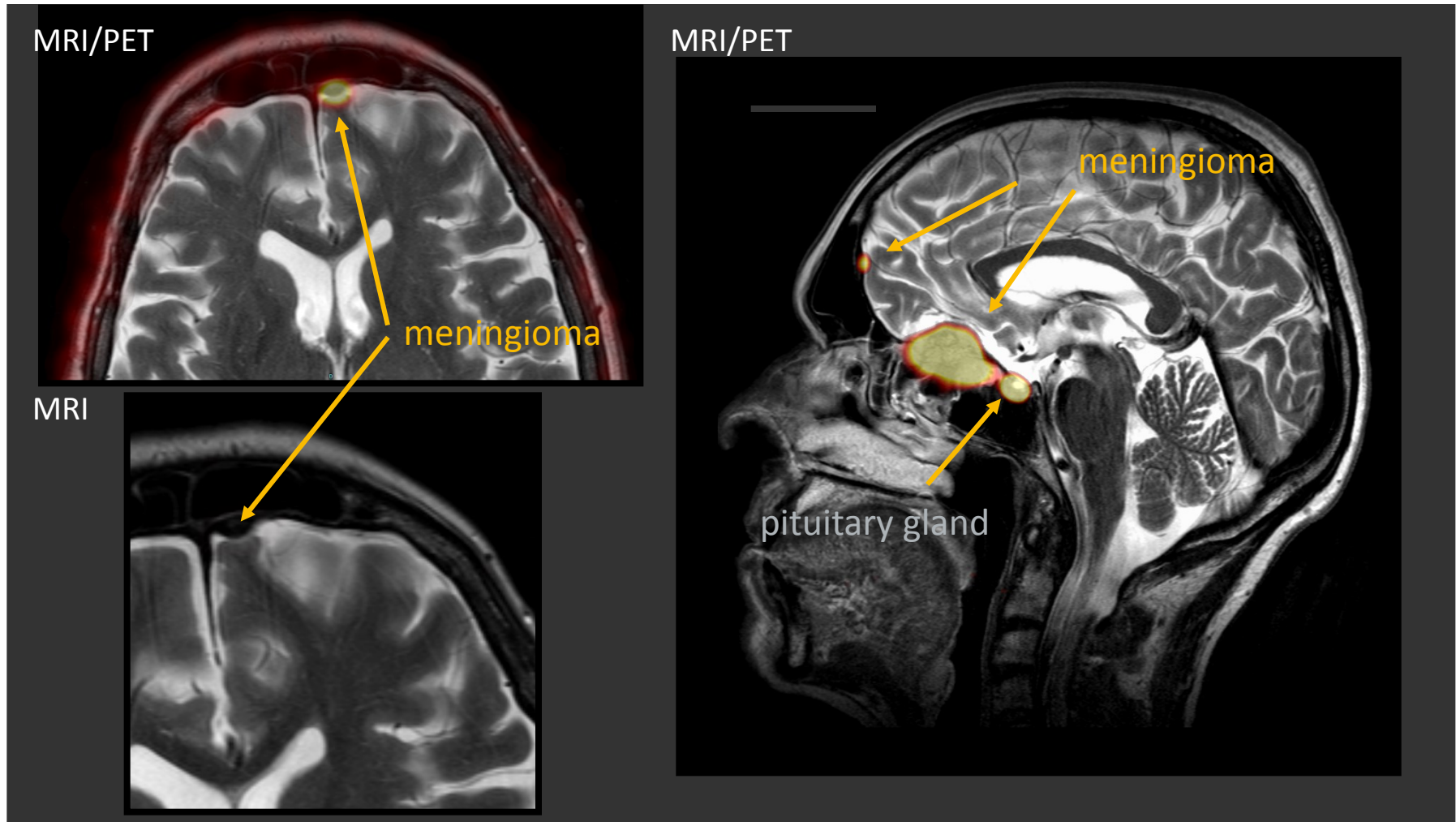
Is there an benefit using combined PET/MRI according to literature?

Pediatric oncology	↑
CNS malignancies	↑
Prostate cancer	↑
Neuroendocrine tumors	↗
Head and neck cancer	↗
Gynecological cancers	↗
Lymphoma	↗
Melanoma	→
Lung cancer	→

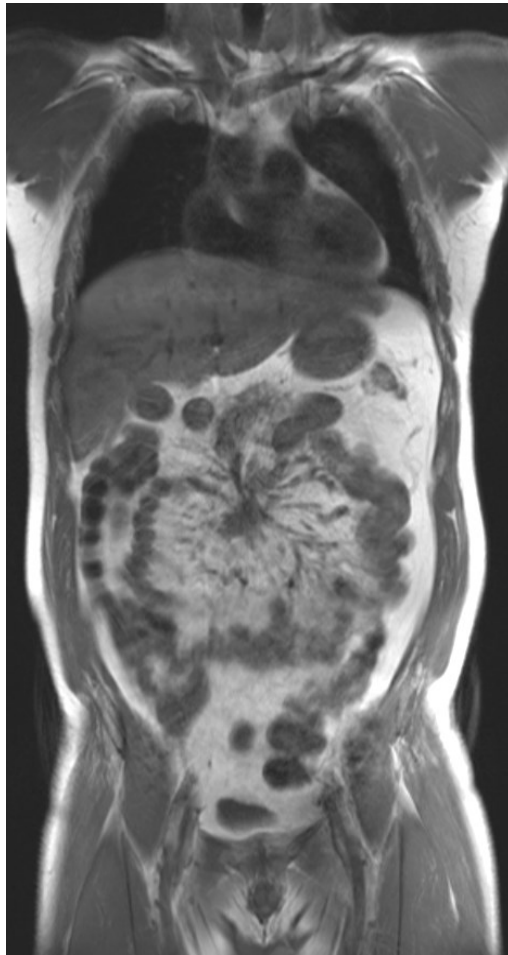


Thank you.

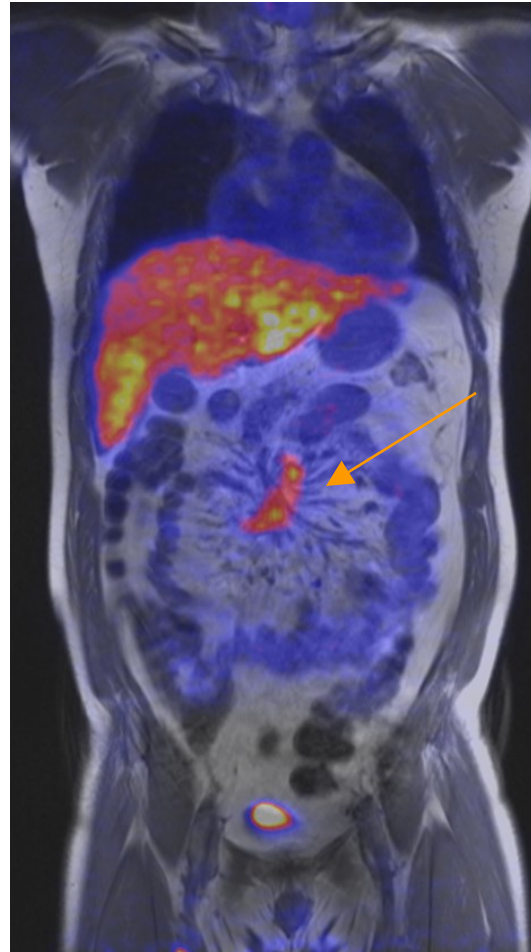
Initial results



Initial results: neuroendocrine tumor



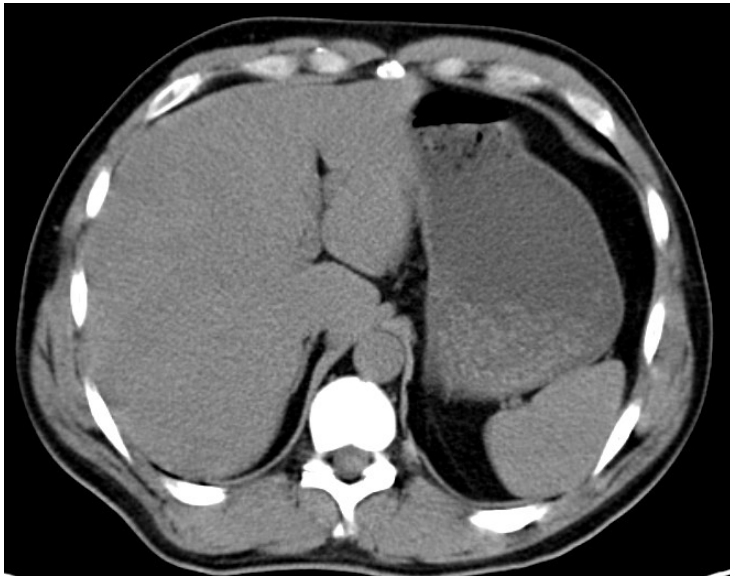
MRI: T1 cor



Mesenteric
tumor manifestation

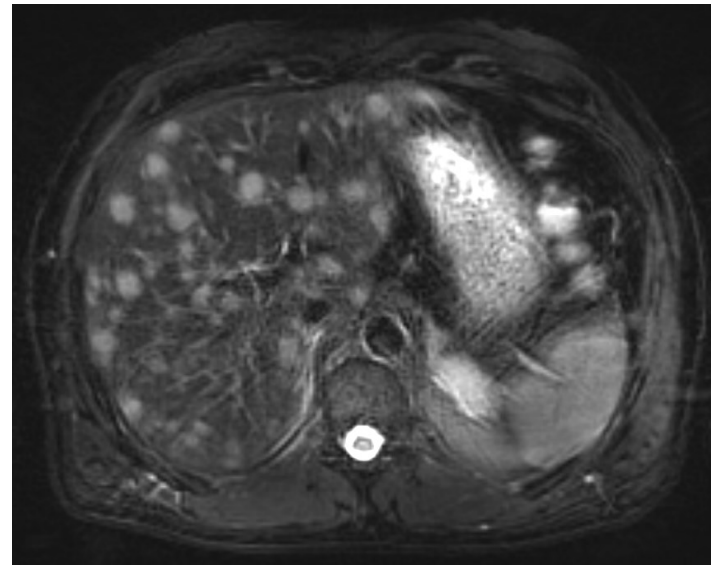
PET: ^{68}Ga -DOTATOC (151 MBq)

Initial results: neuroendocrine tumor



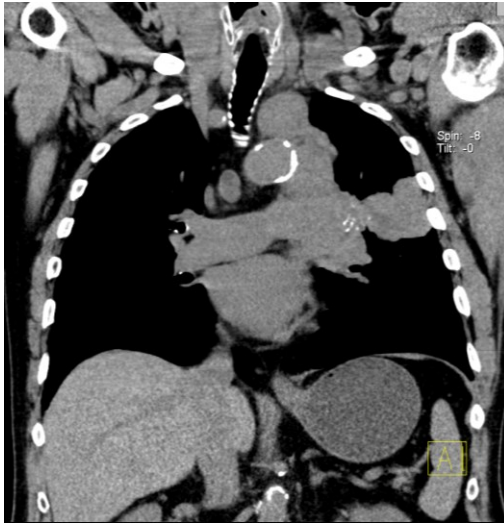
Non-contrast CT

multiple liver metastases

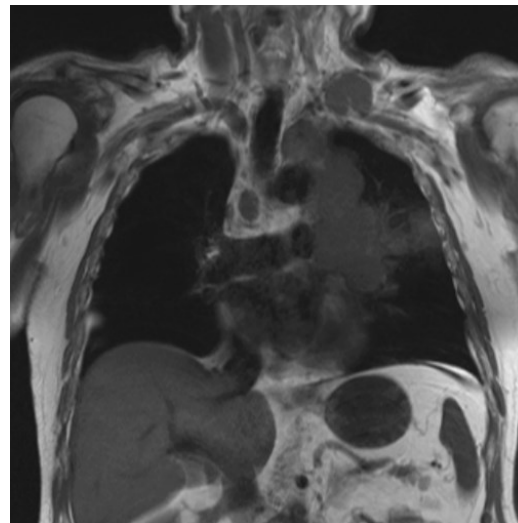


MRI: T2 fs axial

Initial results: lung cancer

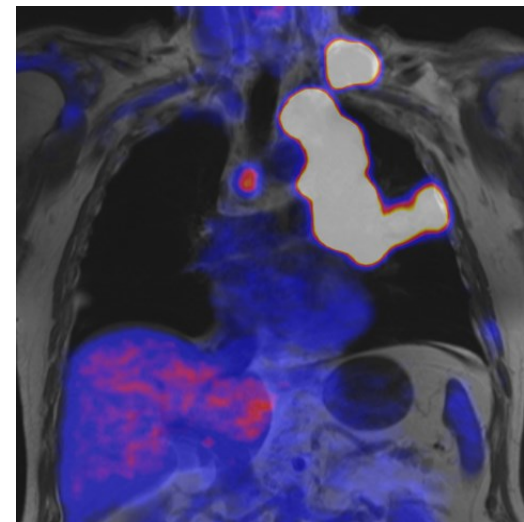


non-enhanced CT



MRI: T1 coronal

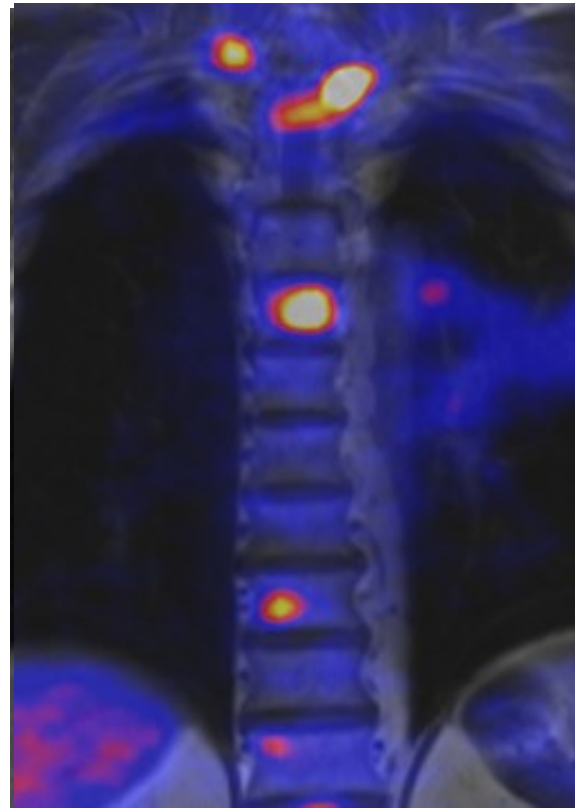
PET: 364 MBq FDG



Initial results: lung cancer

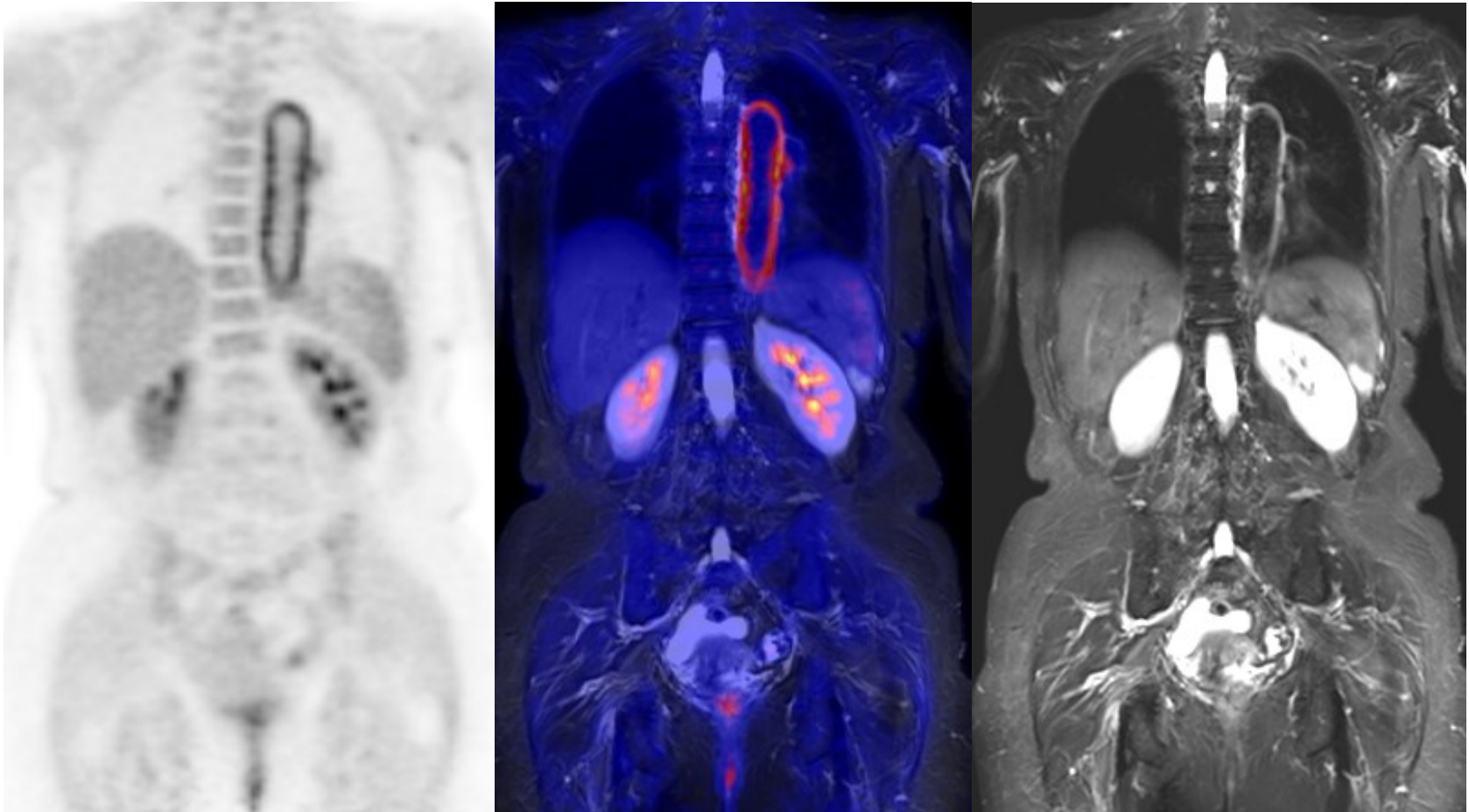


CT bone window



→ bone metastases can be visualized

Initial results: giant cell arteritis



Initial results: giant cell arteritis

