Integrated PET/MRI

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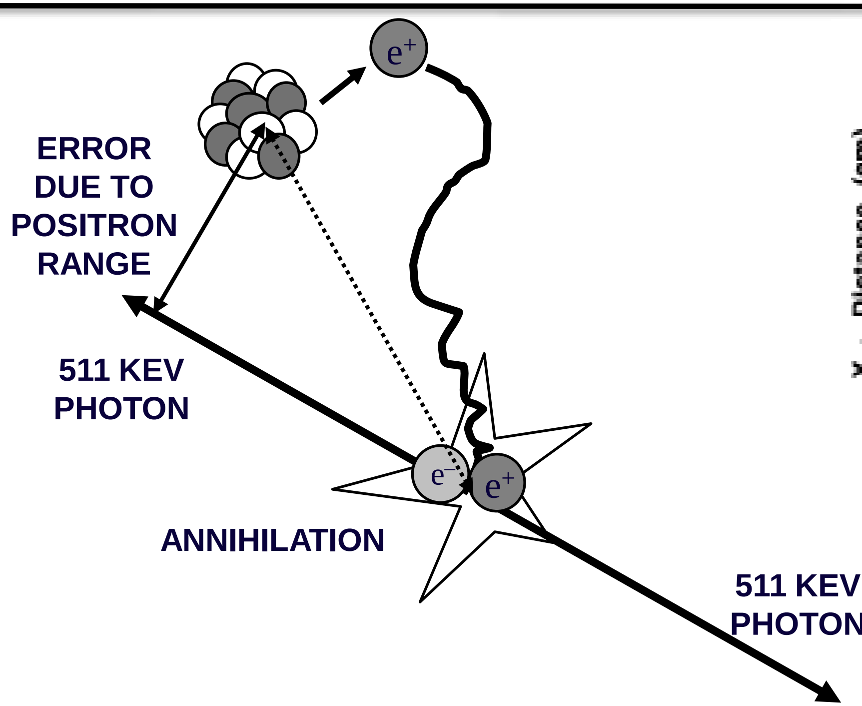
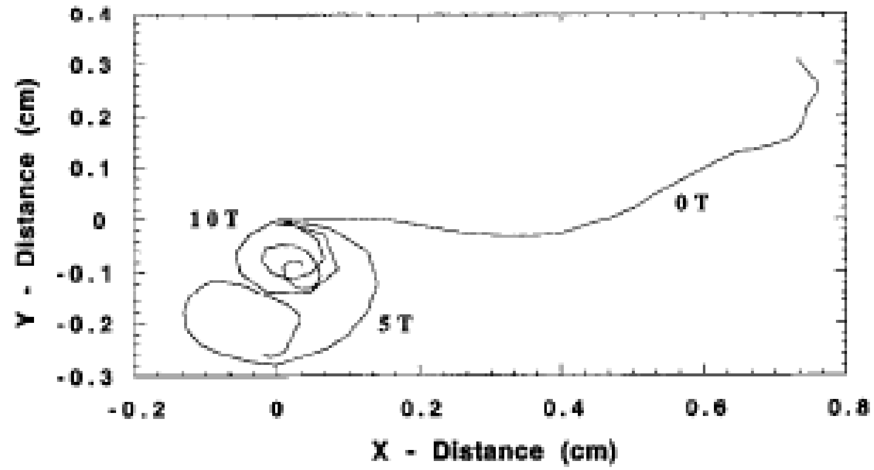
Outline

PET/MRI:

- Brief history and current state-of-the-art
- Methodological advances enabling new science:
  - What MR can do for PET
  - What PET can do for MR
- Potential research and clinical applications

“Physics” motivation for simultaneous PET/MRI - positron range error reduction in magnetic fields





Representative paths in tissue of a 2 MeV electron (Raylman et al. Int J Rad Onc Biol Phys, 1997; 37(5))

$$\vec{F}_{Lor} = q\,\vec{V} \times \vec{B}$$

$$R = \frac{0.334}{B}\sqrt{(2m_p E_t) + E_t^2}$$

q – particle charge; V – positron velocity; B – magnetic field; E_t – component of the positron kinetic energy (MeV) perpendicular to the magnetic field;
m_p – rest mass of the positron

***In-plane PET scanner spatial resolution might improve at high magnetic fields (i.e. B>7T), for high energy positron emitters (i.e. ^{82}Rb, E_t=3.15 MeV) if it is not dominated by other factors (i.e. crystal size, non-colinearity, etc.)**

Integrating PET and MRI does not mean placing an existing PET scanner inside an MR scanner.

PET effects on the MR:

No ferromagnetic components allowed;
Disturb homogeneity of the B_0 field;
RF interference with the MR Tx/Rx coils;
Susceptibility artifacts and eddy currents.
...

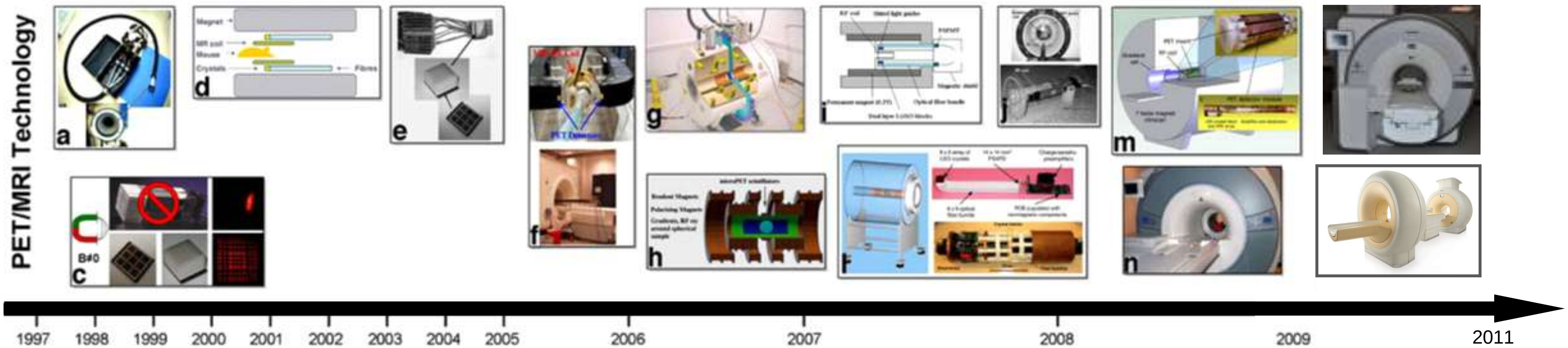
MR effects on the PET:

PMTs very sensitive to magnetic fields;
RFI, heating, vibrations, etc.
...

General considerations:

Space constraints inside the MR;
Cost !

Integrated PET/MR scanners have been developed for small animal and human imaging.



(Wehrl HF, Judenhofer MS, Wiehr S, Pichler BJ,
Eur J Nucl Med Mol Imaging 36 (Suppl 1): S56-58; 2009, updated)

PET-MR(-CT) Scanners Available for Human Use

Philips Ingenuity TF PET/MR

Siemens Biograph mMR

GE PET/CT

Patient Transport

GE MR

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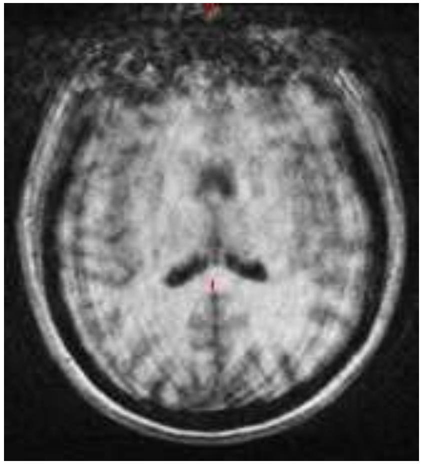
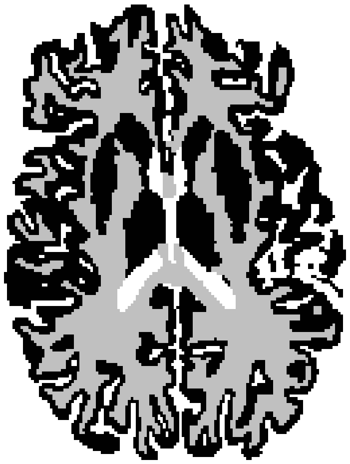
What MR can do for PET

1. Attenuation correction

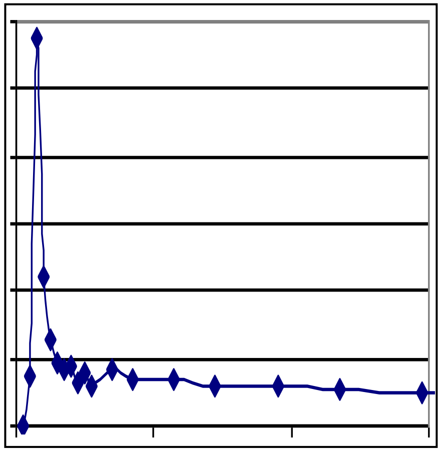
2. Motion correction



3. Partial volume effects corr.



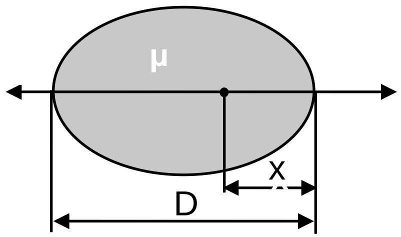
4. Arterial input function estimation



Annihilation photons can interact with the subject before reaching the detectors.

$$I(x) = I(0)e^{-\mu x}$$

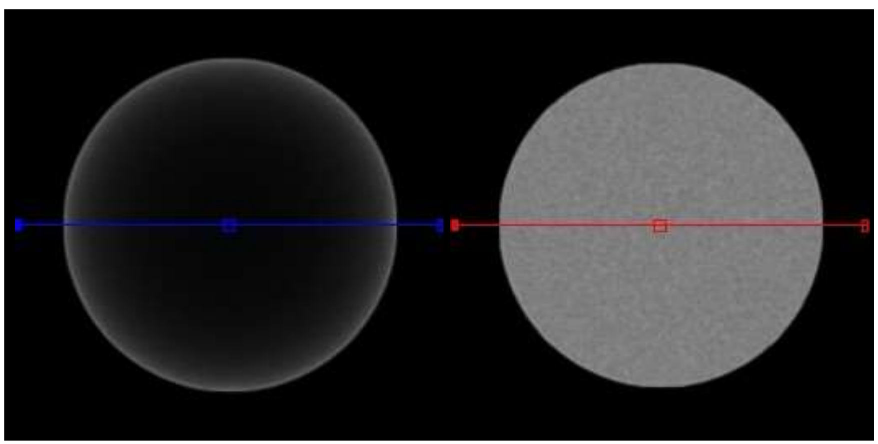
$$p_2 = e^{-\mu(D-x)}$$



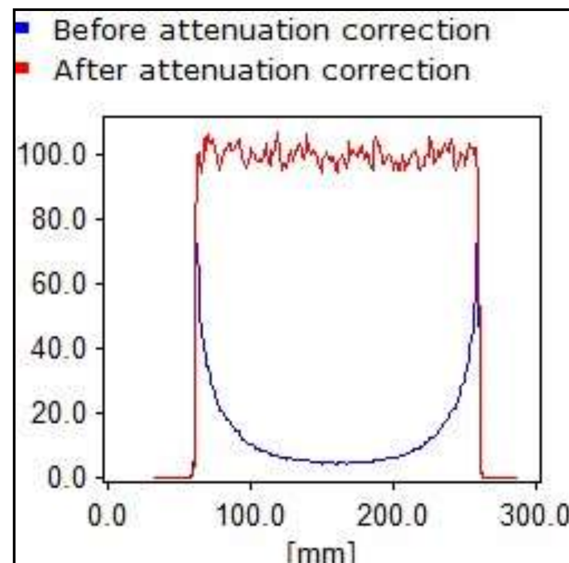
$$p_1 = e^{-\mu x}$$

$$p_{coinc.} = p_1 p_2 = e^{-\mu x} e^{-\mu(D-x)} = e^{-\mu D}$$

$$Atten.Corr. = e^{\mu D}$$



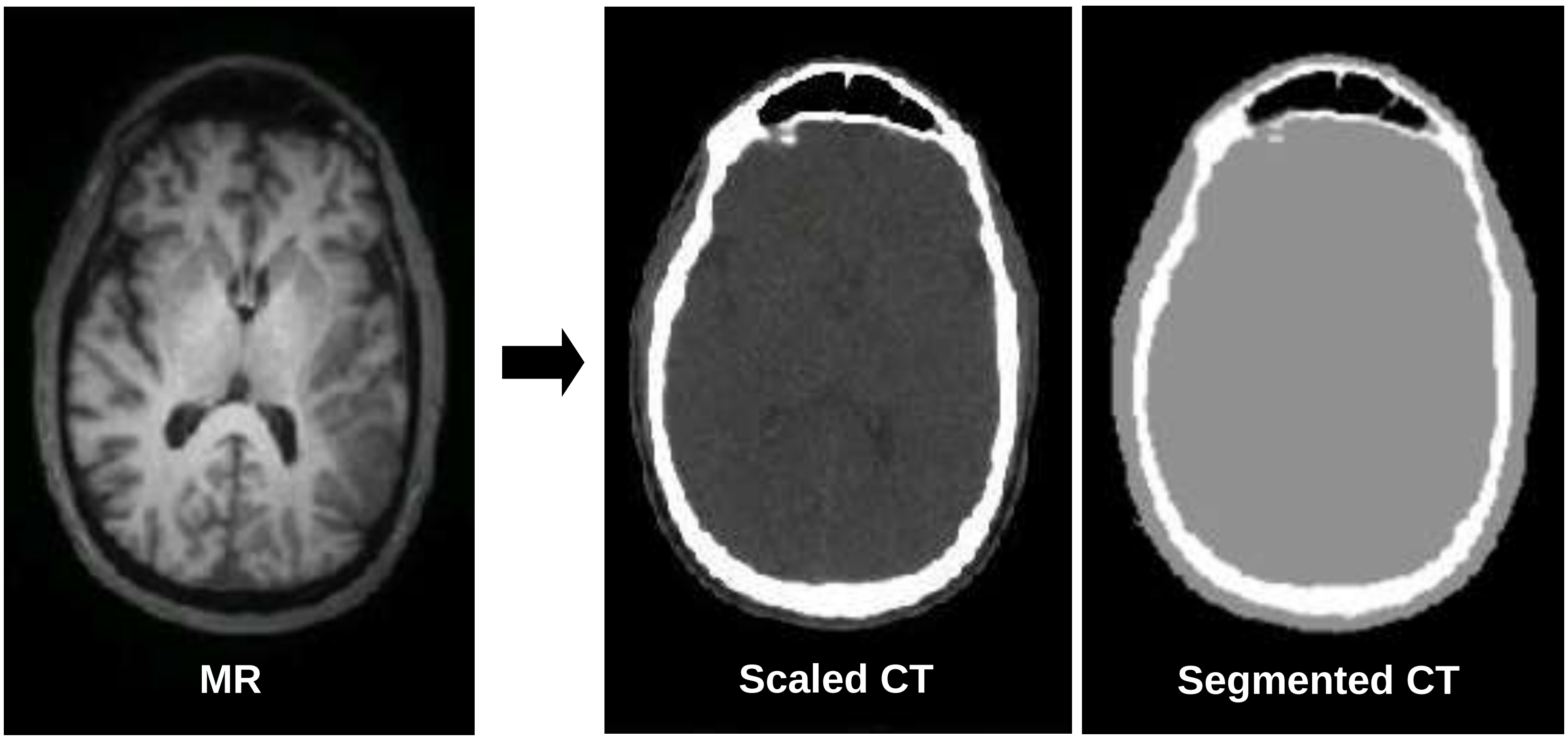
Uniform cylinder before and after AC (Ø=20 cm, μ=0.096 cm^{-1})



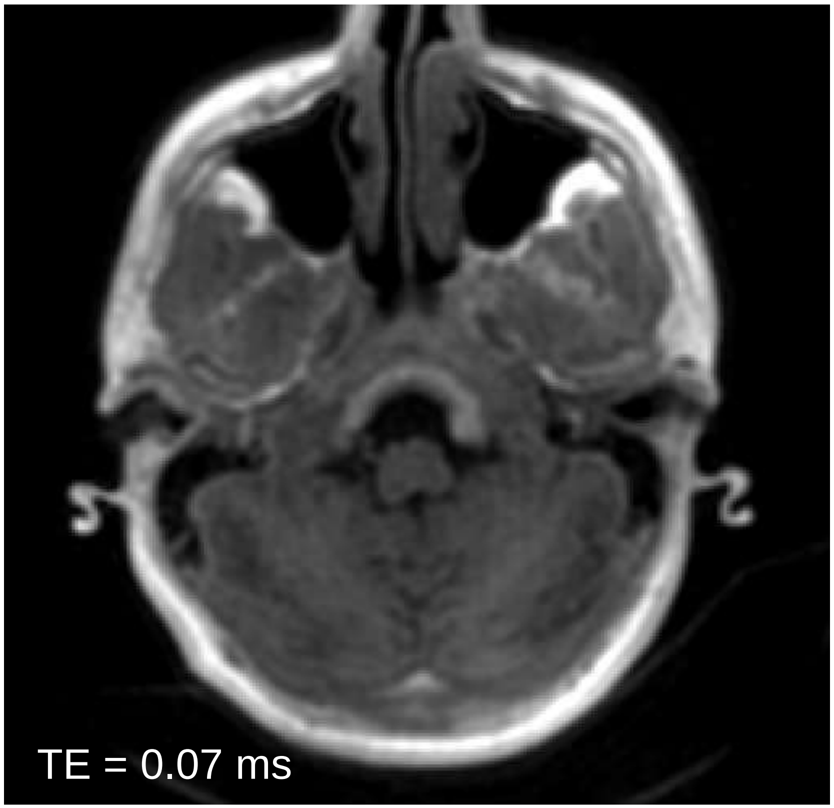
Estimating the tissue linear attenuation correction factors from MR is difficult.

A number of factors have to be considered for implementing an accurate MR-based attenuation correction method.

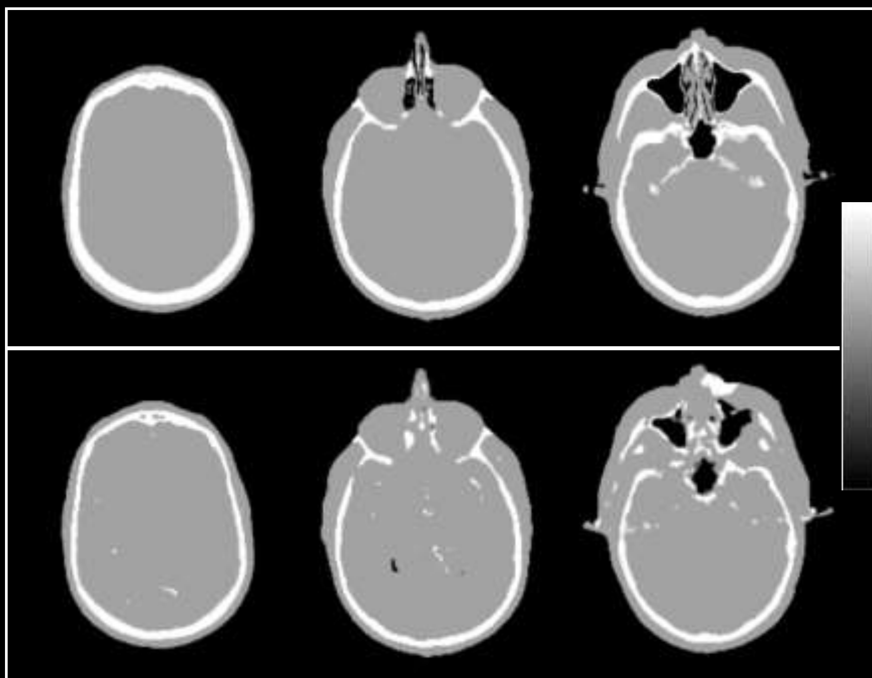
Separating the bone from air-filled cavities is the most challenging task using conventional MR sequences.



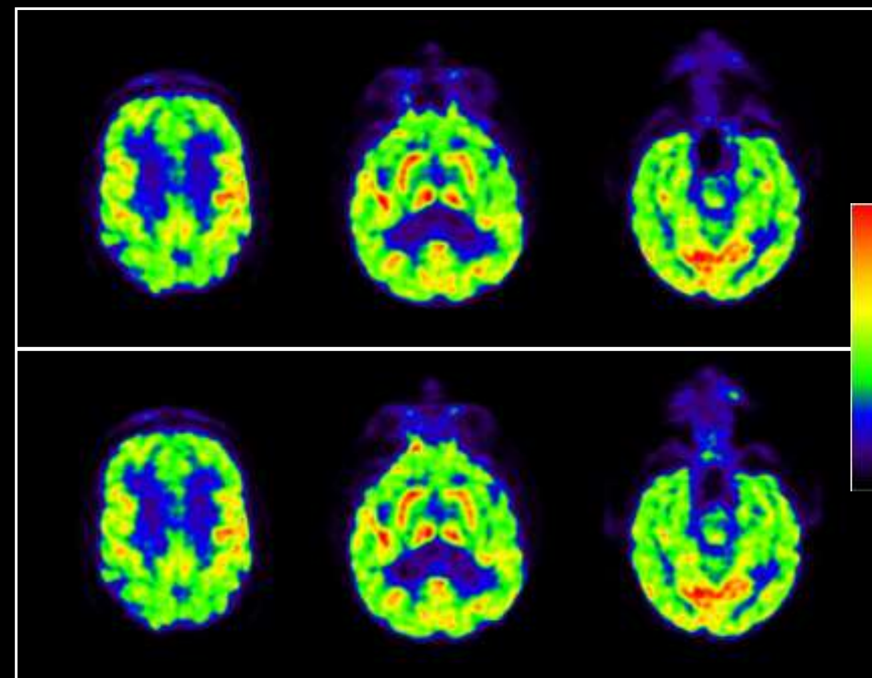
Ultra-short echo time (UTE) sequences can be used for bone imaging.



MR-based PET attenuation correction using DUTE data



ATTENUATION MAPS
$CT_{segmented}$ (top) and $DUTE_{segmented}$ (bottom)

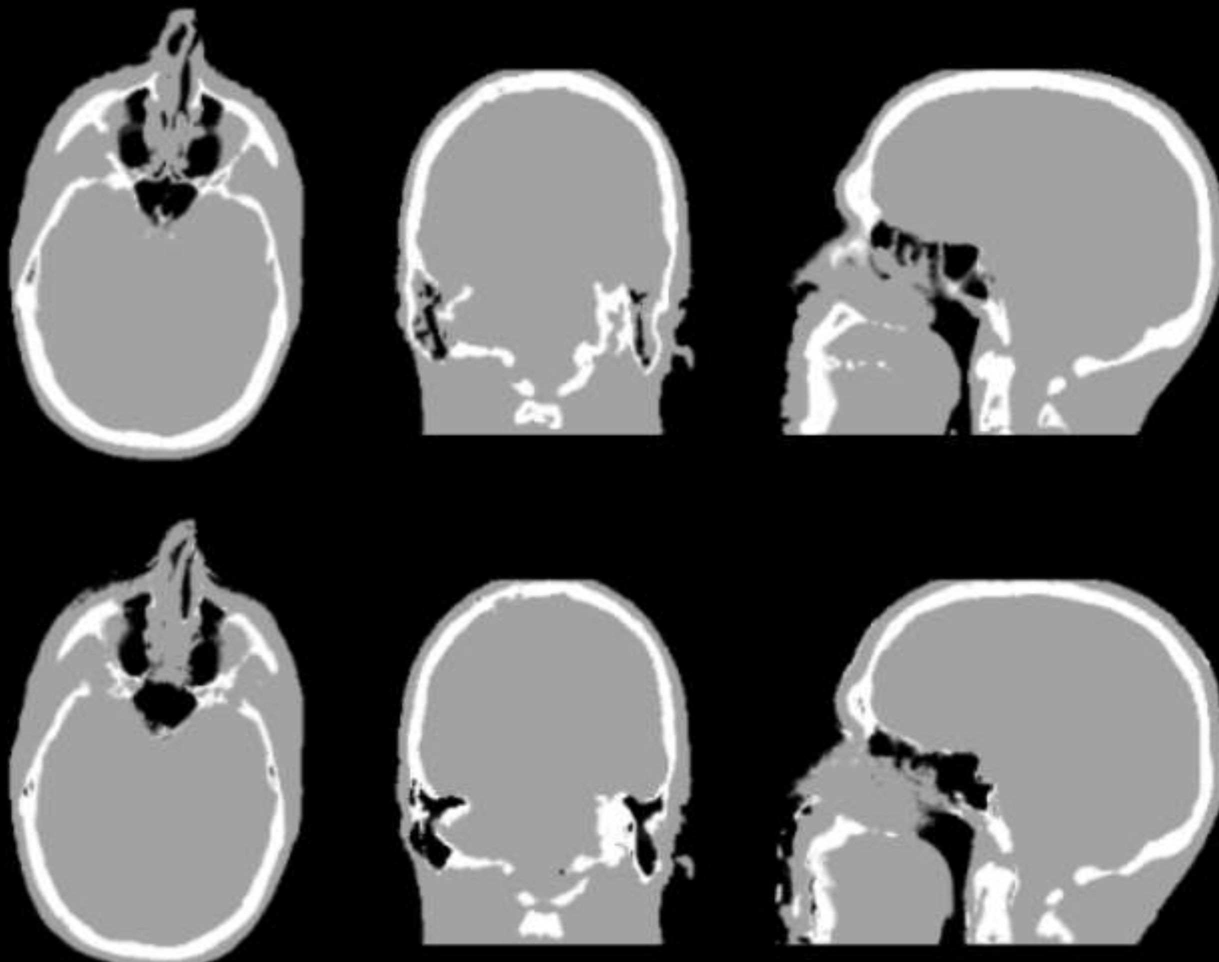


RECONSTRUCTED PET IMAGES
Attenuation correction factors derived from the $CT_{segmented}$ (top) and $DUTE_{segmented}$ (bottom).

(C. Catana et al, J Nucl Med, 2010)

Skull/soft tissue/air segmentation can be achieved from DUTE and MPRAGE data.

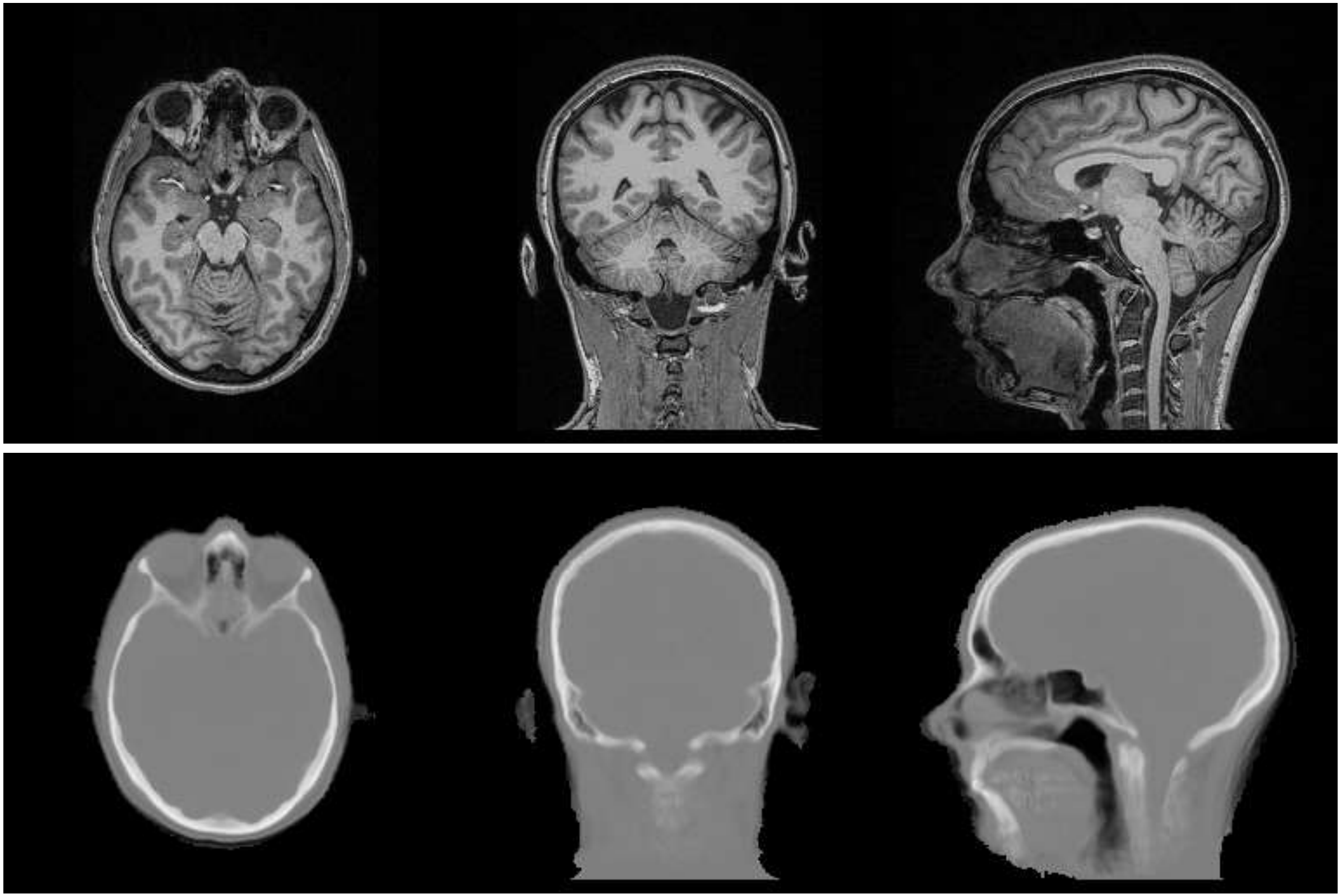
Segmented CT



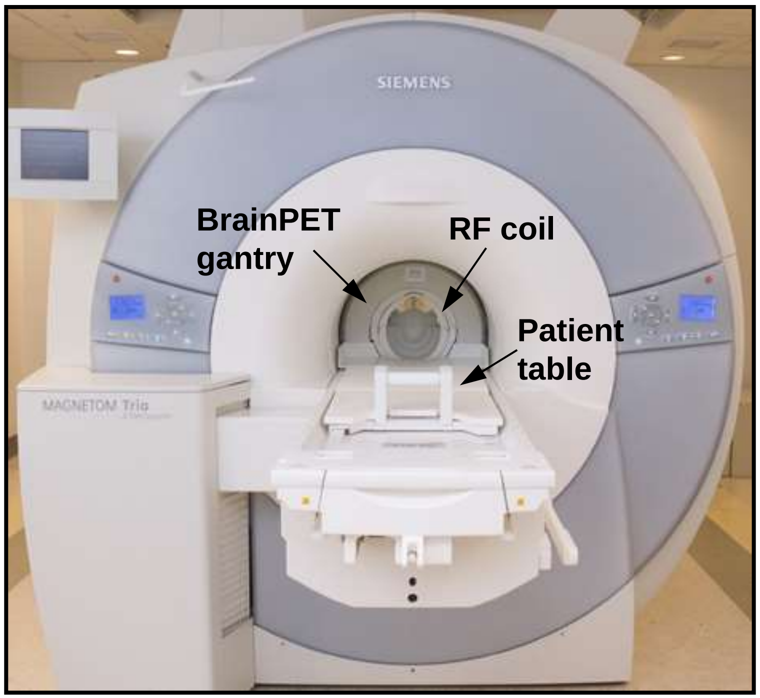
Atlas-T1-DUTE

Clare Poynton

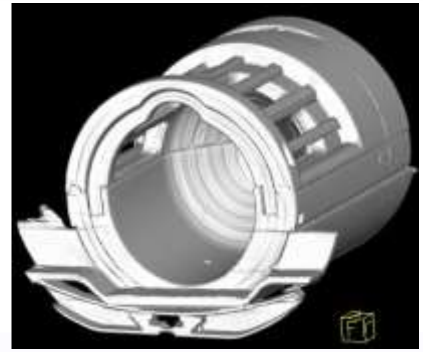
Atlas-based methods allow generation of *continuous-valued* attenuation maps.



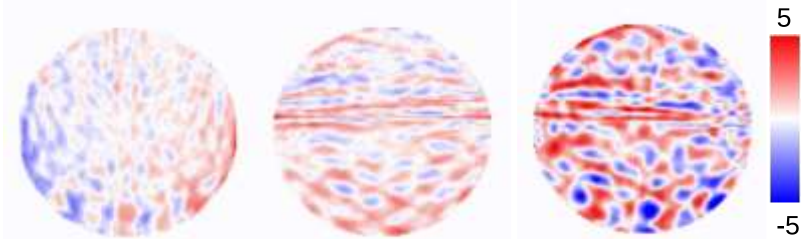
The attenuation caused by the RF coils has to be accounted for in an integrated scanner.



BrainPET prototype inside the 3T MR scanner (MGH installation)



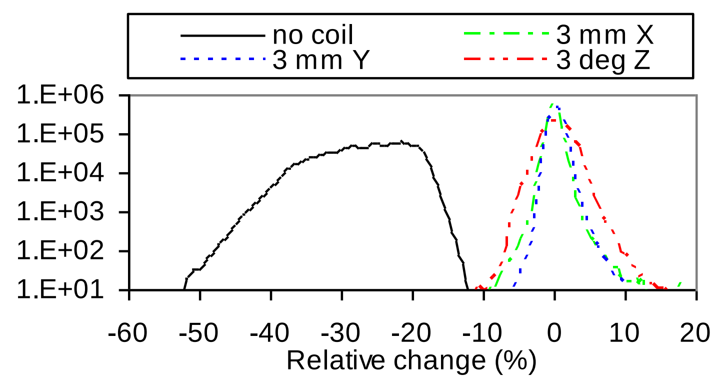
Coil attenuation ignored



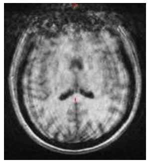
3 mm trans. along X axis

3 mm trans. along Y axis

3° rot. about Z axis



Relative change images and histograms

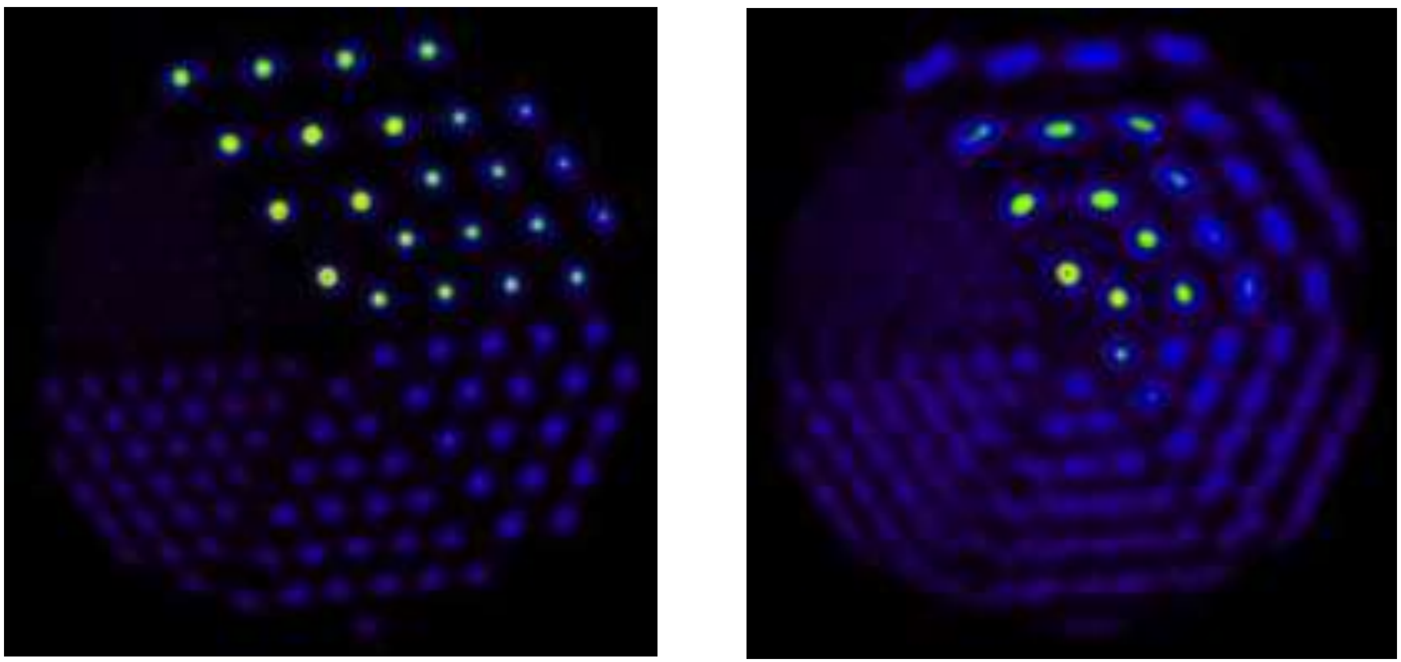


Motion is difficult to avoid in long PET studies.

image blurring/artifacts;

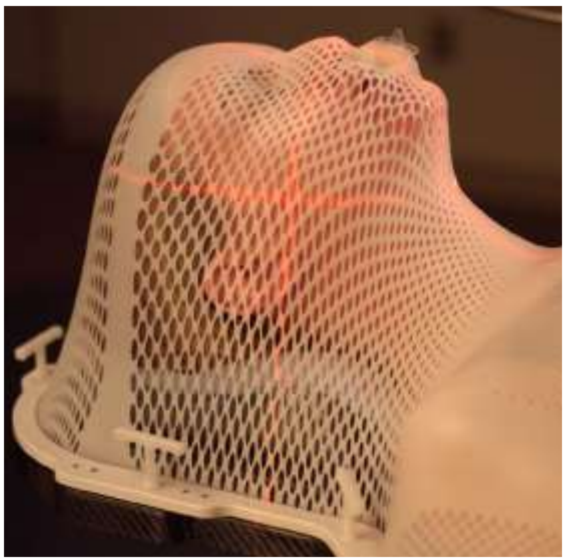
attenuation/emission data mismatch;

inaccurate quantification.

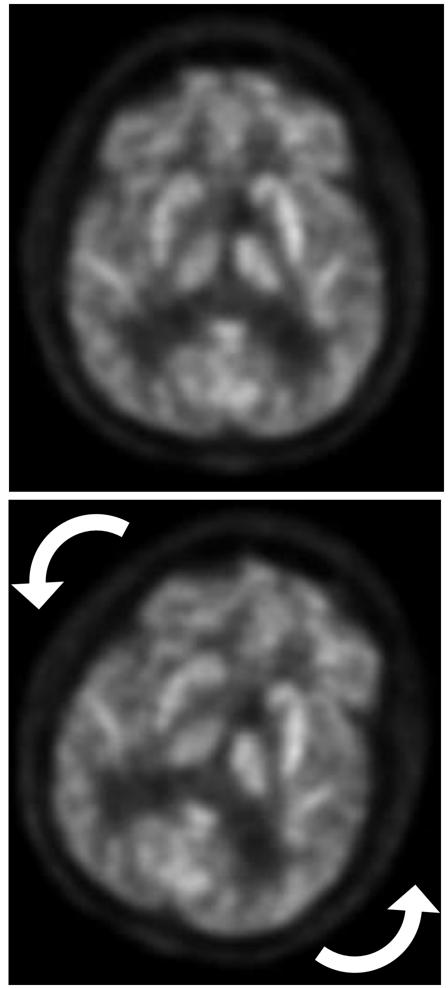


Spatial resolution “loss”

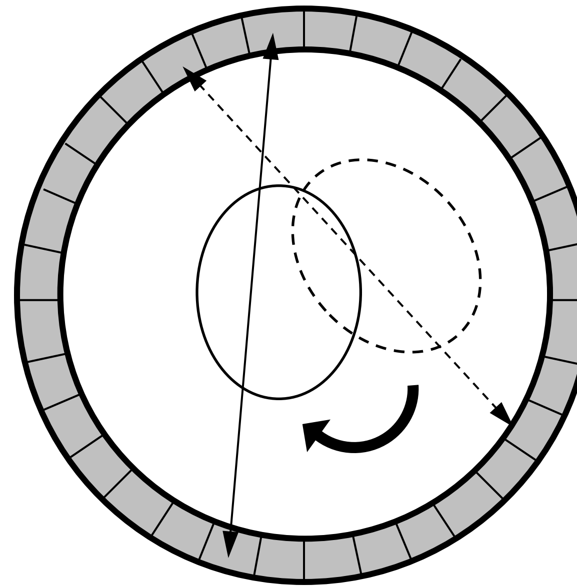
Various motion correction approaches have been investigated for neuroPET studies.



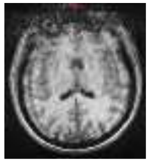
1. Eliminate head motion



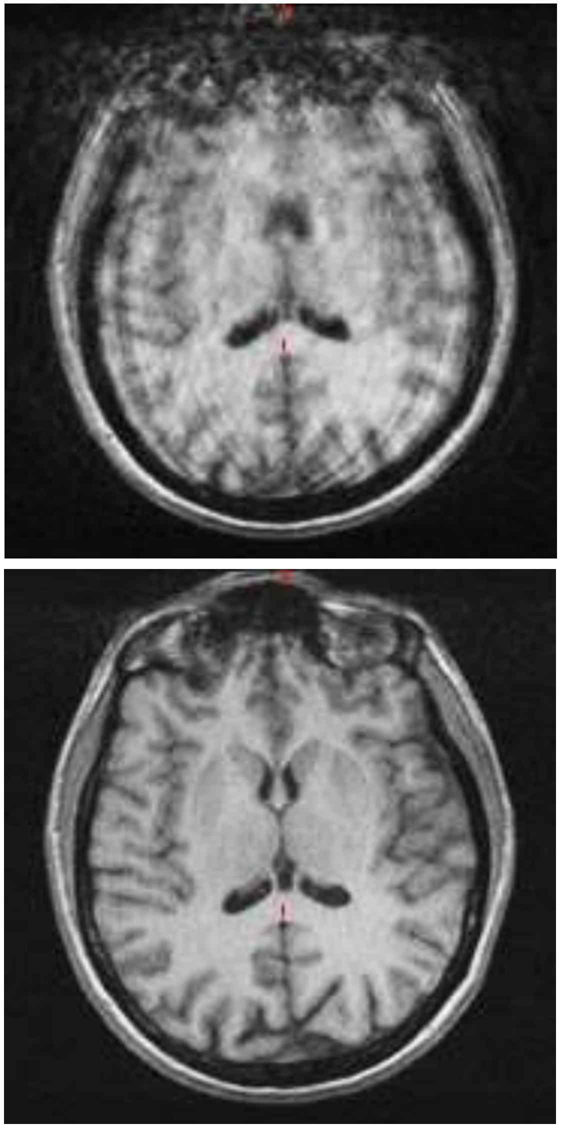
2. Inter-frame correction



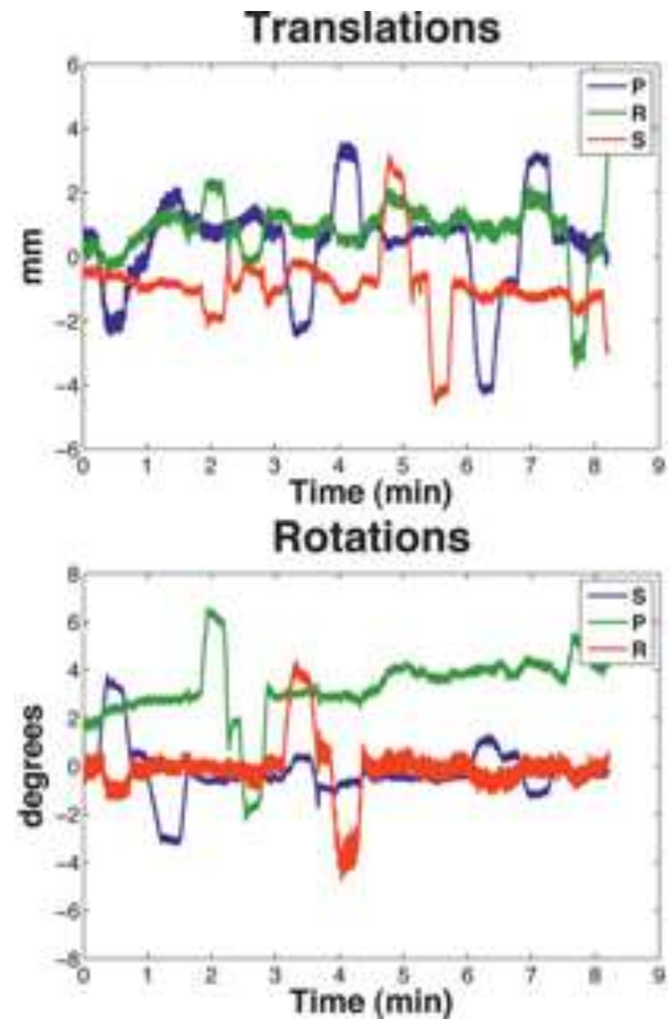
3. Event-by-event correction



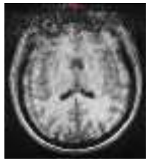
Navigators introduced in standard MR sequences provide high temporal resolution motion estimates.



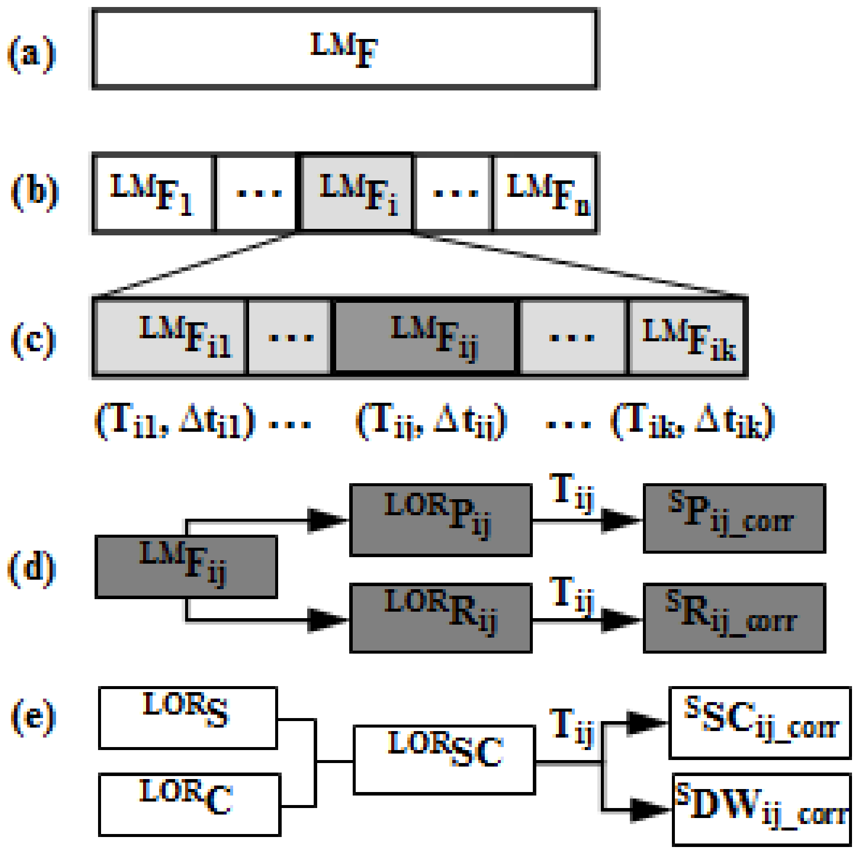
MR before and after MC



(Andre J.W. van der Kouwe et al, Magnetic Resonance in Medicine 2006; 56: 1019-1032)



Motion correction algorithm for dynamic studies on the BrainPET prototype.



(f)

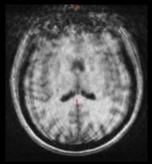
$$ {}^{S}P_{i\_corr} = \sum_{j=1}^{k} {}^{S}P_{ij\_corr} $$

$$ {}^{S}R_{i\_corr} = \sum_{j=1}^{k} {}^{S}R_{ij\_corr} $$

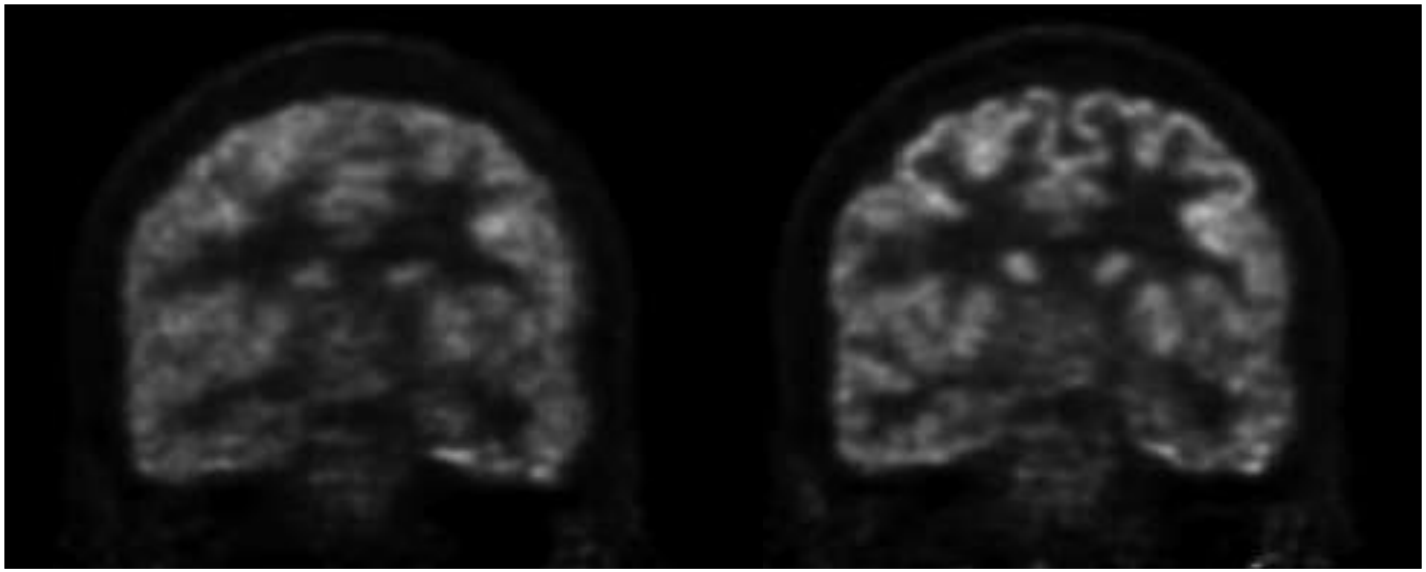
(g)

$$ \left. \begin{aligned} {}^{S}SC_{i\_corr} &= \sum_{j=1}^{k} \Delta t_{ij}\, {}^{S}SC_{ij\_corr} \\ {}^{S}DW_{i\_corr} &= \sum_{j=1}^{k} \Delta t_{ij}\, {}^{S}DW_{ij\_corr} \end{aligned} \right\} N_{i\_corr} $$

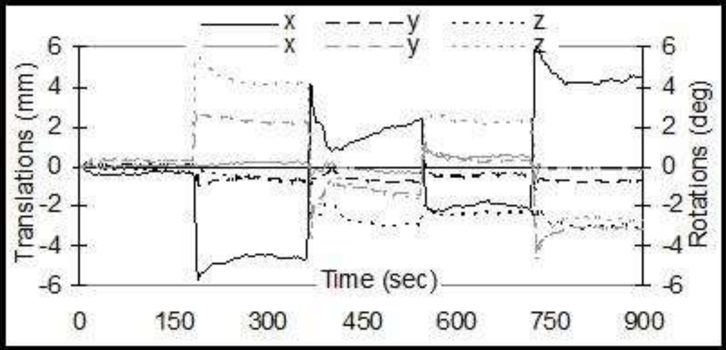
(C. Catana et al, JNM, 2011)



MR-derived motion estimates can be used to retrospectively correct the PET data.



PET data before (left) and after (right) MR-assisted motion correction



Motion estimates derived from EPI MR series every 3 seconds

- Healthy volunteer;
- ~5 mCi ^{18}FDG;
- Simultaneous MR-PET study;
- PET MC applied in LOR space.

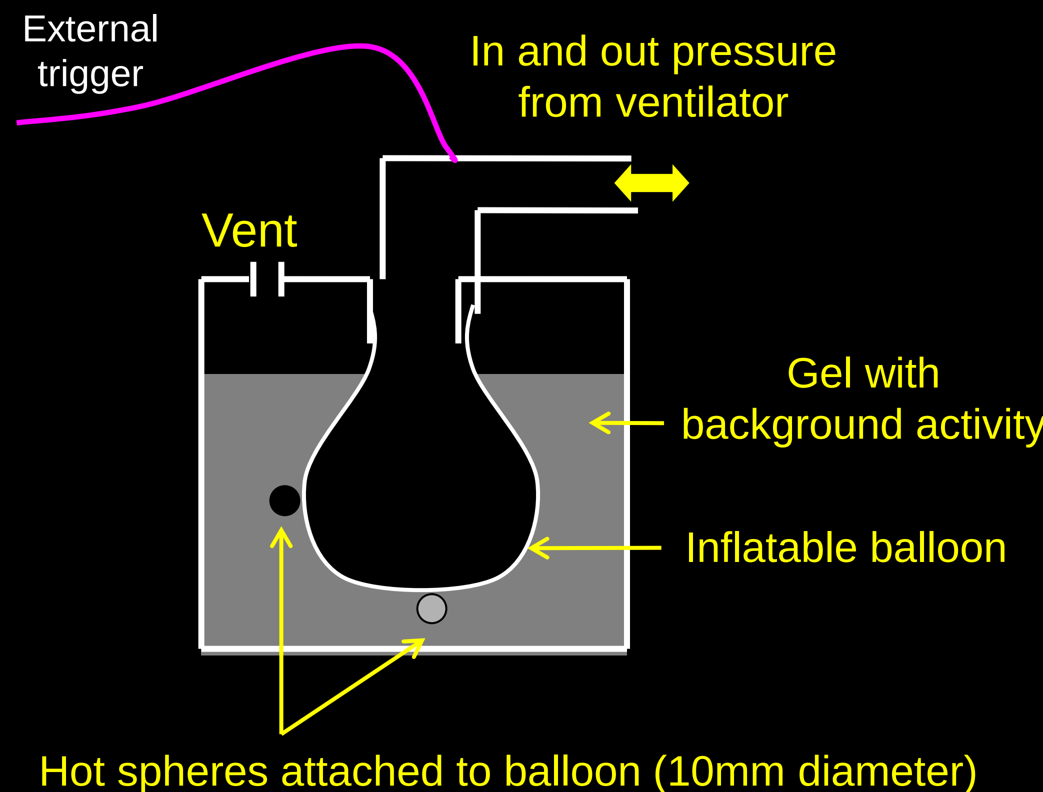
(C. Catana et al, JNM, 2011)

Methods: Phantom Study in PET-MR

Phantom

PET

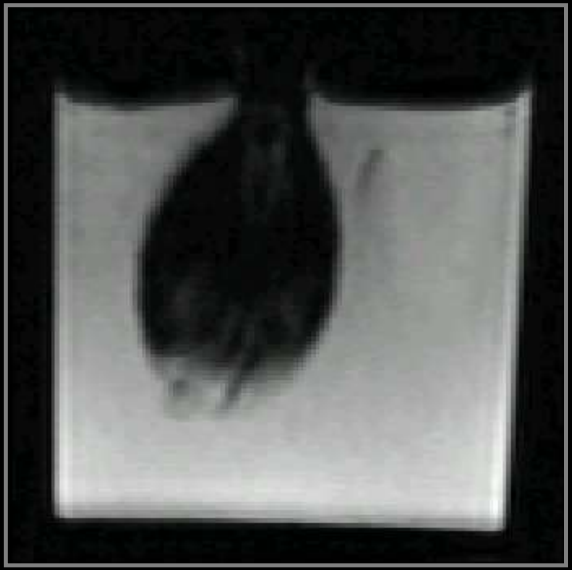
MR



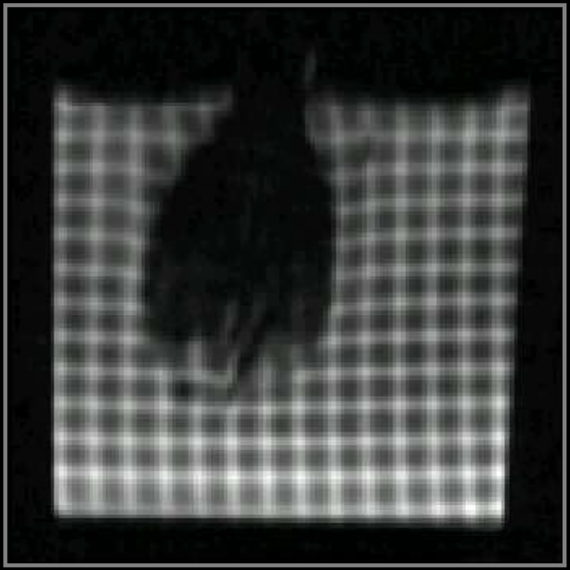
"Beating Phantom"

Guerin and El Fakhri, Med Phys 2011

Methods: Tagged MR



GRE sequence



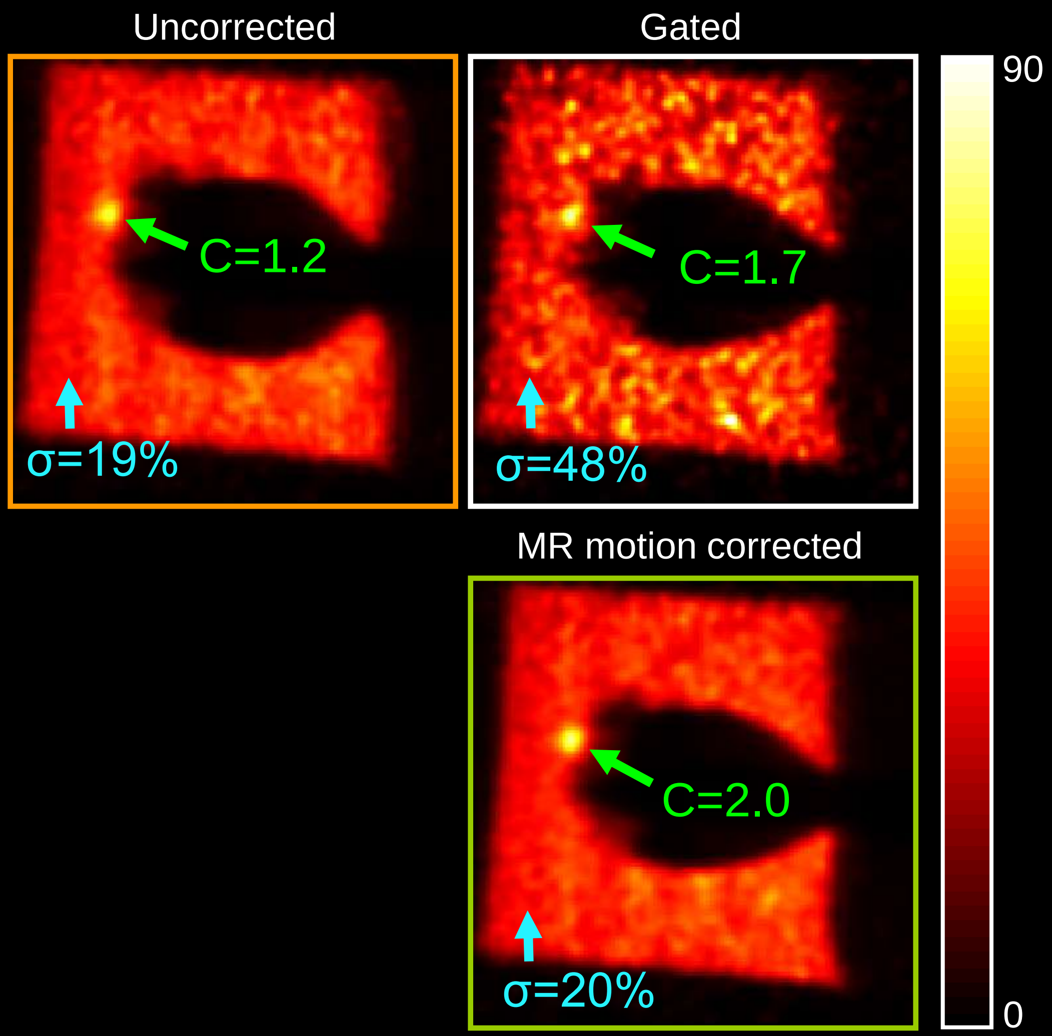
GRE sequence with tagging

Tagging patterns provide additional motion information.

Courtesy G. El Fakhri, MIPI, MGH

MIPI Molecular Imaging Physics & Instrumentation Lab

Phantom Results: Reconstruction



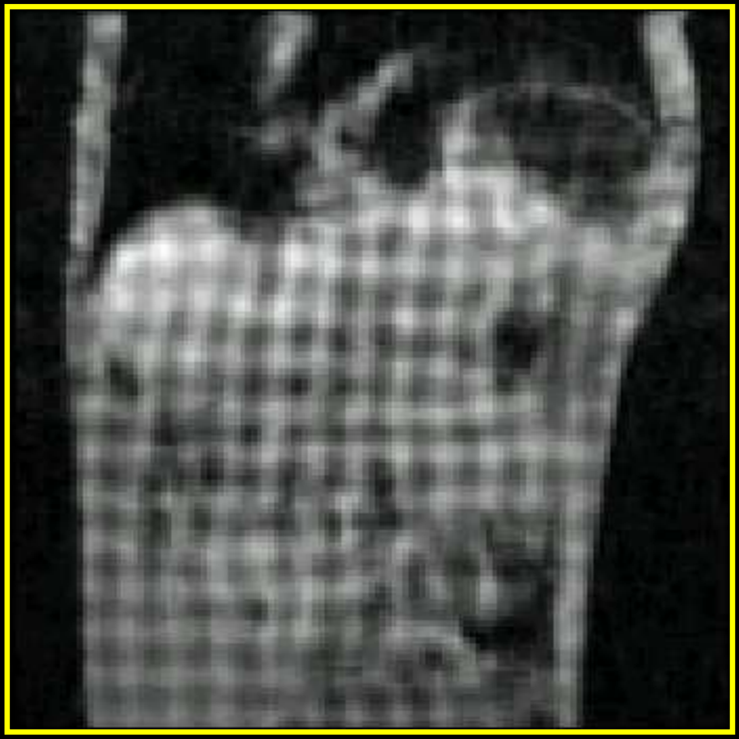
Sphere 2:
Diameter 10mm
Resolution 2mm each
Max motion ~3.0mm
(small motion)

Chun, El Fakhri, JNM 2011

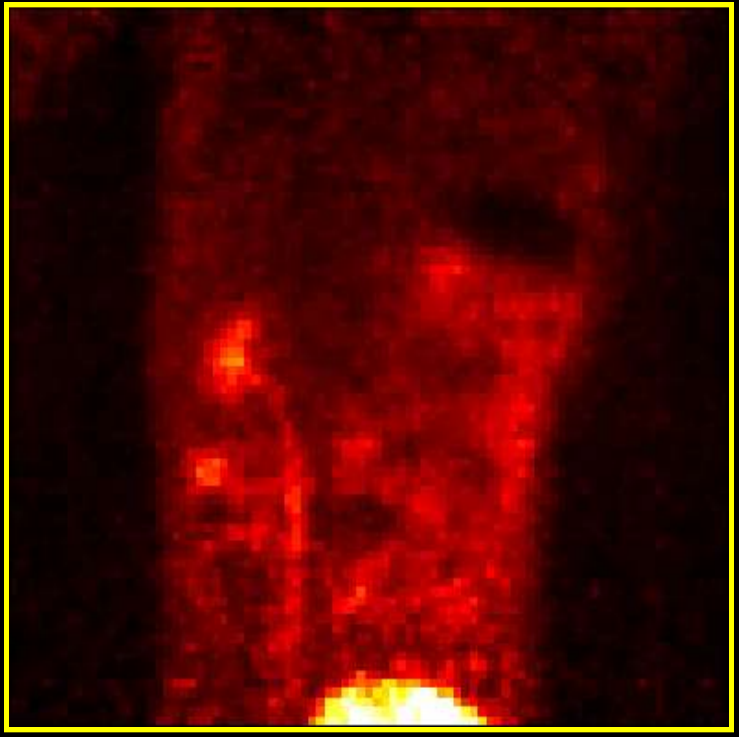
Primate Results

- Motion Correction with *Primate* in simultaneous PET-MR

Gated tagged MR



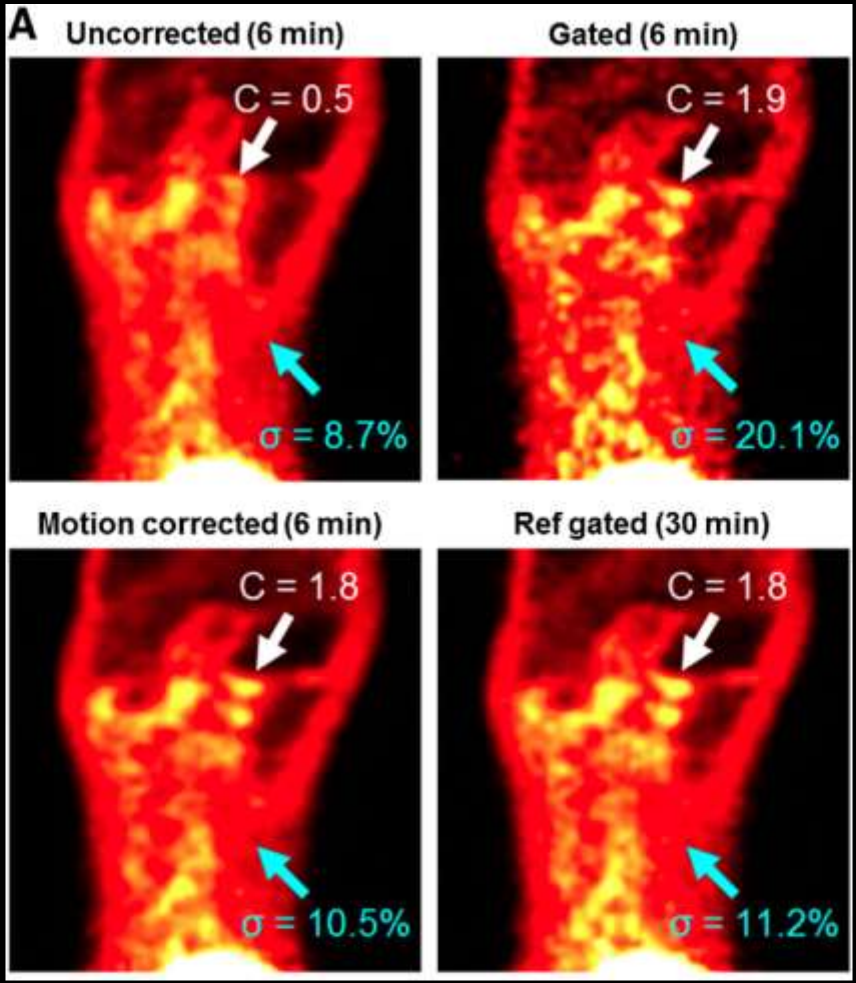
Gated PET

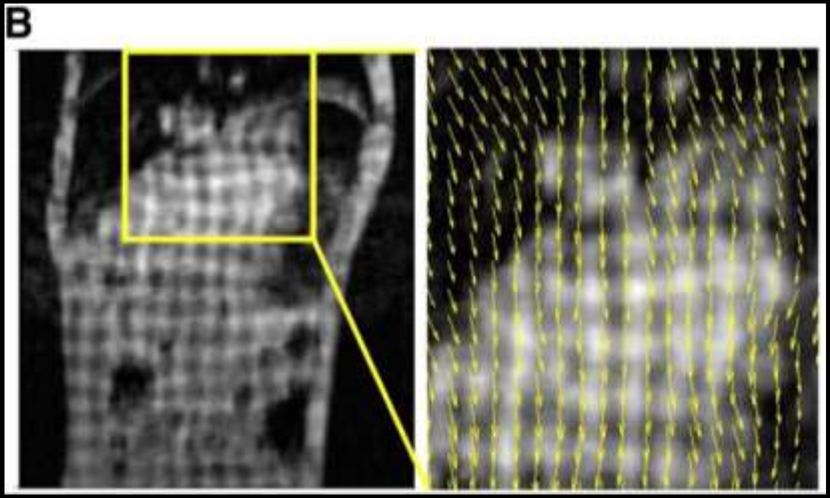


Chun, El Fakhri, JNM 2011

Molecular Imaging Physics & Instrumentation Lab

Primate Results

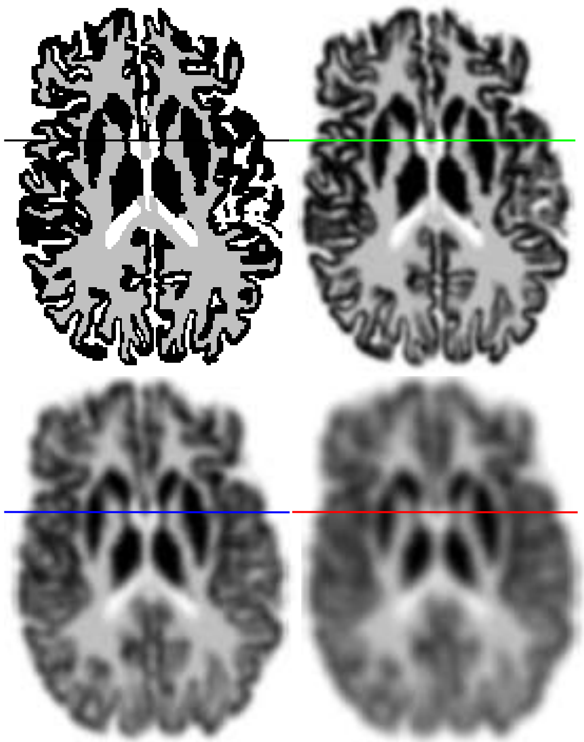


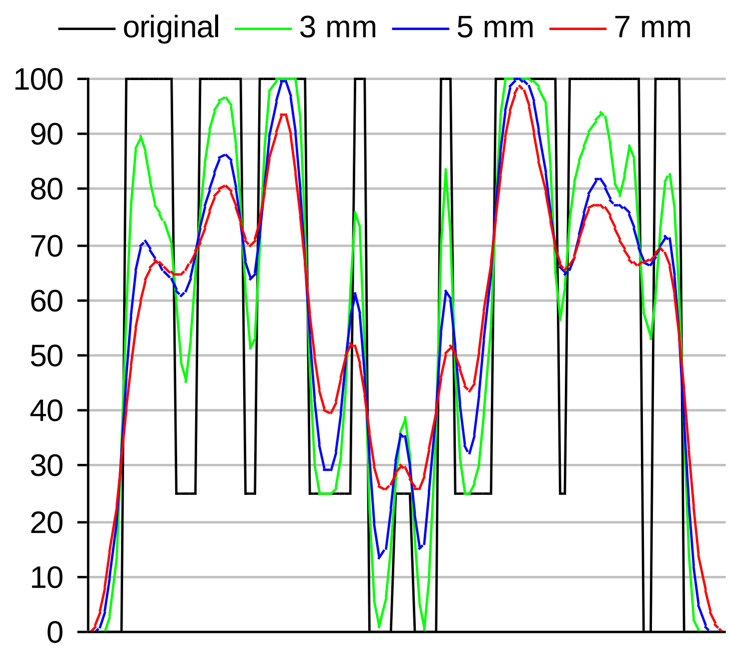


Chun et al. JNM 2012, 53(8):1284-1291

MIPI Molecular Imaging Physics & Instrumentation Lab

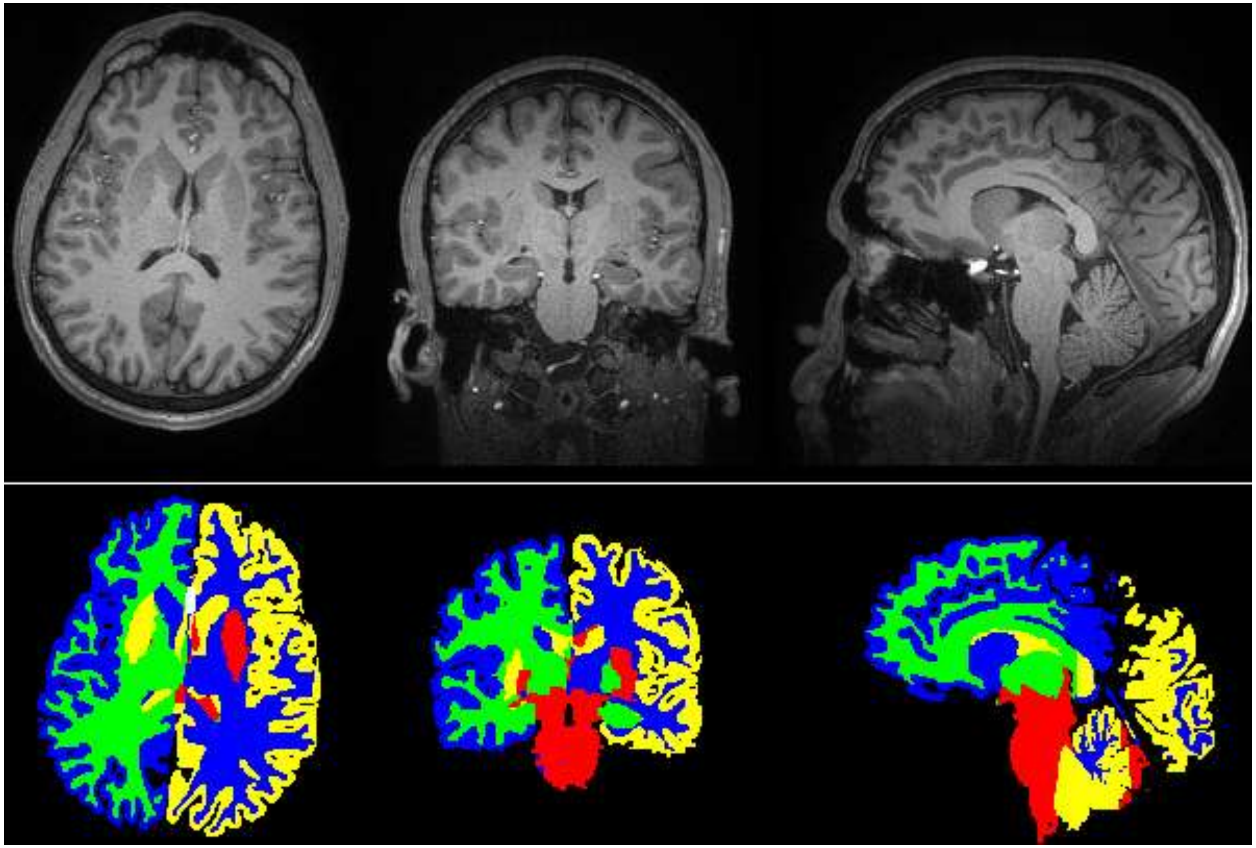
Partial volume effects (PVE) affect PET data quantification.





To account for PVEs, information about the size of the structures of interest and the spatially variant point spread function of the PET scanner is needed.

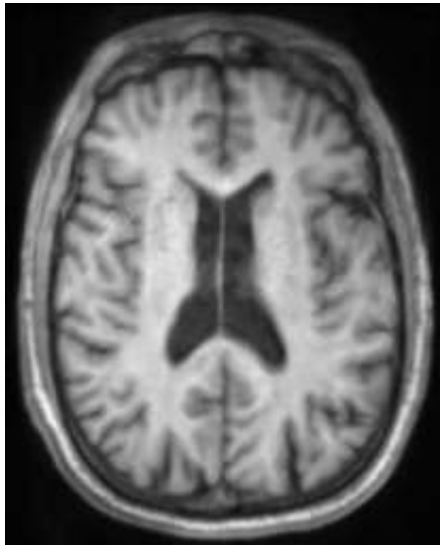
The high resolution morphological MRI data can be used for PET PVE correction.

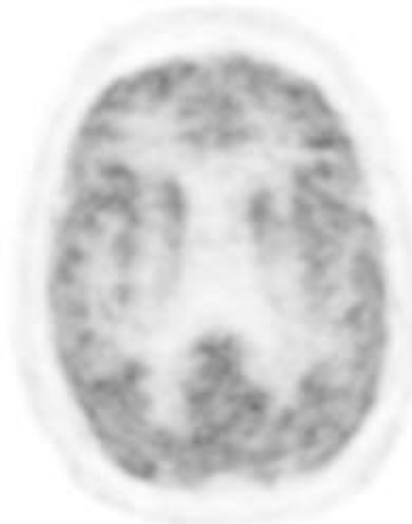


Automated brain structures segmentation from the MPRAGE data.

The high resolution morphological MRI data can be used for PET PVE correction.

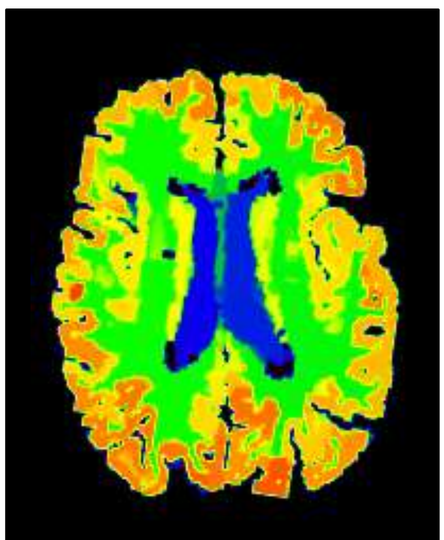
Morphological MR (ME-MPRAGE)

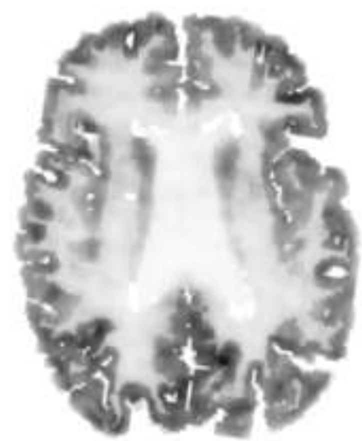




Original PET

Recovery coefficients

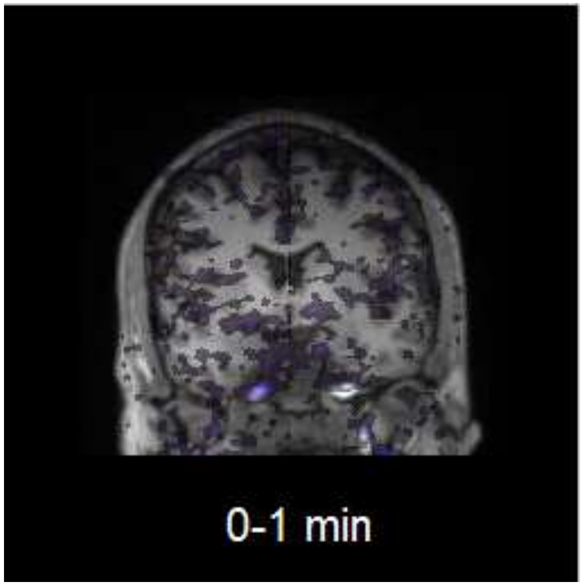




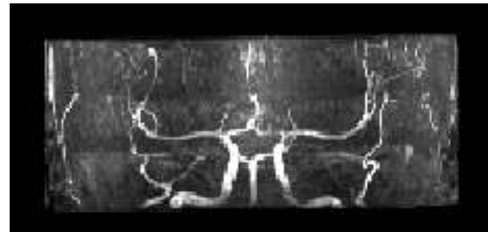
PET after regional PVE correction

Spencer Bowen, MGH

The non-invasive estimation of the radiotracer input function can be improved using MR data.

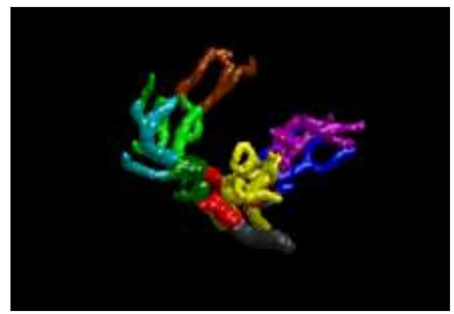


Dynamic PET frames

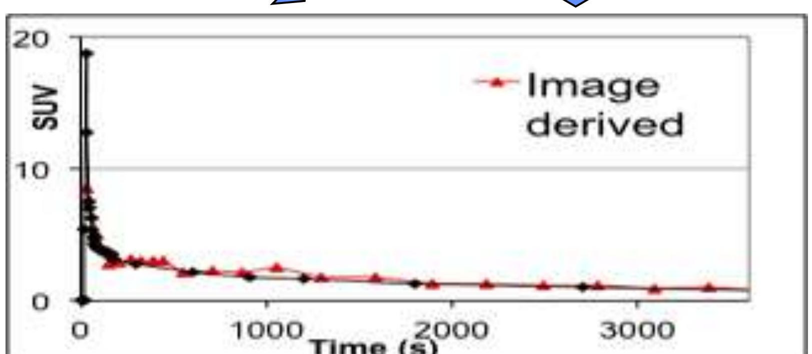


TOF MR

ME-MPRAGE

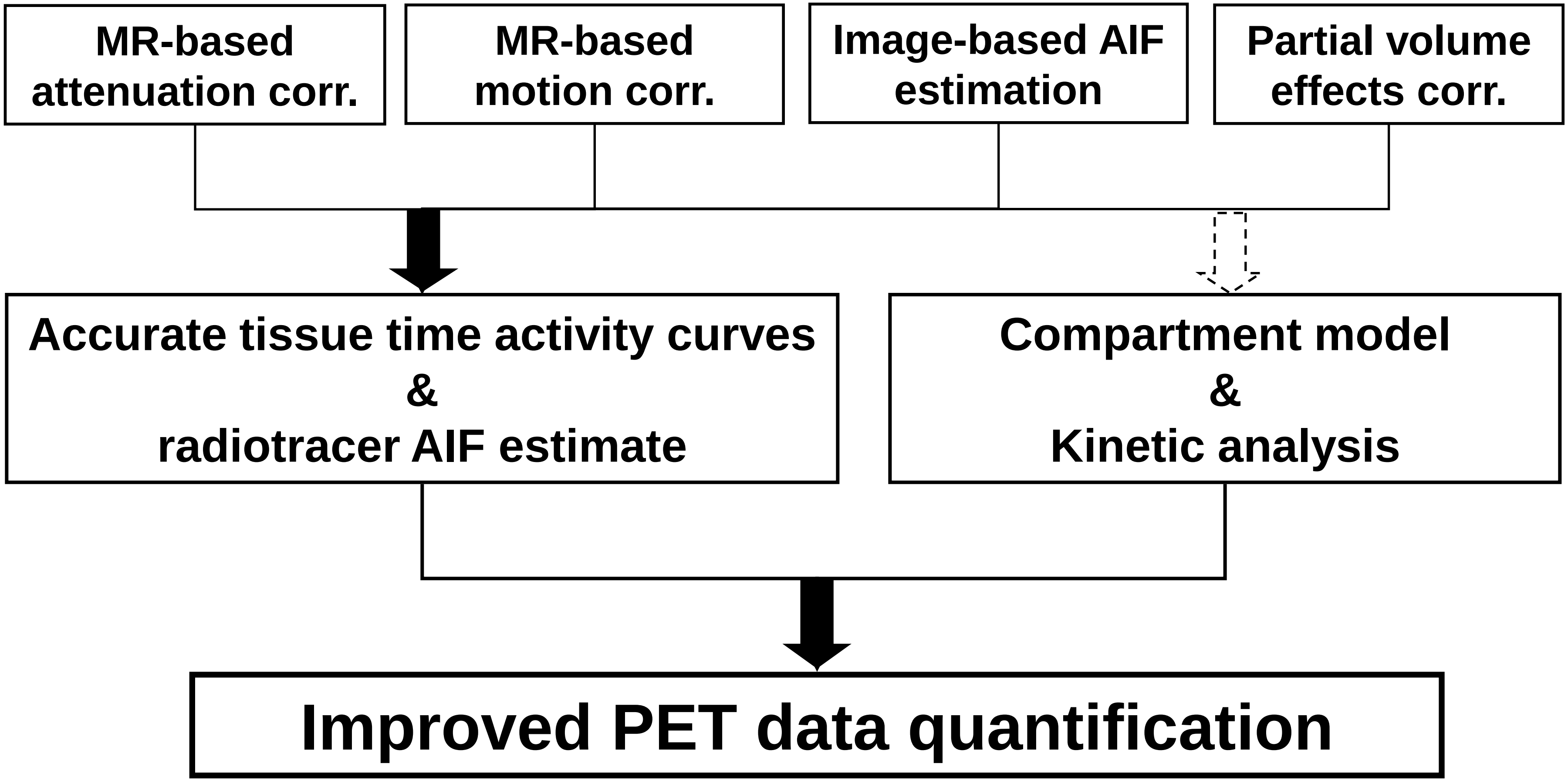


FDG AIF



Daniel Chonde, MGH

What MR can do for PET



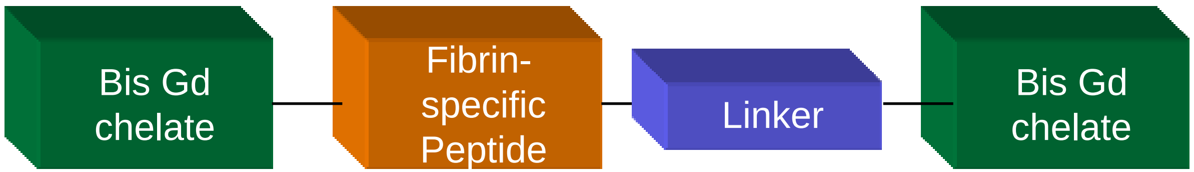
What PET can do for MR

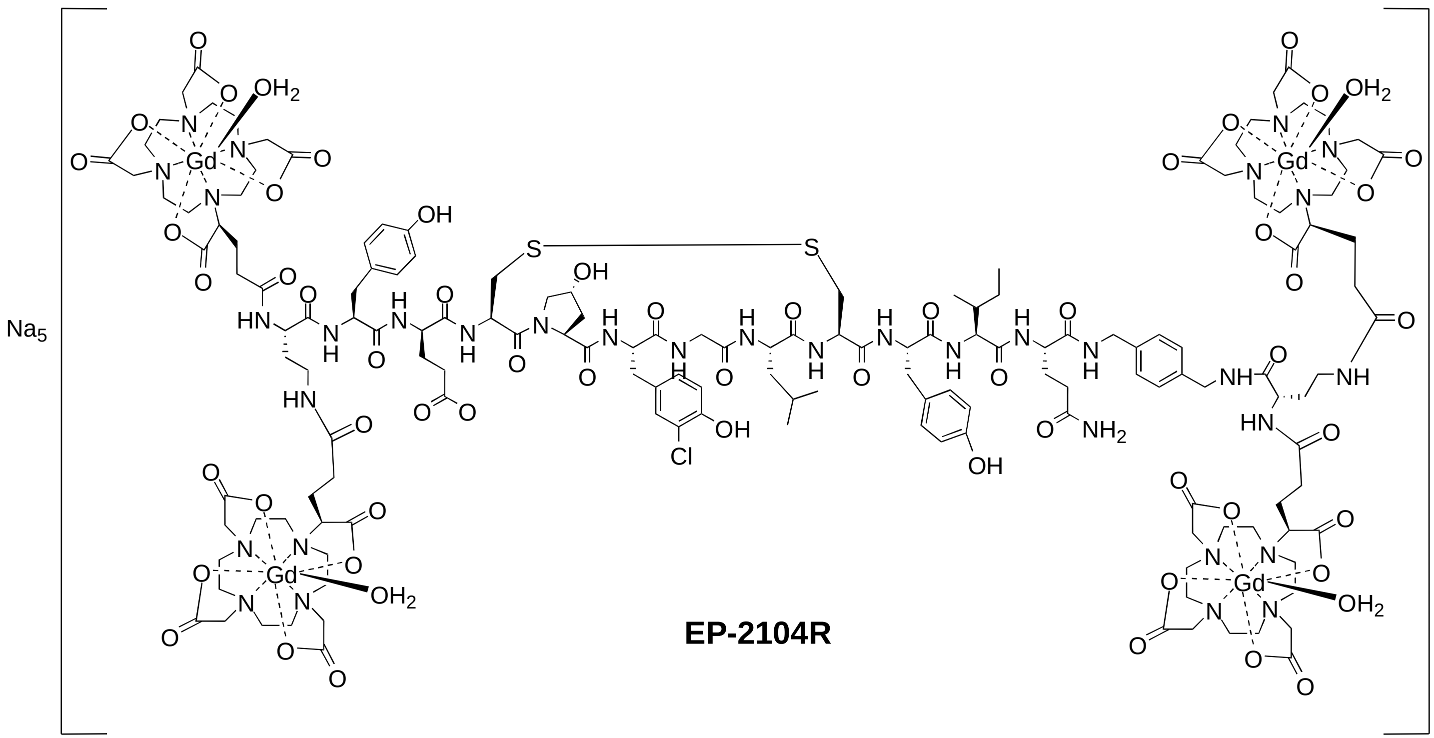
PET-guided MR imaging

In-vivo quantification of “smart” MR probes

Techniques cross-calibration and validation

Fibrin Targeted Gd-based Contrast Agent





Improved fibrin affinity. High relaxivity: 4 Gd + protein binding. No metabolism issues. Minimal Gd retention.

Overoye-Chan et al., J Am Chem Soc 2008, 130:6025-39

Embolic Stroke Model

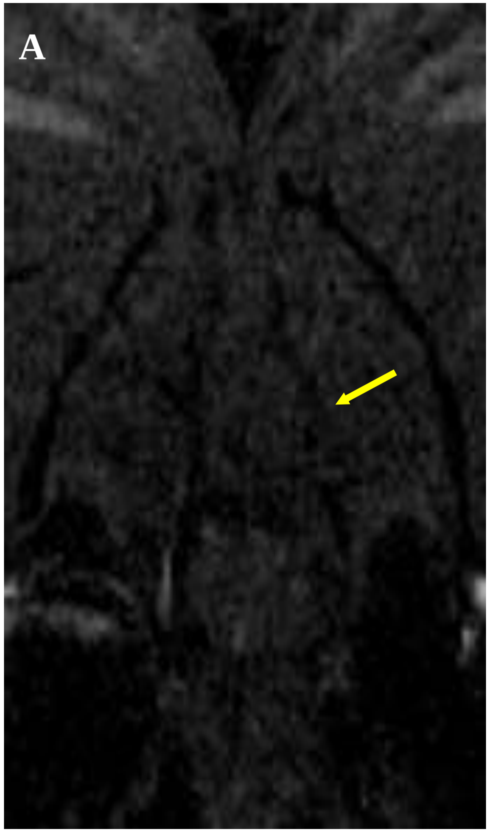
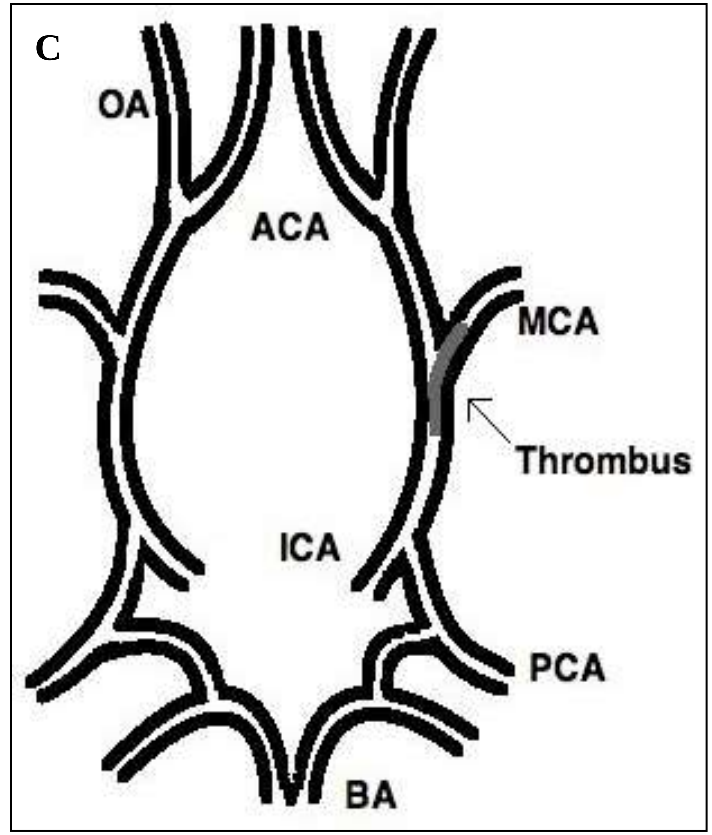


Image pre contrast agent

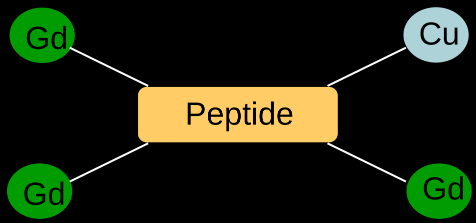
Image post contrast agent



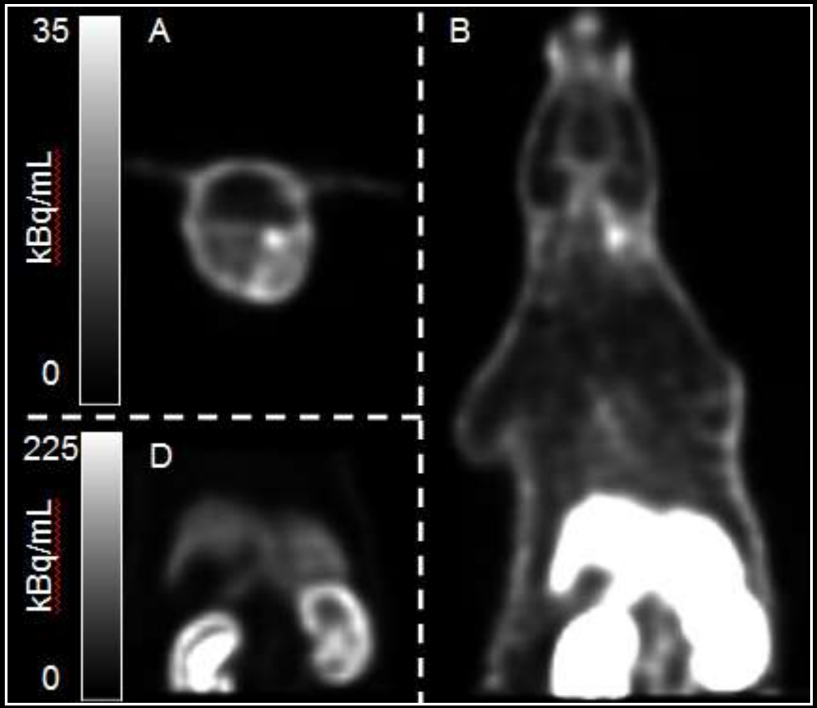
Arterial anatomy

(Ritika Uppal, Ilknur Ay, Peter Caravan)

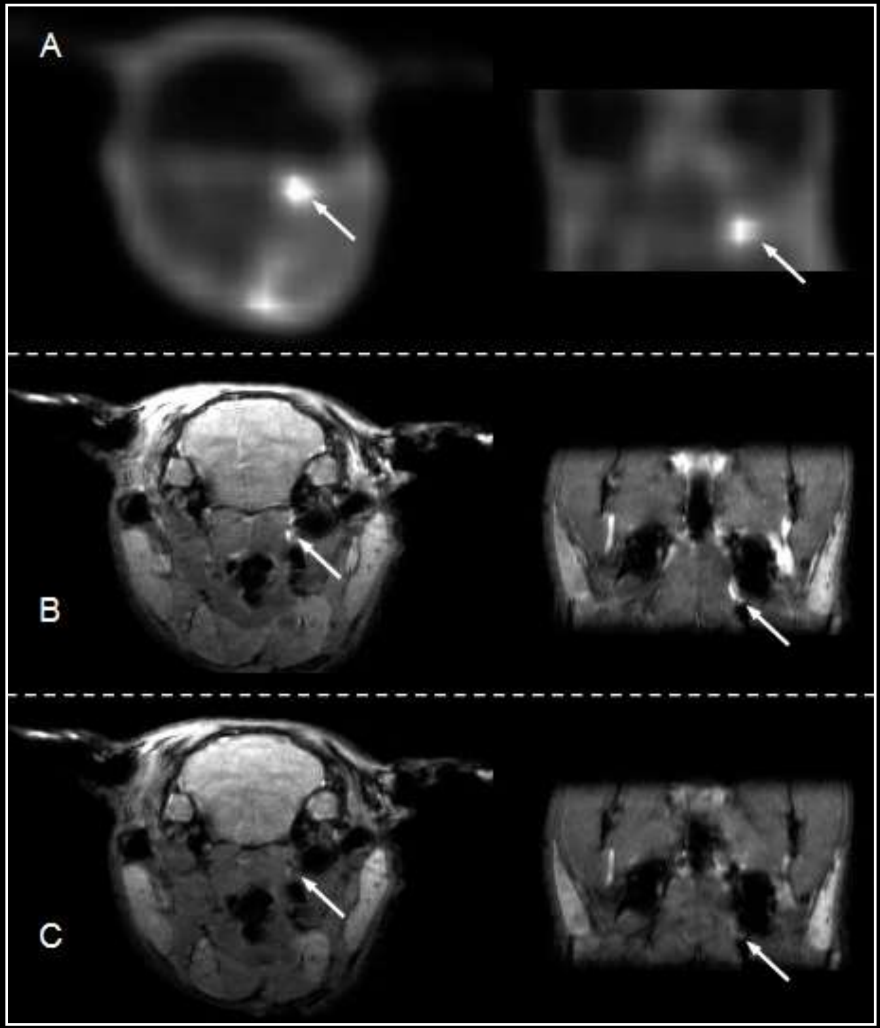
High sensitivity PET can guide the high resolution MR study.



Fibrin-targeted MR-PET Probe



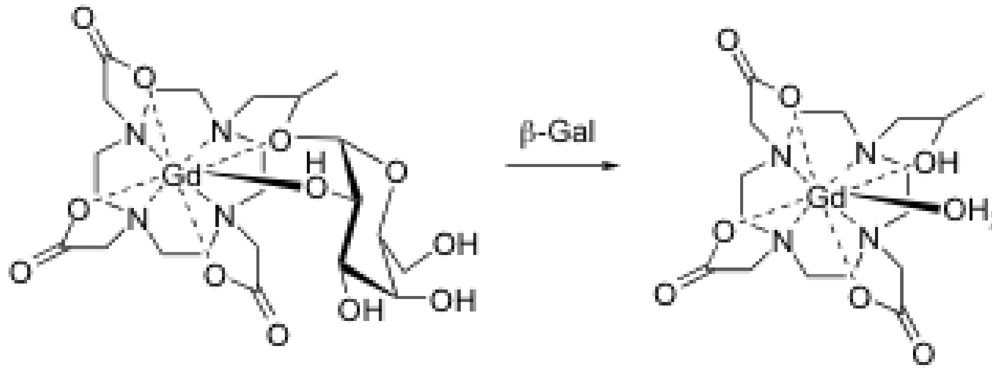
Whole-body PET "screening"



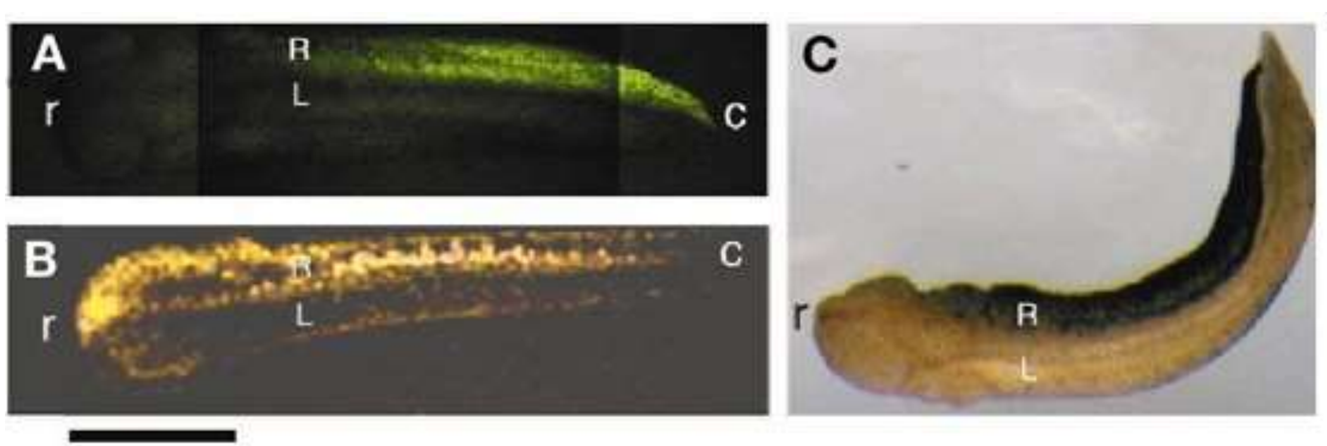
Uppal, Caravan, Radiology, 2011;258(3):812-20

Focused MR study

Relaxivity is sensitive to many molecular factors that can be modulated to induce an MR signal.



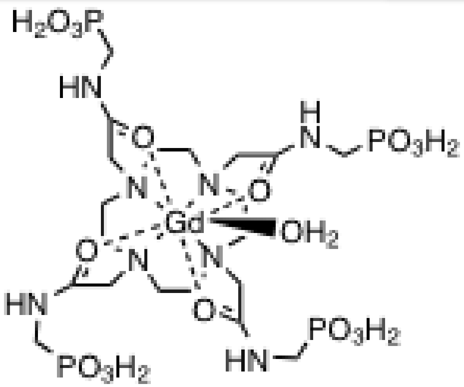
Enzyme activation → change property of contrast agent



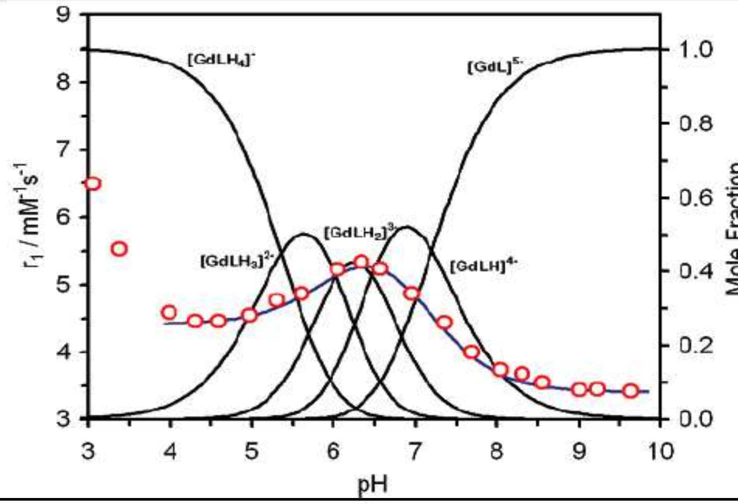
A) GFP mRNA injection in R; B) EgadMe, **β**-gal injection in R; C) β-gal staining

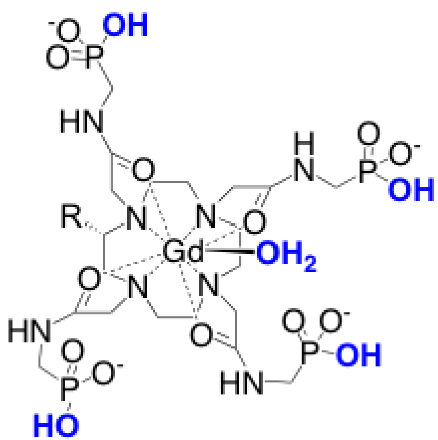
(Louie, Meade et al, Nature Biotech, 2000)

pH-responsive “smart” MR probe

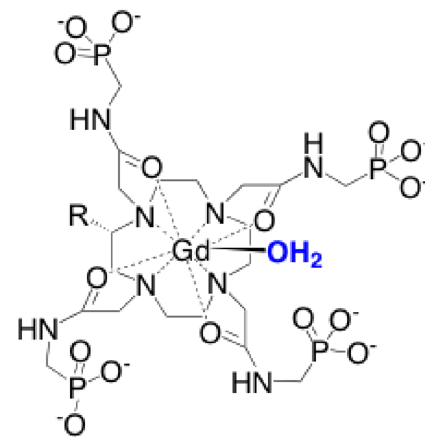


GdDOTA-4AmP





Low pH: more exchangeable protons (blue)
proton exchange rate ideal



High pH: fewer exchangeable protons (blue)
proton exchange too fast

(Kalman, Sherry, Caravan et al, Inorg Chem 2007, 46,5260;
Ali, Sherry, Caravan et al, Chem Eur J 2008, 14:7250-8)

The MR signal depends on both relaxivity and contrast agent concentration.

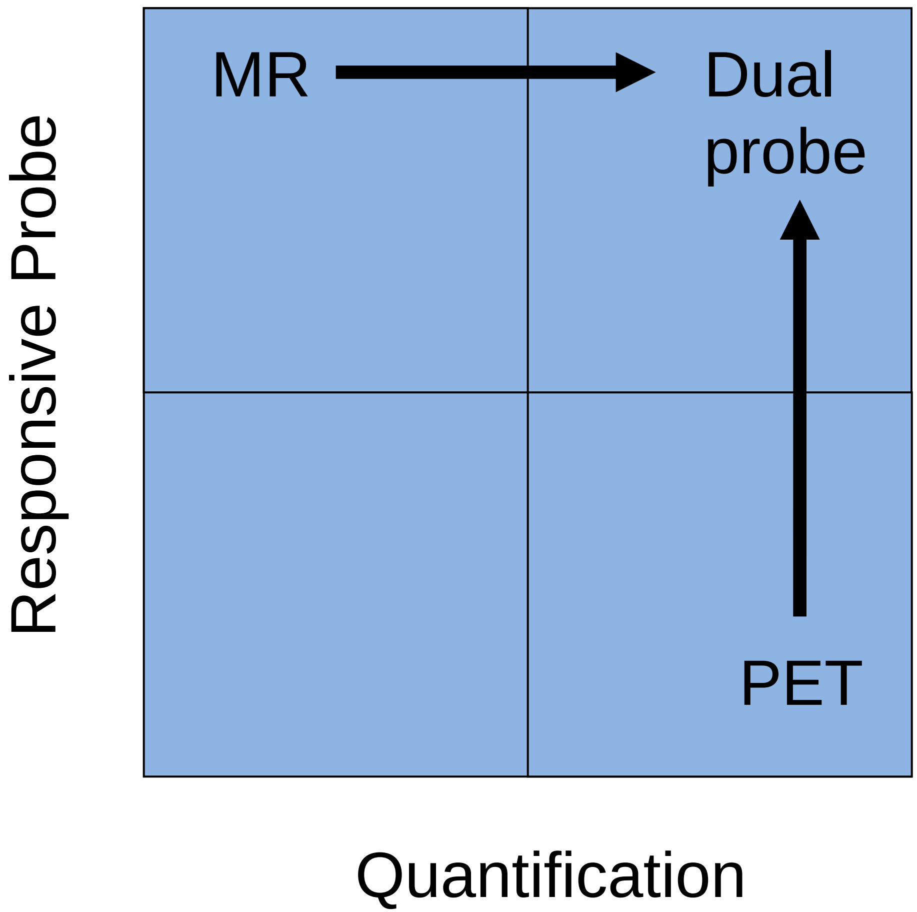
Two unknowns, one measurement

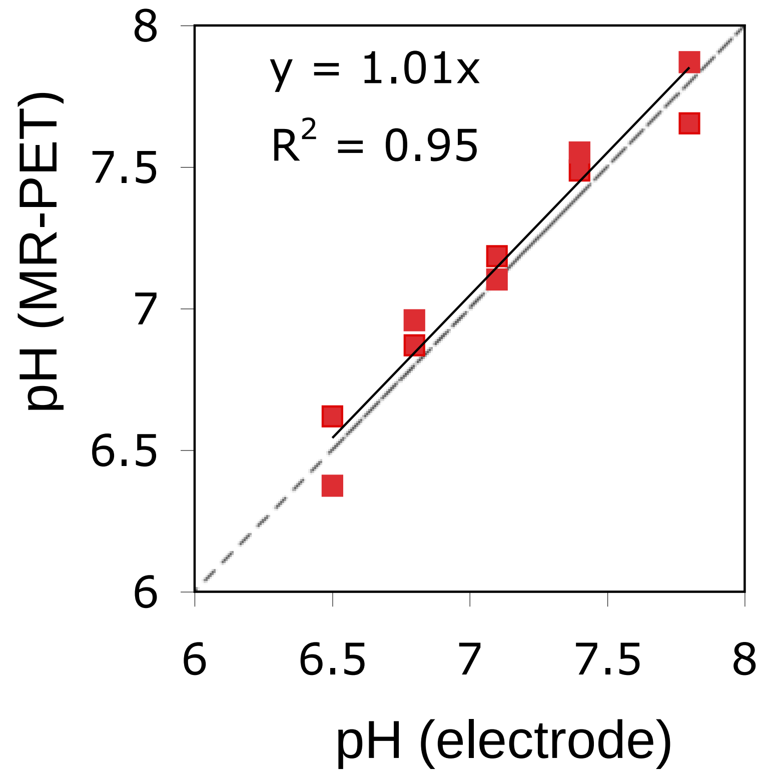
$$\frac{1}{T_1} = r_1[Gd] + \frac{1}{T_1^0}$$

relaxivity

contrast agent concentration

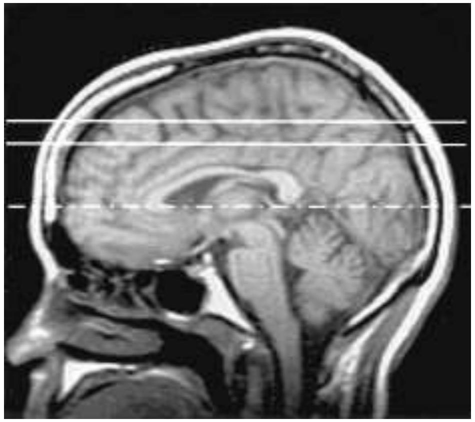
A “smart” dual-modal MR-PET agent can quantitatively and non-invasively measure pH.



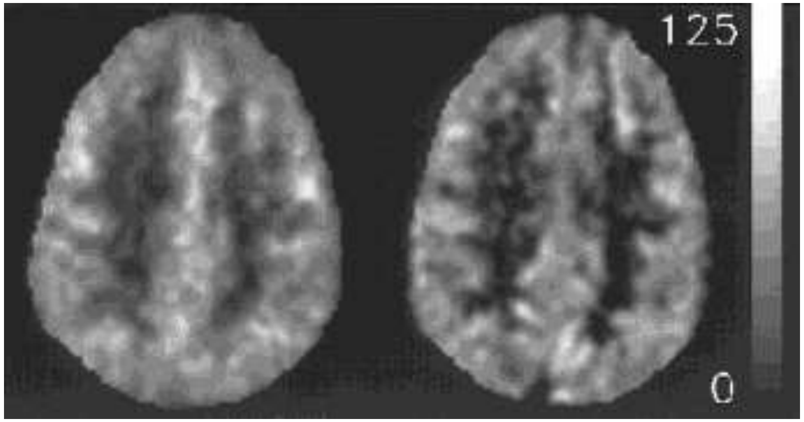


(L. Frullano, C. Catana, T. Benner, A. Sherry, P. Caravan. Angew. Chem. Int. Ed. 2010; 49:2382-4)

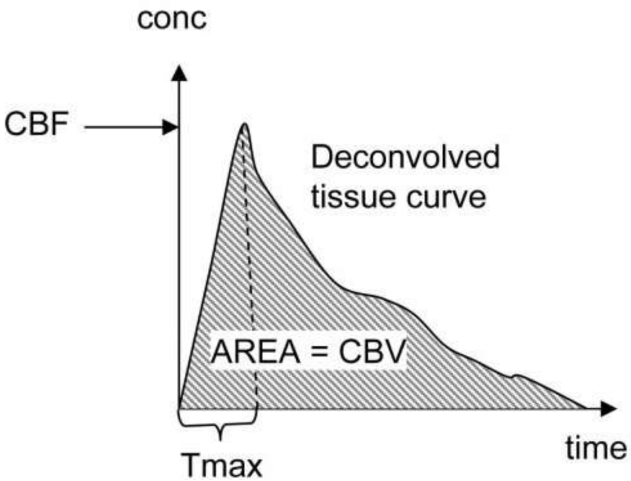
Cross-validate PET and MRI cerebral perfusion measurements.



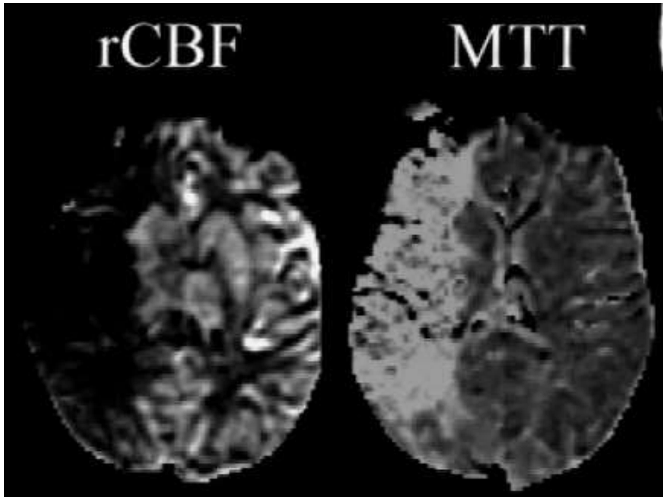
Arterial spin labeling technique



[O^{15}]H_2O PET and steady-state ASL MR
(F.Q.Ye et al. MRM 2000; 44:450-456)

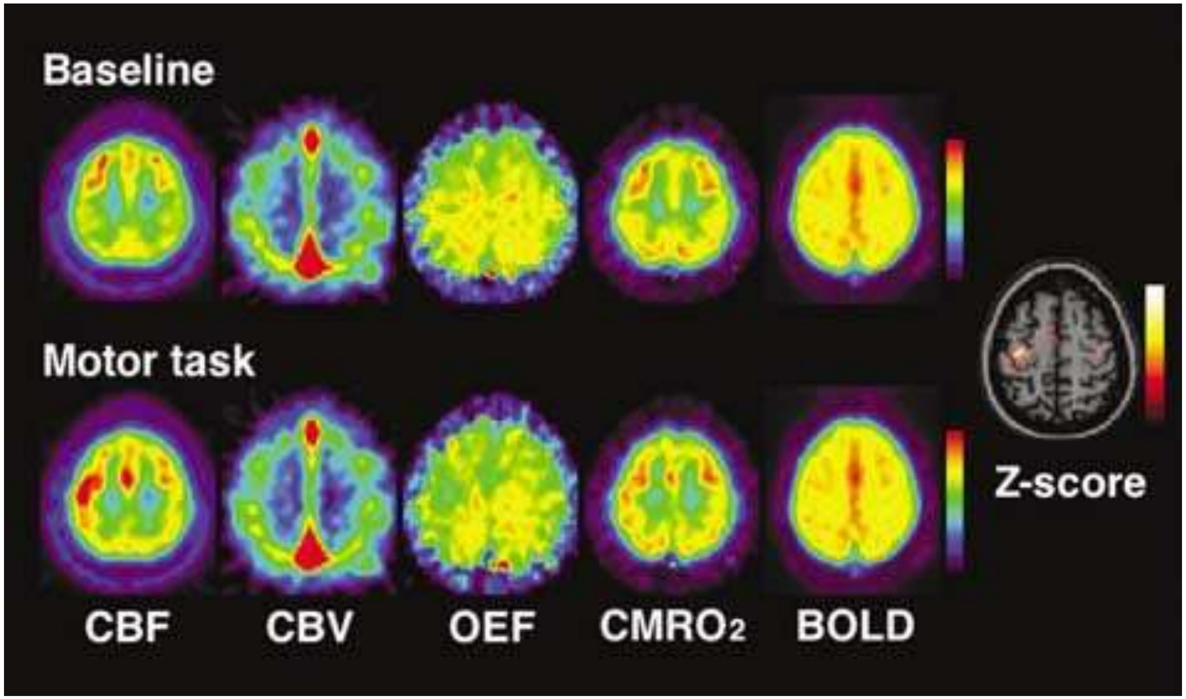


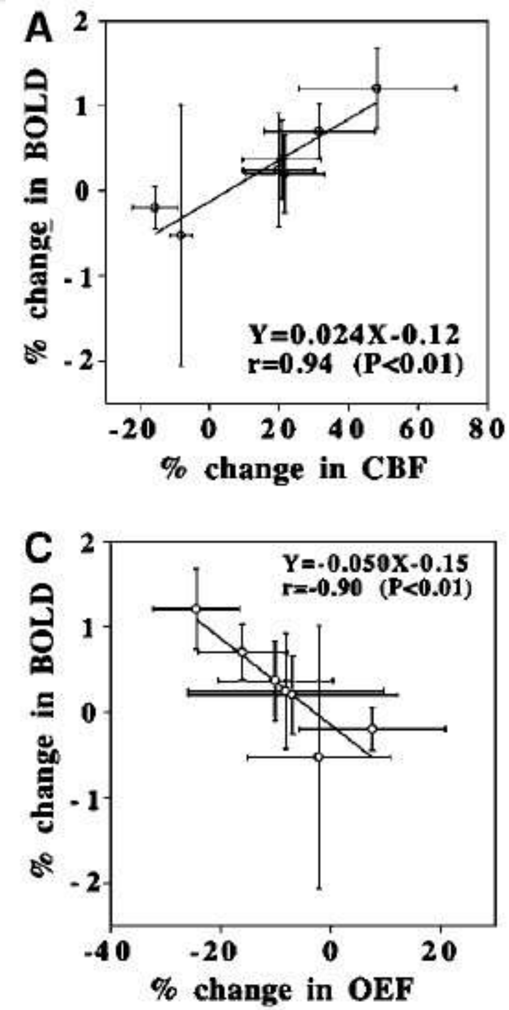
Bolus tracking technique
(L Ostergaard. JMRI 2005, 22:710-7)



(Y Ozsunar and AG Sorensen et al;
Topics in MRI 2000; 11(5): 259-272)

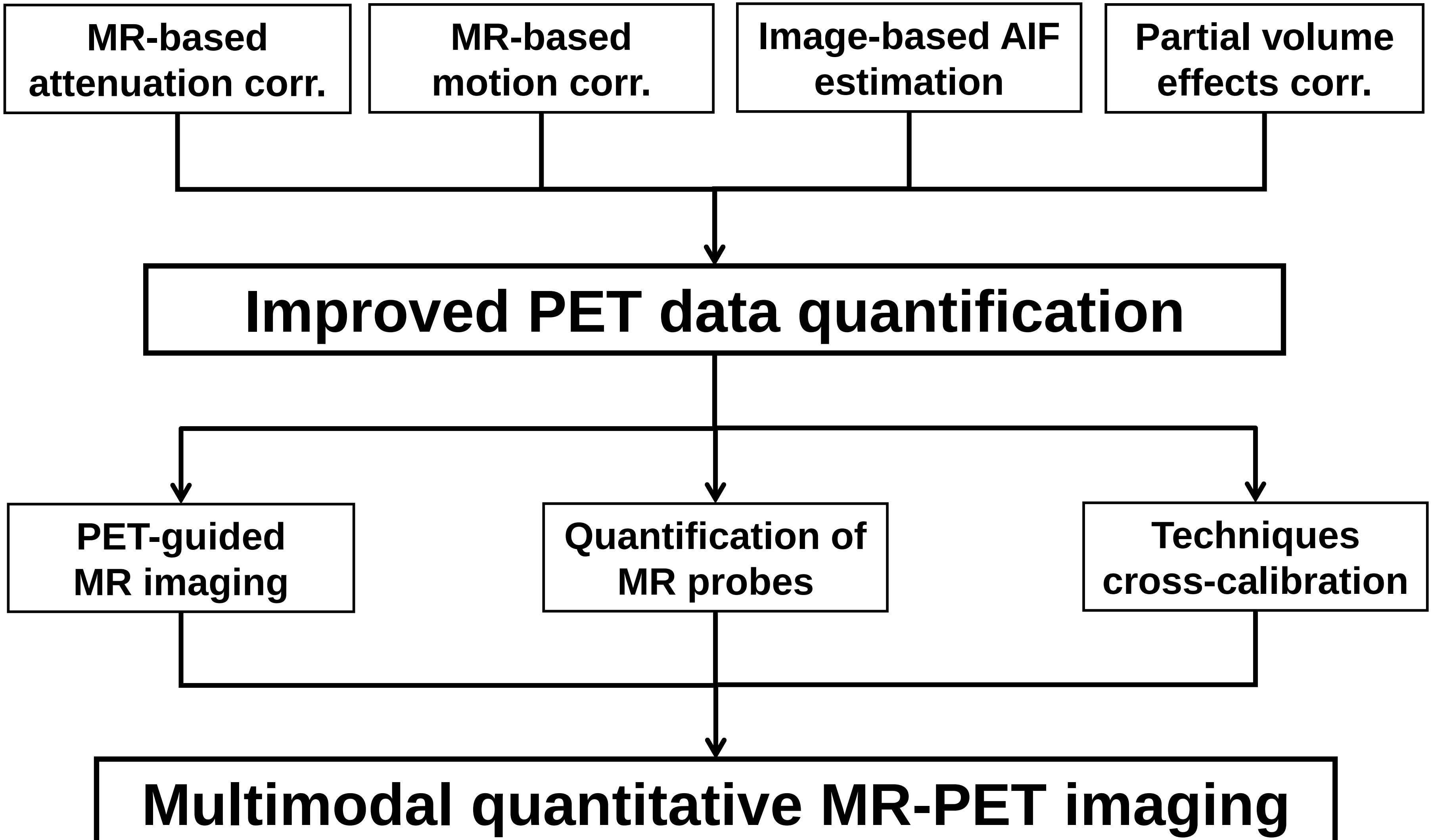
Validate and model the relationship between OEF and BOLD signal during neuronal activation.



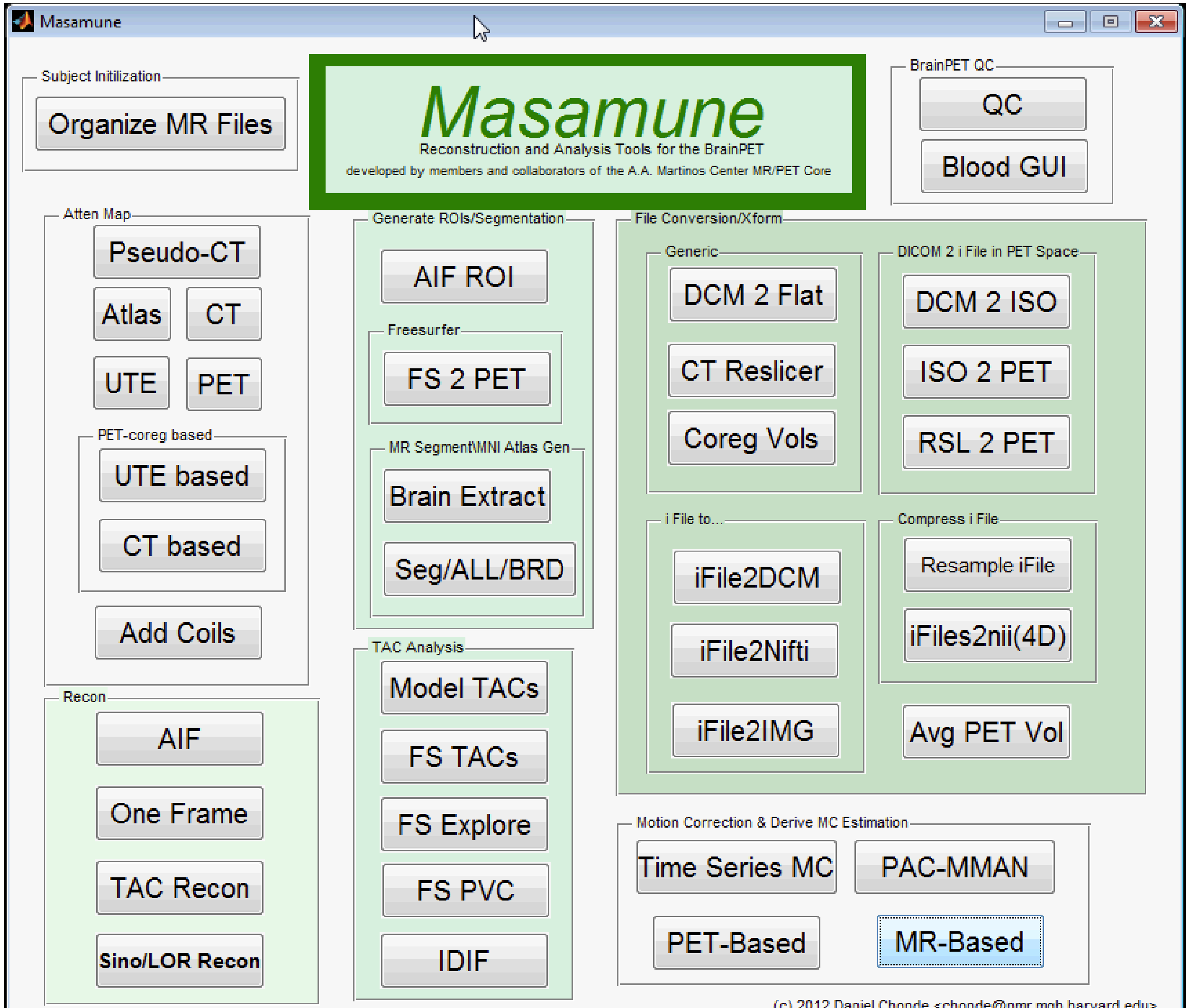


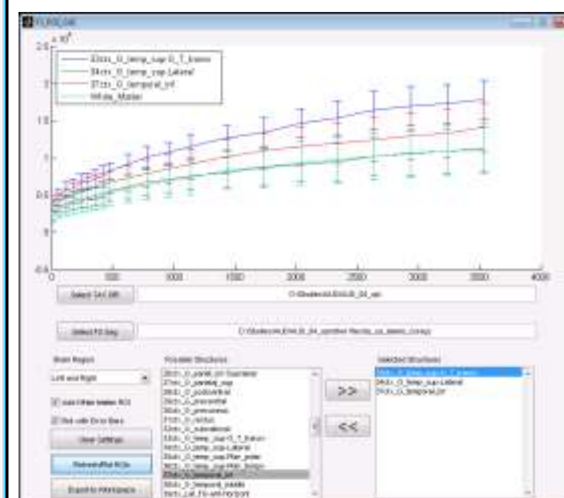
(H. Ito et al. J Cerebral Blood Flow and Metab. 2005; 25: 371-377)

MR and PET Can Help Each Other



Automated Data Processing and Analysis





Dan Chonde, MGH

Outline

Integrated PET/MRI:

- Brief history and current state-of-the-art
- Methodological advances enabling new science:
  - What MR can do for PET
  - What PET can do for MR
- Potential research and clinical applications

Potential Applications

How can MR-PET …

1) **increase diagnostic accuracy?**
   oncology, cardiology, neurology
2) improve patient experience?
3) advance scientific discovery?

“Indications in which PET/MRI may be favorable over PET/CT, depending on tumor entity”

	Most frequent site of metastases*				**PET/MRI is relevant for (favorable to PET/CT) …**	
Tumor entity	Brain	Lung	Liver	Bone	Staging category	Special objective/prognostic factor
Head and neck SCC	−	+	−	+	T	Extracapsular spread; bone infiltration
Non-small cell lung cancer	+	+	+	+	M	Distant metastases
Breast cancer	+	+	+	+	T/M	Primary diagnosis and T-stage (benefit compared with PET/CT; potential benefit over MRI mammography alone is questionable); distant metastases
HCC	−	+	+	+	T	Pretransplantation evaluation
Colorectal carcinoma	−	+	+	−	T/M	Circumferential resection margin; liver metastases; tumor regression rate to neoadjuvant therapy
Soft-tissue sarcoma	−	+	+	−	T/M	Tumor size and depth of infiltration defines T category; muscular, neurovascular, and bone invasion
Primary bone tumors	−	+	−	−	T	Presurgical evaluation (e.g., neurovascular invasion); exact tumor size and response to neoadjuvant treatment
Melanoma	+	+	+	+	M	Exact number and location of metastases for presurgical evaluation
Lymphoma					M	Extranodal dissemination; early therapy response assessment

*Frequency of metastatic spread (frequently [+], rare [−]) is according to AJCC Cancer Staging Manual, seventh edition; PET/CT and PET/MRI are considered equally accurate for N-staging, and thus importance of N-staging is not discussed.

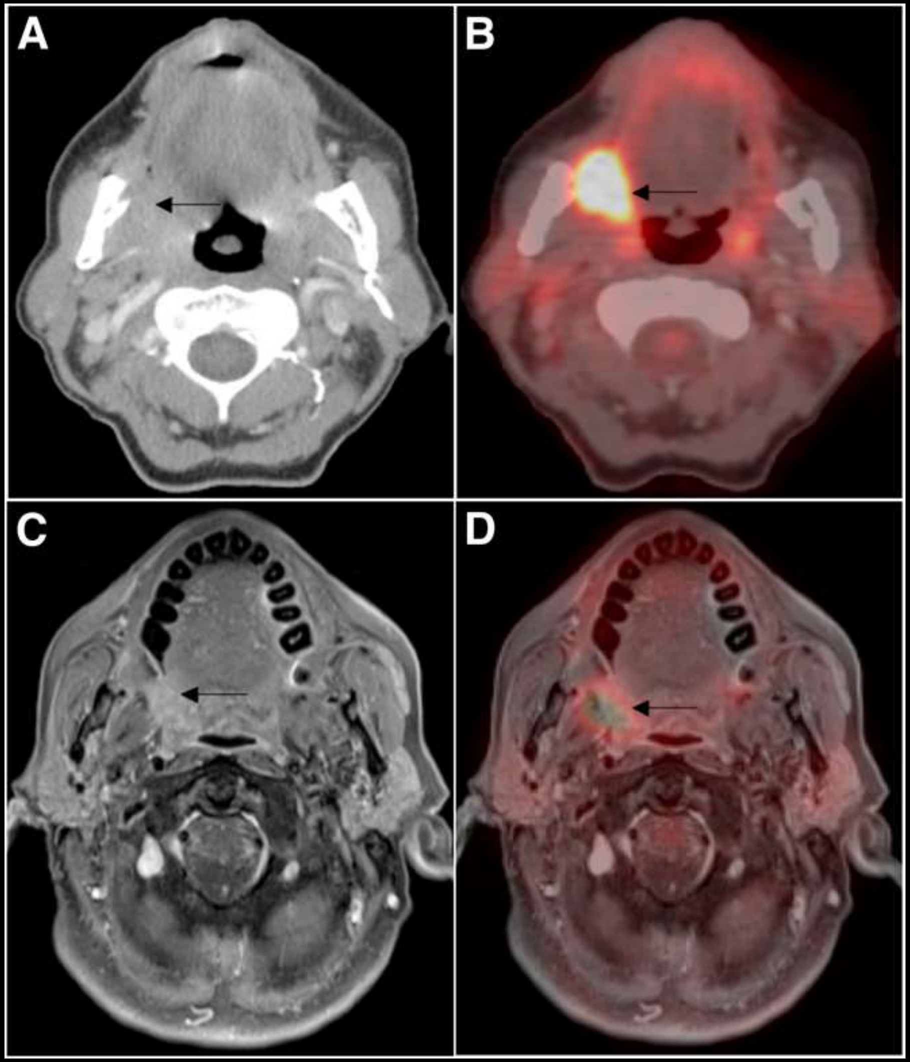
C. Buchbender et al. Oncologic PET/MRI, Part 1 & 2. JNM 2012; 53: 928-938 &1244-1252

Head & Neck MR-PET

More precise metabolic-anatomic allocation of the FDG-avid lesion

FDG-PET/CT

FDG-PET/MR

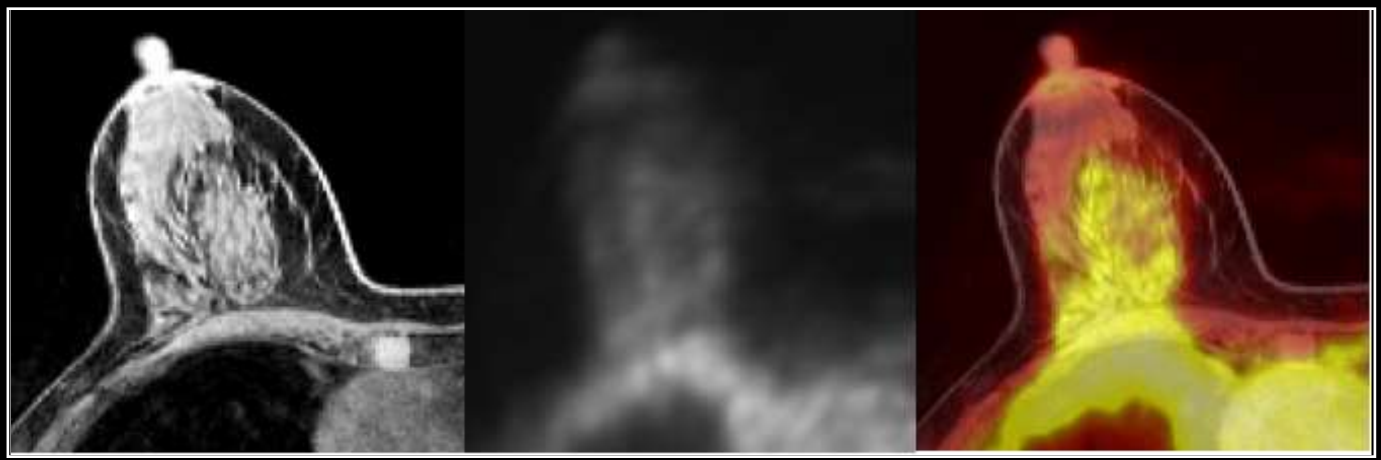


54-y-old man with gingival SCC arising from maxilla

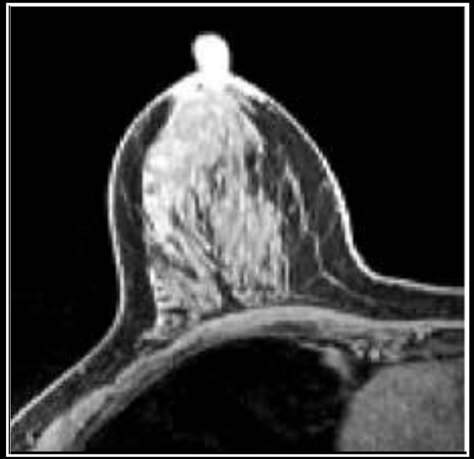
C. Buchbender et al.
J Nucl Med 2012; 53:928
938

Breast MR-PET

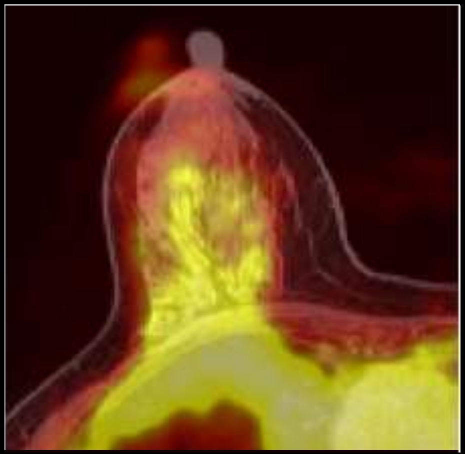
Accurate spatial registration



$MR_{scan\ 1}$ $PET_{scan\ 1}$ Fused $MR_{scan\ 1}$-$PET_{scan\ 1}$



$MR_{scan\ 2}$

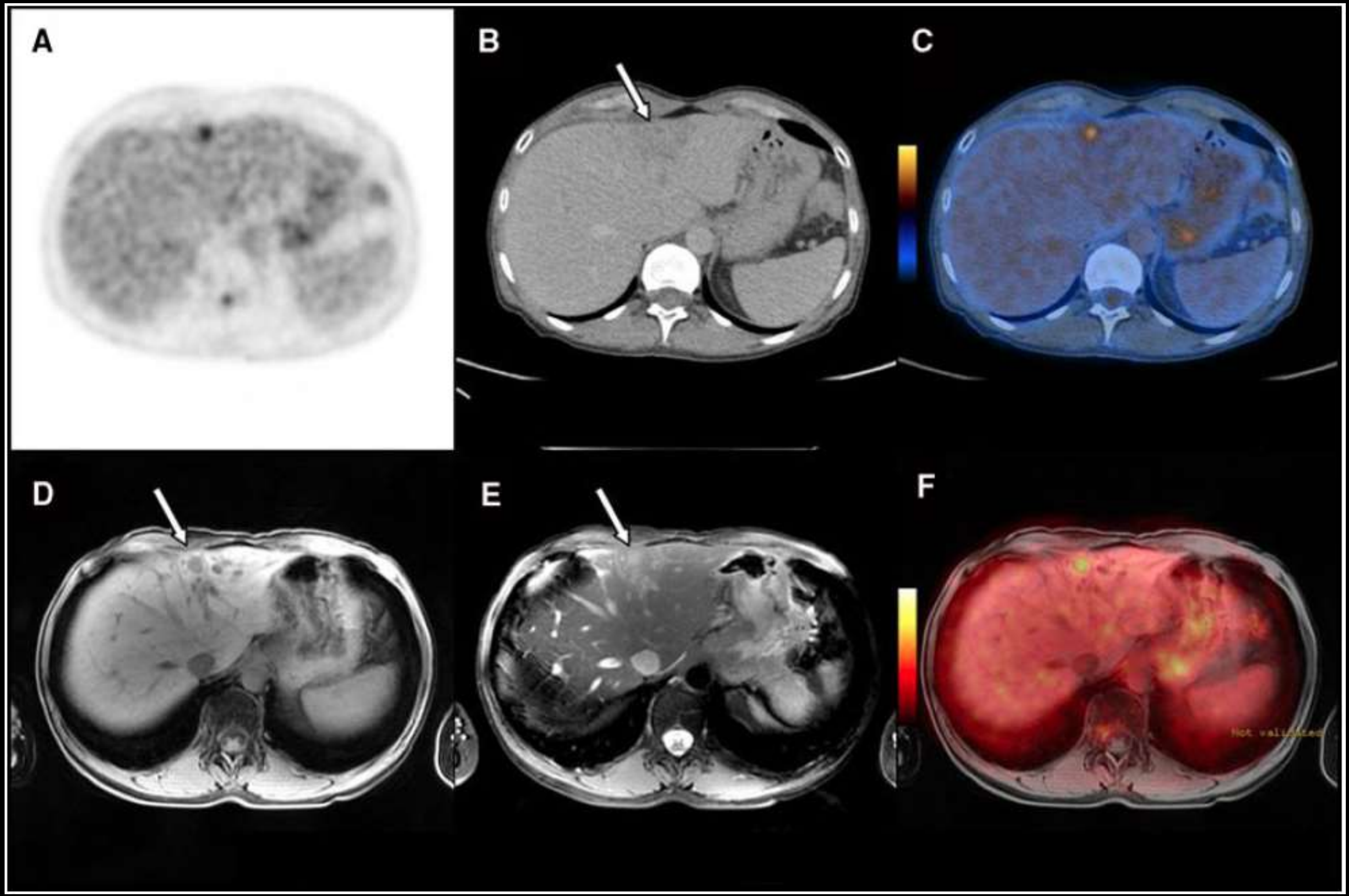


Fused $MR_{scan\ 2}$-$PET_{scan\ 1}$

Spencer Bowen, MGH

Liver PET/CT + MRI

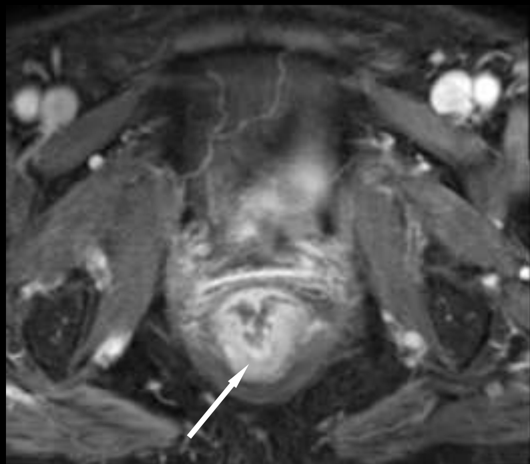
Increased lesion conspicuity



P. Veit-Haibach, F.P. Kuhn, F. Wiesinger, G. Dalso and G. van Schulthess.
Magn Reson Mater Phy (2013) 26: 25-35

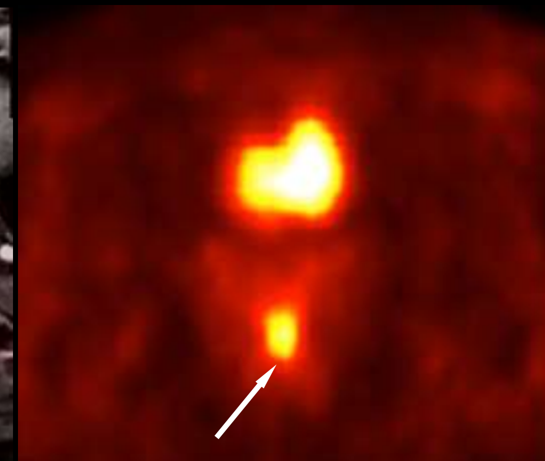
Pelvis MR-PET

Improved soft tissue discrimination and functional information

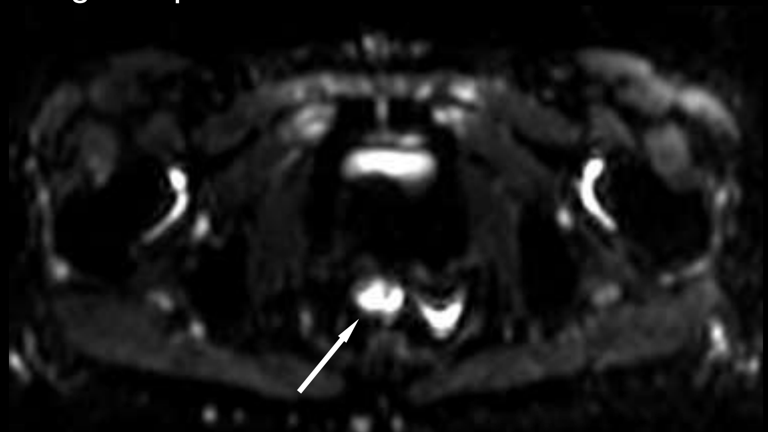


T1-weighted post-contrast MRI

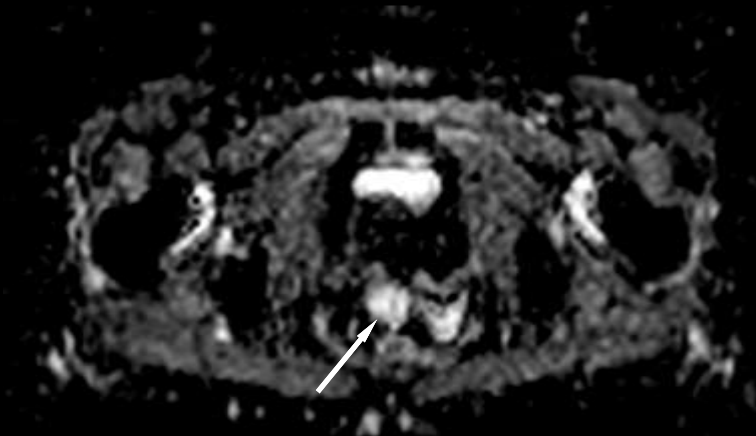
PET/MRI fusion



FDG PET



DWI MRI



ADC map

Collaboration with A. Guimaraes, MGH

Whole-body PET/MRI

Total body bone scan with 219 MBq ^{18}F-NaF of a 61-year-old female (76 kg), with 80 s per bed position for PET acquisition and 105 min uptake time.
Images courtesy of HZDR, Dresden
Data acquired using the Philips WB PET/MR scanner

Magn Reson Mater Phy (2013) 26:5-23

“Advantageous Features of Combined PET/MR with Focus on Cardiac Applications”

Assessment of...	Advantageous features of PET/MR
Morphology	No ionizing radiation, high soft-tissue contrast, coronaries +, plaque imaging +, cardiac structure +++, fiber architecture +++
LV function	Gold standard; correlation with metabolic information/perfusion (risk stratification, prognosis)
Perfusion	Cross-validation of myocardial blood flow quantification; no contrast agents for arterial spin-labeled MR imaging; attenuation correction by MR; motion and partial-volume correction for myocardial blood flow quantification
Infarction and viability	Scar delineation (LGE) +++; combination of glucose metabolism (viable vs. nonviable), perfusion (normal perfusion, hypoperfusion, no perfusion), LV parameters, and LGE (transmural vs. nontransmural scar); potential additional value for risk stratification/prognosis/ therapy guidance
Molecular imaging (e.g., inflammation, angiogenesis, sympathetic innervation, gene transfer, and cell transplantation)	MR spectroscopy (cardiac metabolism and composition); ideal combination of high sensitivity of PET and vast variety of PET radiotracers for detection and quantification of molecular targets as well as localization and volume correction by MR; still large scope for development of new tracers, imaging techniques, and applications in MR

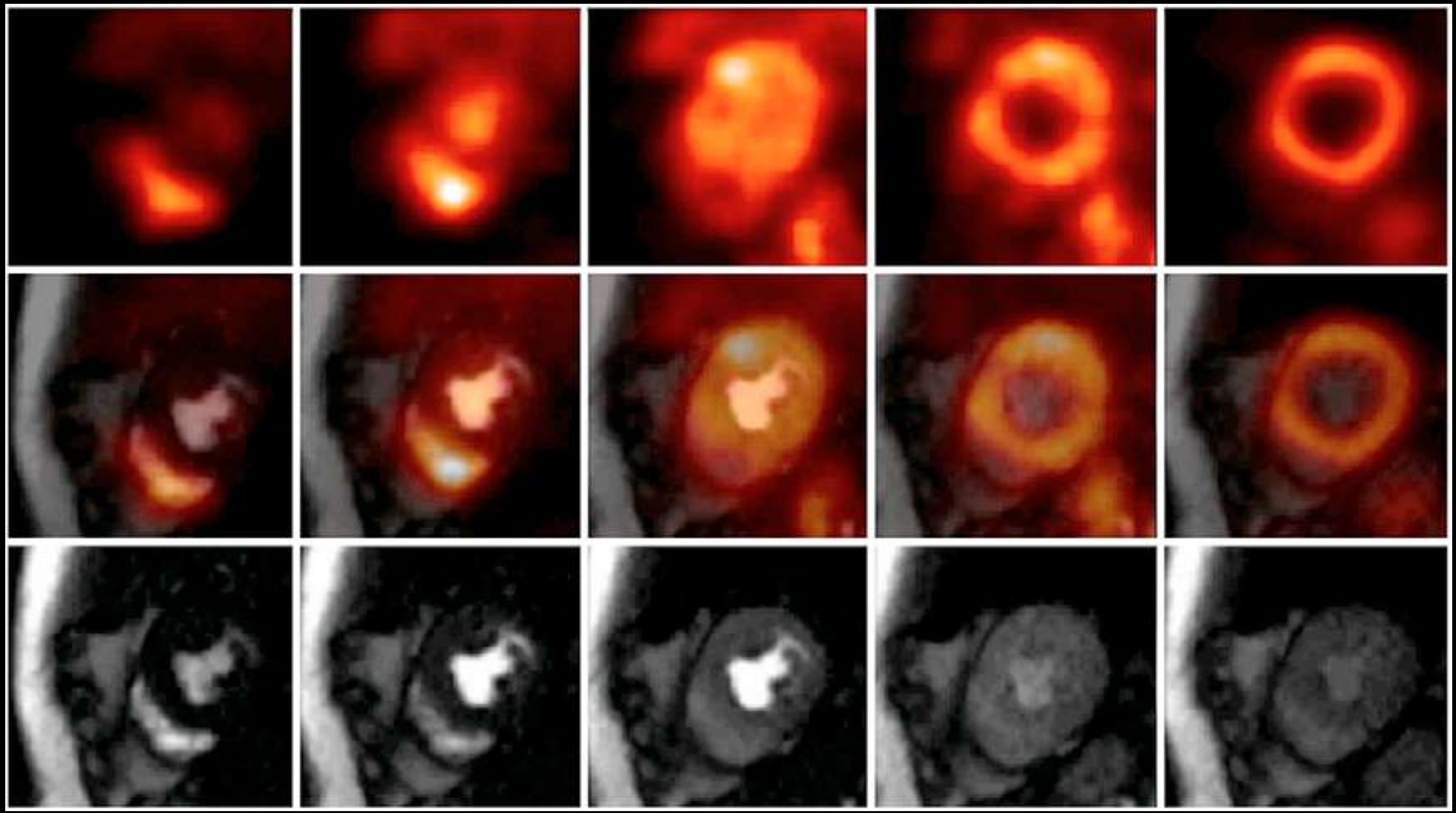
C. Rischpler, S.G. Nekolla, I. Dregely and M. Schwaiger. Hybrid PET/MR Imaging of the Heart: Potential, Initial Experiences, and Future Prospects. JNM 2013; 54:402-415

Myocardial Perfusion MR-PET Study

$^{13}NH_3$ PET

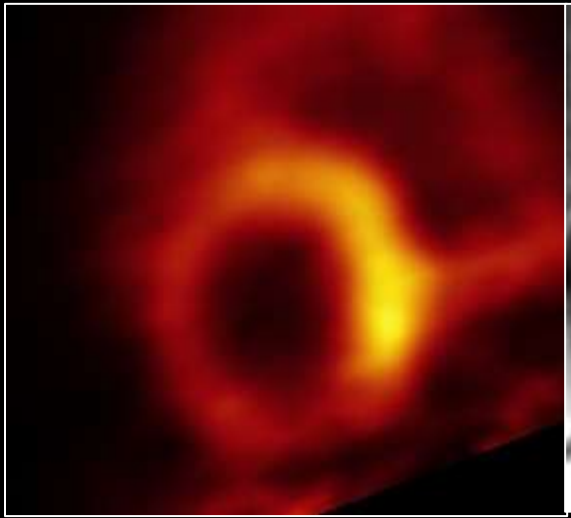
Fused MR-PET

Gd-DTPA MR

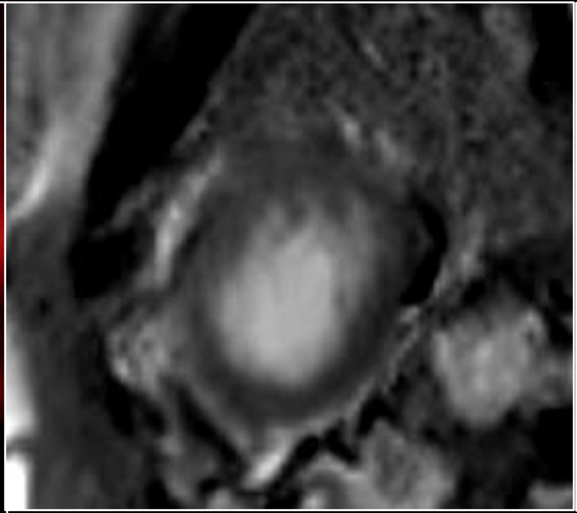


C. Rischpler, S.G. Nekolla, I. Dregely and M. Schwaiger. Hybrid PET/MR Imaging of the Heart: Potential, Initial Experiences, and Future Prospects. JNM 2013; 54:402-415

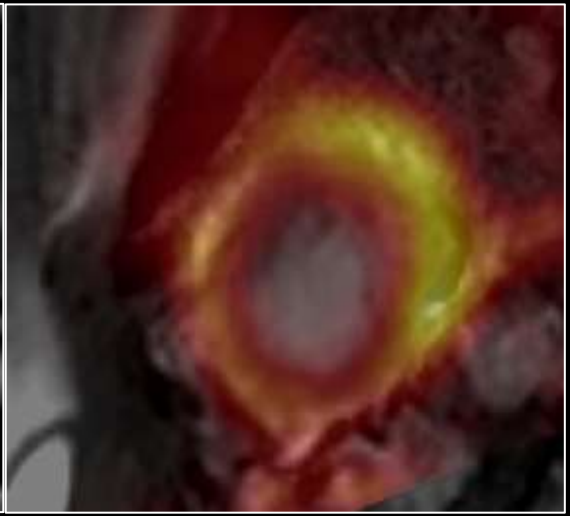
Simultaneous $^{13}NH_3$-PET/MR study demonstrates stress-induced ischemia.



$^{13}NH_3$-PET Stress



LGE MRI



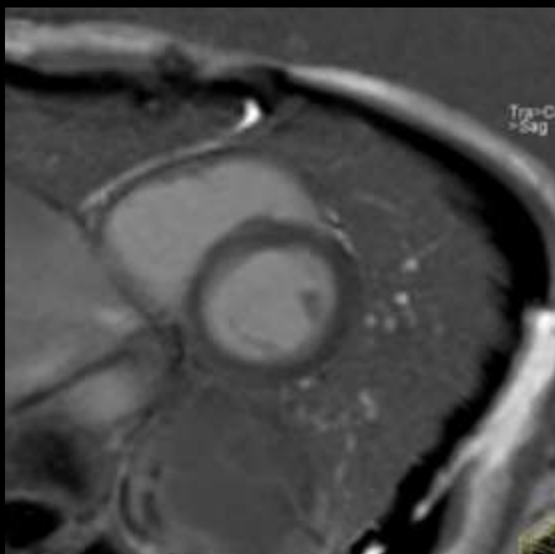
Fused LGE MRI with ^{13}N-PET Stress

Anterior/anterolateral ischemia (PET) without significant delayed contrast enhancement (MRI). Left anterior descending artery disease was subsequently confirmed by catheterization.

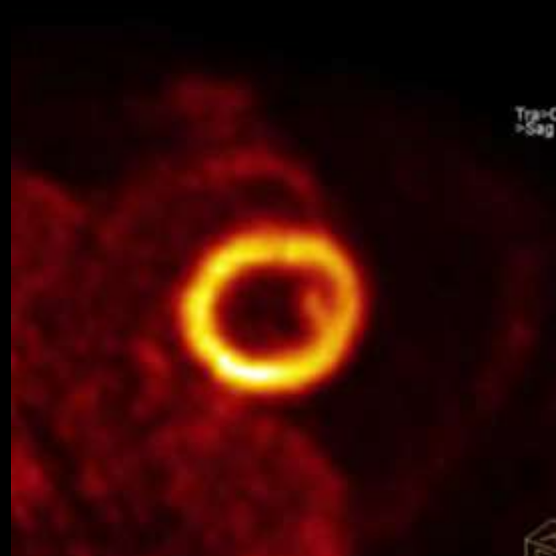
Courtesy of J. Lau, R. Laforest, P. Woodard

Simultaneous FDG-PET and DCE MR study allows myocardial viability assessment.

MR



FDG-PET



Fused PET/MR Cine

Delayed contrast enhancement MR and FDG-PET images acquired in diastole. Fused cine created from the PET list mode data binned into 8 phases fused with simultaneously acquired free-breathing real time SSFP cardiac cine.

[J. Lau, R. Laforest, S. Sharma, J. McConathy, A. Priatna, L. Amado, R. Gropler, P. Woodard. ISMRM 2013, Oral: #0573]

Washington University in St. Louis
School of Medicine
MIR Mallinckrodt Institute of Radiology

Potential Benefits

How can MR-PET …

1) increase diagnostic accuracy?

2) **improve patient experience?**

3) advance scientific discovery?

MR-PET can improve patient experience

- **Two exams in one session:**
  - Increased patient compliance
  - Reduced need for sedation/anesthesia in pediatric patients
  - One pharmacological challenge for two exams

- **Reduced radiation exposure:**
  - Pediatric patients, women of childbearing age, chronic patients

The radiation dose from CT vs FDG-PET is significantly higher in children compared to adults.

Table 1 Radiation Dosimetry for FDG

	Patient Age				
	1 Year	5 Years	10 Years	15 Years	Adult
Mass (kg)	9.8	19.0	32.0	55.0	70.0
Administered activity (MBq)	54.5	105.6	177.8	305.6	389.0
Bladder (mSv)	32.1	33.8	49.8	64.2	62.2
Brain (mSv)	2.6	3.6	5.3	8.6	10.9
Heart (mSv)	19.1	21.1	21.3	24.8	24.1
Kidneys (mSv)	5.2	5.7	6.4	7.6	8.2
Red marrow (mSv)	3.3	3.4	3.9	4.3	4.3
Effective dose (mSv)	5.2	5.3	6.4	7.6	7.4

The doses are reported in mSv [ICRP Report 80] based upon the administered activity of 5.55 kBq/kg (0.15 μCi/kg). Patient masses represent the 50% percentile for that age [ICRP Report 56: Age-dependent doses to members of the public from intake of radionuclides: Part 1, International Commission on Radiation Protection, 1989, p 4].

Table 4 Dose from CT

kvp	Newborn	1 Year	5 Years	10 Years	Med Adult
80	7.0	5.7	4.5	3.8	1.5
100	13.5	11.3	9.0	7.9	3.5
120	21.4	18.2	14.9	12.9	6.0
140	30.1	25.8	21.8	18.9	9.0

All doses are reported in mGy. All data were obtained at 130 mAs and a pitch of helical 1.5:1.

TABLE 1. Excess Attributable Risk (Deaths) from All Solid Tumors per 10,000 People per Year per Sievert at Age 60 Years

Age at exposure (y)	Excess Attributable Risk (mortality)	Relative to >30 y
1	35.1	2.92
5	30.3	2.52
10	25.2	2.1
20	17.4	1.45
>30	12	1

Data are based on models presented in *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2 (15)*.

(F.H. Fahey, “Dosimetry of Pediatric PET/CT”. J Nucl Med 2009; 50: 1483-1491)

(H. Jadvar et al, “PET and PET/CT in Pediatric Oncology”. Semin Nucl Med 2007; 37:316-331)

www.thelancet.com Published online June 7, 2012 DOI:10.1016/S0140-6736(12)60815-0

Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study

Mark S Pearce, Jane A Salotti, Mark P Little, Kieran McHugh, Choonsik Lee, Kwang Pyo Kim, Nicola L Howe, Cecile M Ronckers, Preetha Rajaraman, Sir Alan W Craft, Louise Parker, Amy Berrington de González

Findings During follow-up, 74 of 178 604 patients were diagnosed with leukaemia and 135 of 176 587 patients were diagnosed with brain tumours. We noted a positive association between radiation dose from CT scans and leukaemia (excess relative risk [ERR] per mGy 0·036, 95% CI 0·005–0·120; p=0·0097) and brain tumours (0·023, 0·010–0·049; p<0·0001). Compared with patients who received a dose of less than 5 mGy, the relative risk of leukaemia for patients who received a cumulative dose of at least 30 mGy (mean dose 51·13 mGy) was 3·18 (95% CI 1·46–6·94) and the relative risk of brain cancer for patients who received a cumulative dose of 50–74 mGy (mean dose 60·42 mGy) was 2·82 (1·33–6·03).

Interpretation Use of CT scans in children to deliver cumulative doses of about 50 mGy might almost triple the risk of leukaemia and doses of about 60 mGy might triple the risk of brain cancer. Because these cancers are relatively rare, the cumulative absolute risks are small: in the 10 years after the first scan for patients younger than 10 years, one excess case of leukaemia and one excess case of brain tumour per 10 000 head CT scans is estimated to occur. Nevertheless, although clinical benefits should outweigh the small absolute risks, radiation doses from CT scans ought to be kept as low as possible and alternative procedures, which do not involve ionising radiation, should be considered if appropriate.

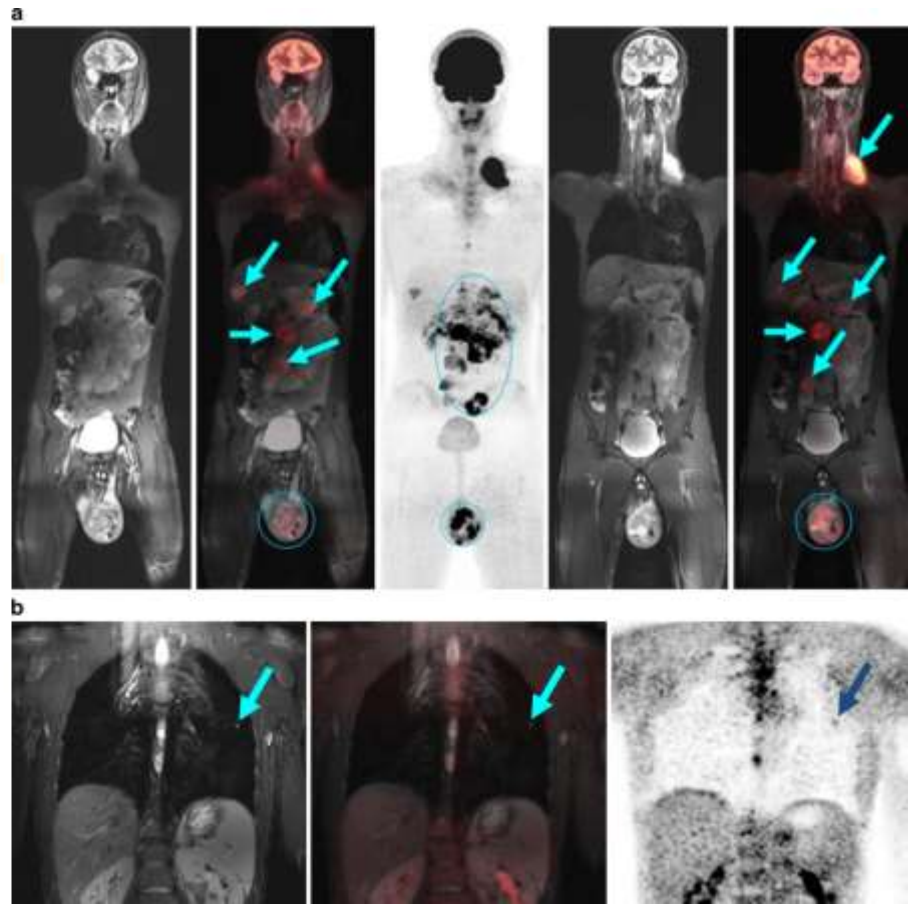
Pediatr Radiol
DOI 10.1007/s00247-012-2570-4

TECHNICAL INNOVATION

PET/MR in children. Initial clinical experience in paediatric oncology using an integrated PET/MR scanner

F.W. Hirsch, B. Sattler et al. University of Leipzig

Abstract Use of PET/MR in children has not previously been reported, to the best of our knowledge. Children with systemic malignancies may benefit from the reduced radiation exposure offered by PET/MR. We report our initial experience with PET/MR hybrid imaging and our current established sequence protocol after 21 PET/MR studies in 15 children with multifocal malignant diseases. The effective dose of a PET/MR scan was only about 20% that of the equivalent PET/CT examination. Simultaneous acquisition of PET and MR data combines the advantages of the two previously separate modalities. Furthermore, the technique also enables whole-body diffusion-weighted imaging (DWI) and statements to be made about the biological cellularity and nuclear/cytoplasmic ratio of tumours. Combined PET/MR saves time and resources. One disadvantage of PET/MR is that in order to have an effect, a significantly longer examination time is needed than with PET/CT. In our



15-yo boy with left testicular tumor with retroperitoneal, supraclavicular, hepatic and lung metastases

Potential Benefits

How can MR-PET …

1) increase diagnostic accuracy?

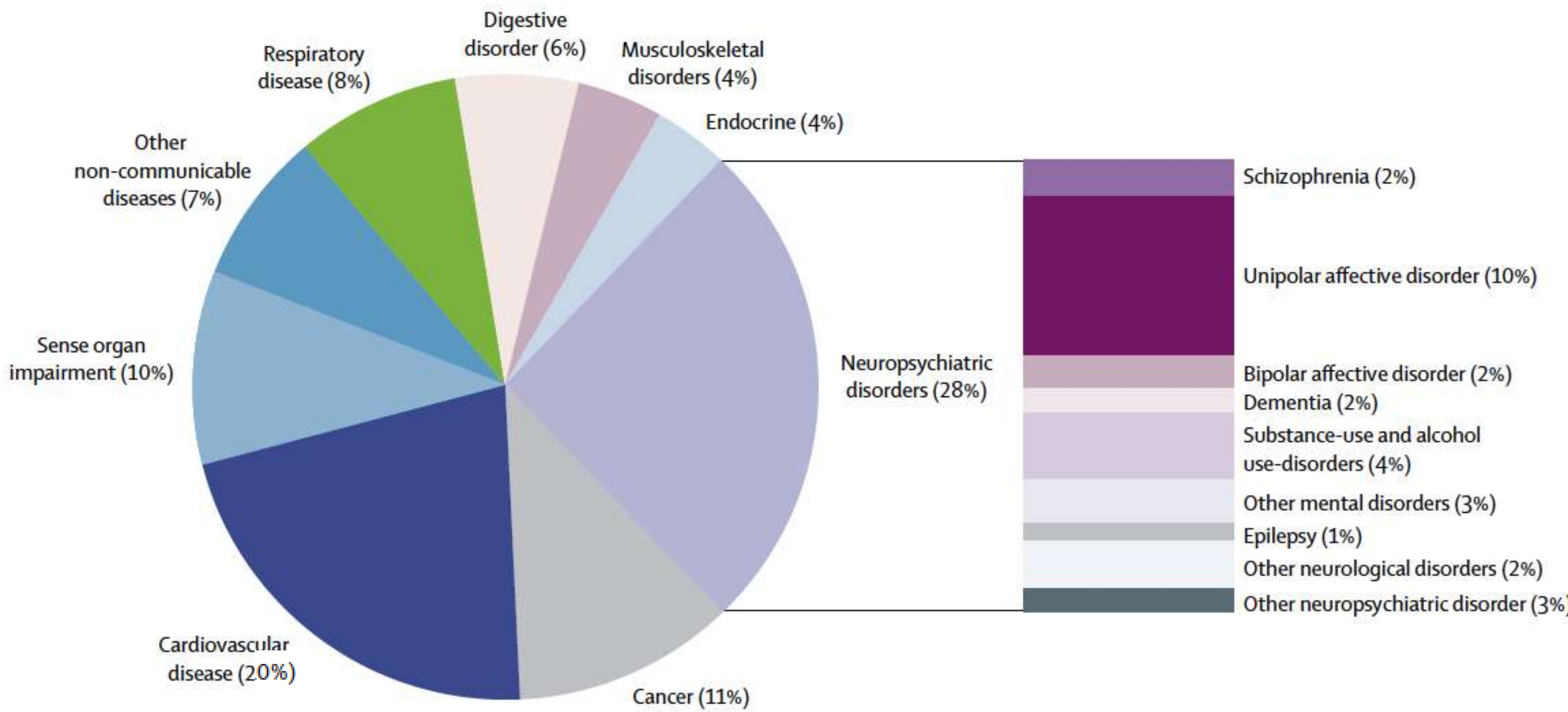
2) improve patient experience?

3) **advance scientific discovery?**

Simultaneous MR-PET opens new opportunities for studying the brain.

(Figure from “Imaging of the Human Brain in Health and Disease”, J.E. Johnson ed.)

Neuropsychiatric conditions contribute the most to the overall burden of non-communicable disease, more than either cardiovascular disease or cancer.



Contribution by different non-communicable diseases to DALYs worldwide in 2005
DALY – disability-adjusted life-year (sum of the years lived with disability and years of life lost)

Prince M et al. No health without mental health. Lancet 2007; 370(9590): 859-77

PET and MRI provide complementary information about the brain.

PET RADIOTRACERS	MR TECHNIQUES
Hemodynamic parameters: cerebral blood flow ($H_2{}^{15}O$, ^{15}O-butanol, $^{13}NH_3$,…), cerebral blood volume (^{11}CO) **Substrate metabolism:** glucose (^{18}F-FDG), oxygen ($^{15}O_2$) **Protein synthesis:** ^{11}C-methionine, ^{11}C-leucine, ^{11}C-tyrosine **Amino acid transport:** ^{18}F-fluoroethyltyrosine, ^{18}F-fluorophenylalanine,… **Nucleosides and DNA synthesis:** ^{18}F-fluorothymidine,… **Neurotransmitter biochemistry:** precursors (^{18}F-FDOPA, ^{11}C-AMT,…), transporters (^{11}C-methylphenidate, ^{11}C-cocaine,…), receptors (^{11}C-raclopride, ^{11}C-nicotine, ^{18}F-altanserin,…), enzyme activity (^{11}C-deprenyl, ^{11}C-donepezil,…) …	**Anatomy:** high resolution morphology, angiography **Perfusion:** cerebral blood flow and blood volume, mean transit time, time to peak, relative vessel size and permeability,… **Water diffusion:** mean diffusivity, fractional anisotropy, apparent diffusion coefficient, fiber orientation **Brain function:** BOLD contrast, PWI **Chemical composition:** ^{1}H-MRS (NAA, Cr, Cho, Lac, mI) , ^{31}P-MRS …

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SPECIAL ARTICLE

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Monetary Costs of Dementia in the United States

Michael D. Hurd, Ph.D., Paco Martorell, Ph.D., Adeline Delavande, Ph.D., Kathleen J. Mullen, Ph.D., and Kenneth M. Langa, M.D., Ph.D.

RESULTS

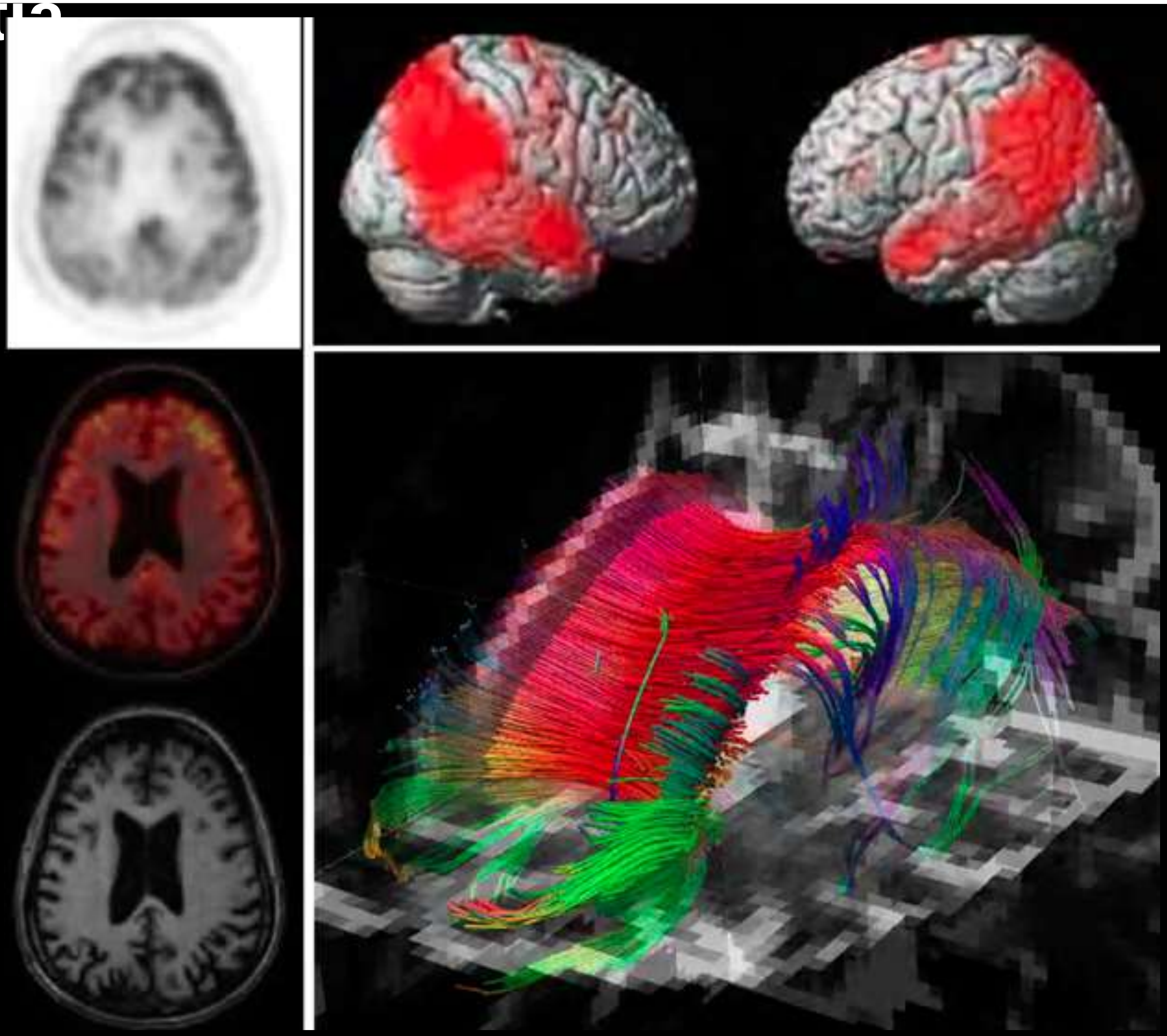
The estimated prevalence of dementia among persons older than 70 years of age in the United States in 2010 was 14.7%. The yearly monetary cost per person that was attributable to dementia was either $56,290 (95% confidence interval [CI], $42,746 to $69,834) or $41,689 (95% CI, $31,017 to $52,362), depending on the method used to value informal care. These individual costs suggest that the total monetary cost of dementia in 2010 was between $157 billion and $215 billion. Medicare paid approximately $11 billion of this cost.

CONCLUSIONS

Dementia represents a substantial financial burden on society, one that is similar to the financial burden of heart disease and cancer. (Funded by the National Institute on Aging.)

MR-PET allows the assessment of anatomical/functional/molecular changes in dementia

FDG PET



Surface projections show areas with reduced metabolism

Fused MR-PET

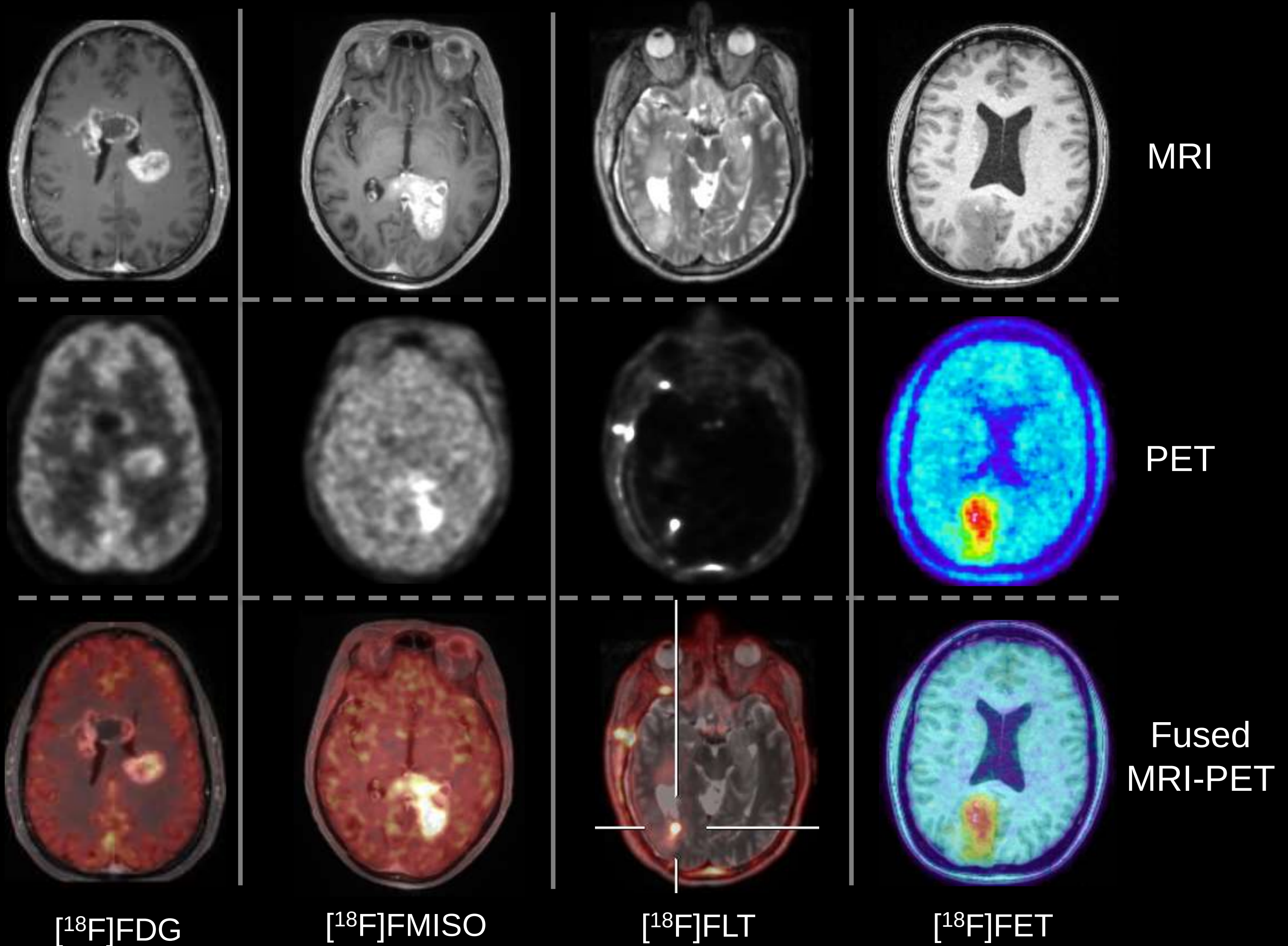
MPRAGE

DTI

Collaboration with Brad Dickerson, Alexander Drzezga

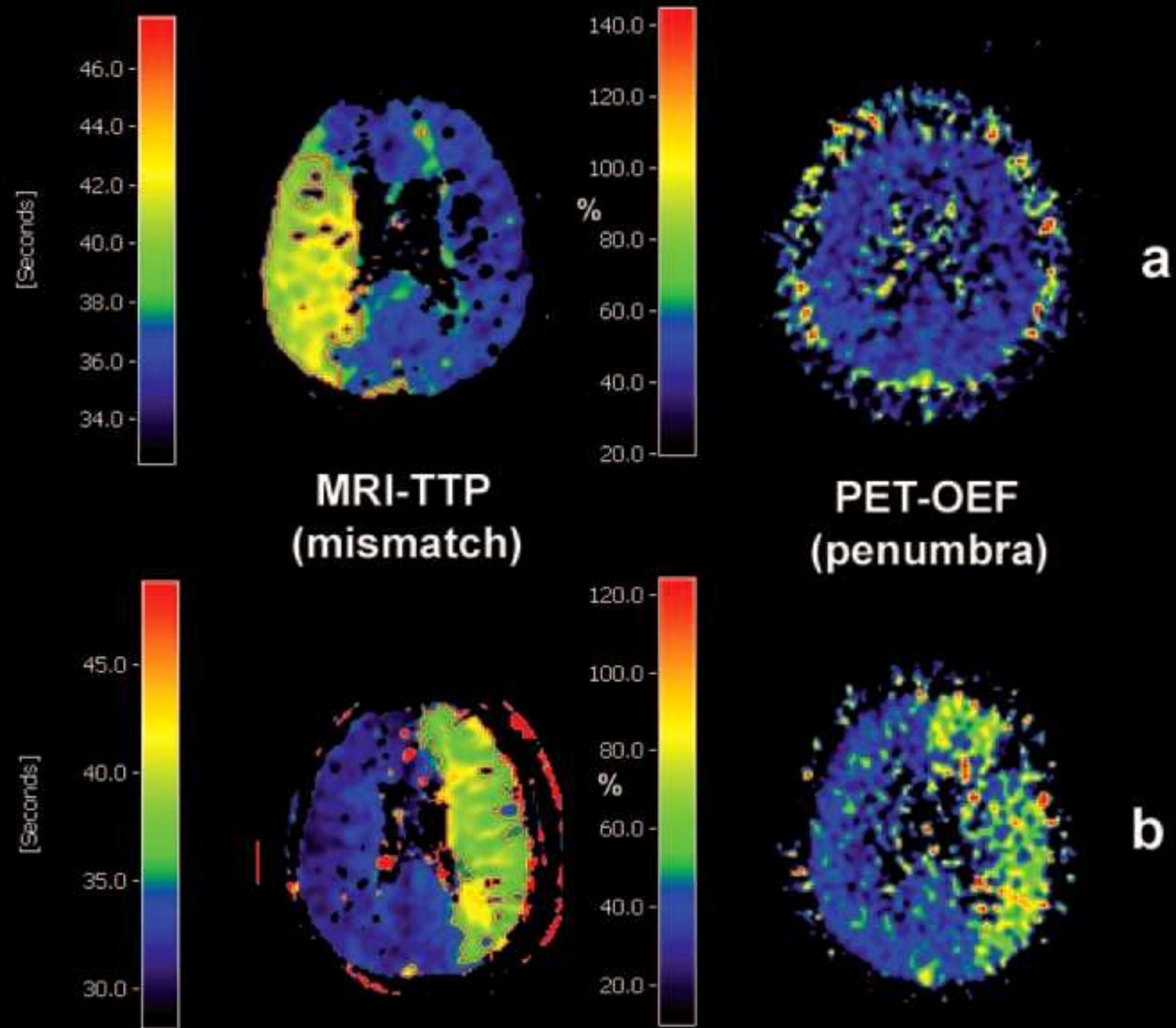
C. Catana et al. “PET and MR Imaging: The odd couple or a match made in heaven?” JNM 2013; 54:1-10

MR-PET could help us understand the mechanism of action of therapeutic agents in GBM patients.



(C. Catana et al. “PET/MRI for Neurological Applications”. JNM 2012; 53:1916-1925)

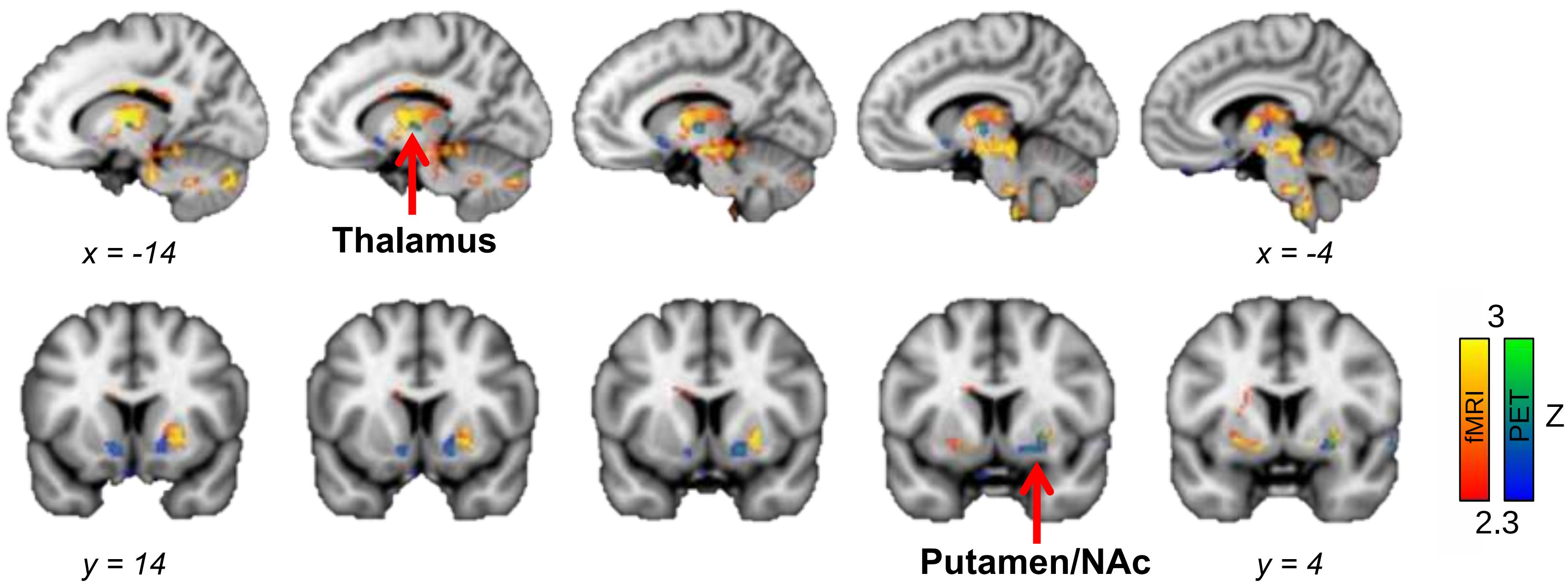
Cross-calibration measures could elucidate the mismatch-penumbra debate in ischemic stroke patients.



Sobesky et al *Stroke* 2005; 36: 980-985

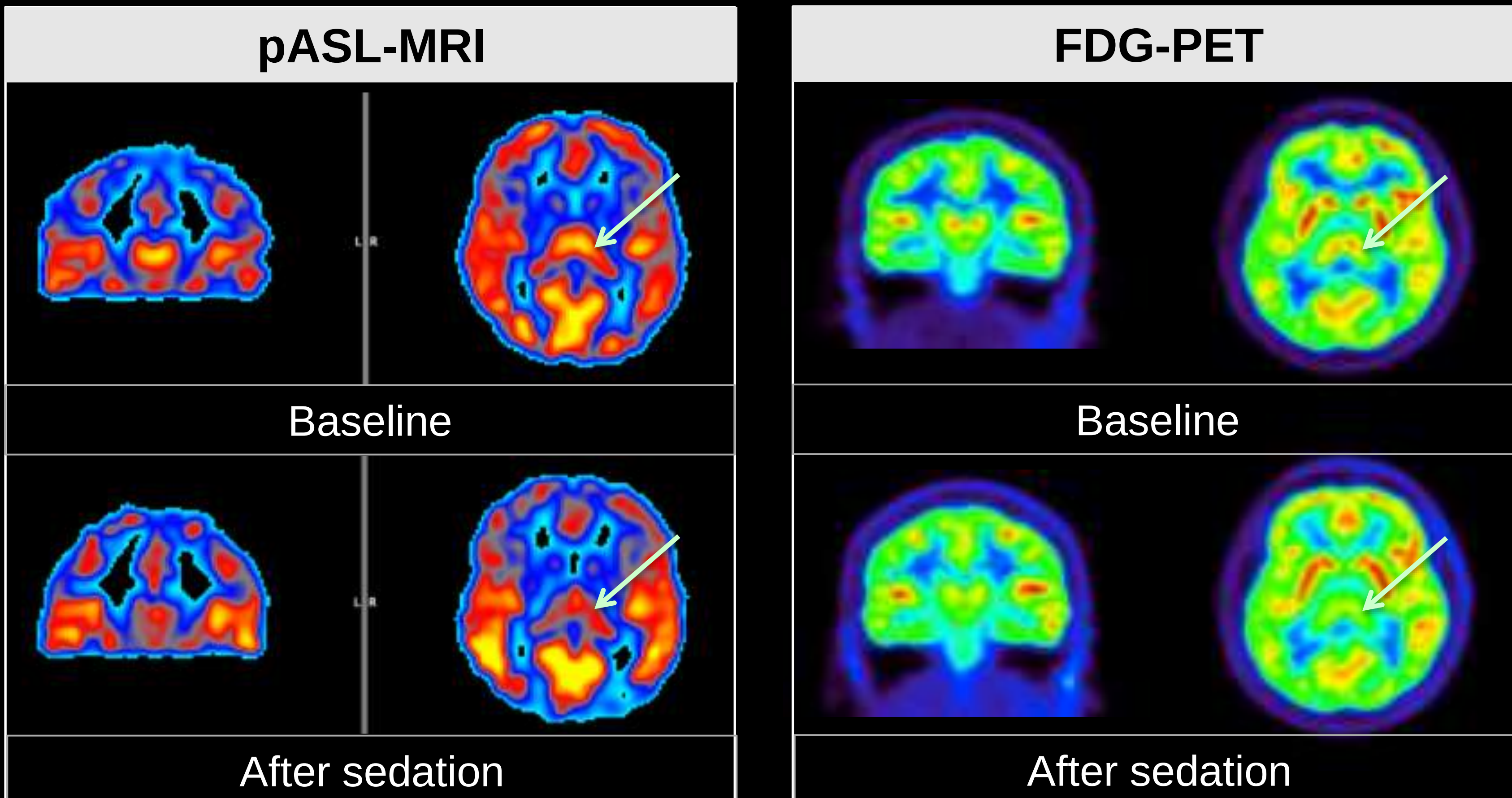
fMRI-PET Assessment of the Response to a Physiological Challenge (i.e. experimental pain)

Brain regions show fMRI-PET activation overlap



Wey, Gollub, Kong et al.

FDG-PET/MRI Study of Dexmedetomidine Sedation



Seun Akeju, MGH

Neurovascular coupling to D2/D3 dopamine receptor occupancy using simultaneous PET/functional MRI

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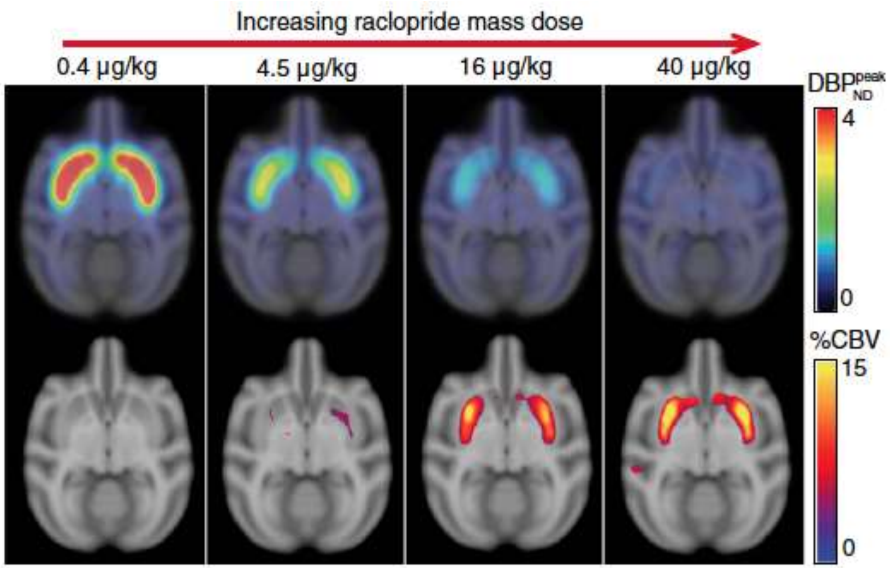

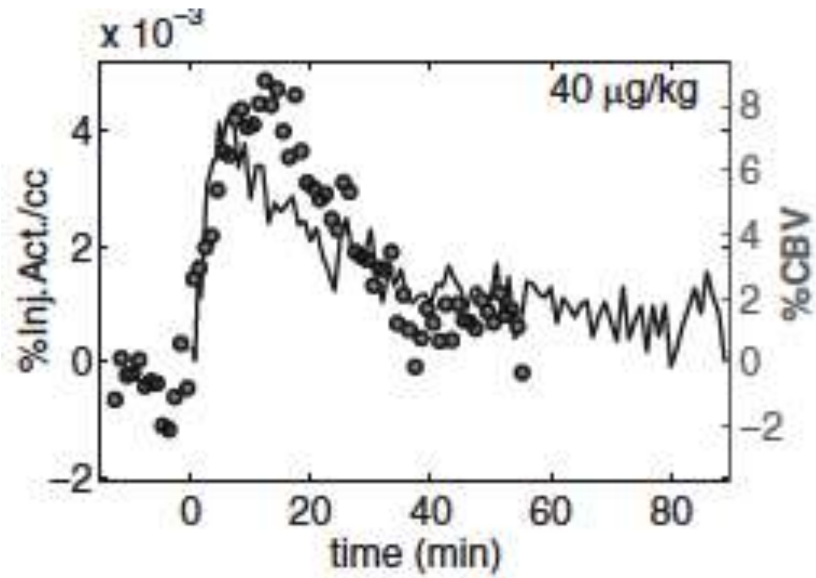

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