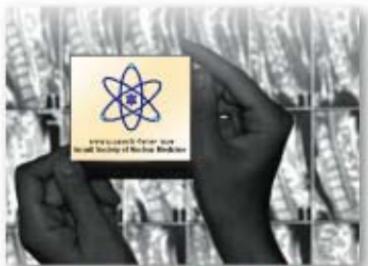


Image fusion in 2020



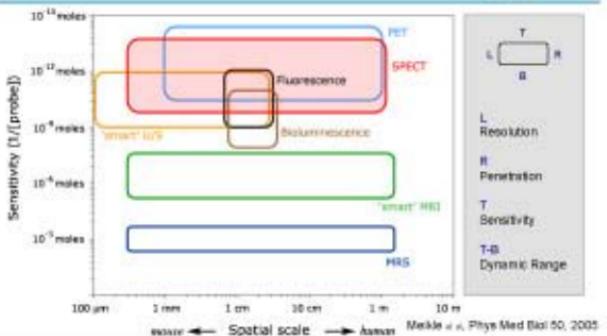
Thomas Beyer, PhD
thomas.beyer@meduniwien.ac.at



Imaging



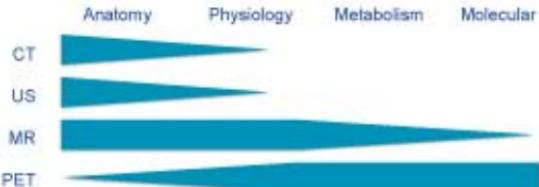
Imaging combinations



Expectations versus Technical feasibility



Imaging modalities



Adapted from Weissleder and Mahmood, Molecular Imaging Radiology 219 (2), 2001

Image fusion to complement standalone imaging ?



Hardware fusion



	Anatomy	Physiology	Metabolism	Molecular
SPECT/CT				
PET/CT				
PET/MR				

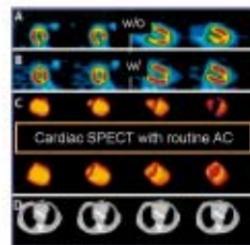
Adapted from Wessling and Mahmood, Molecular Imaging, Radiology 219(2), 2001



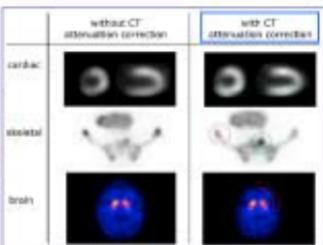
Hardware fusion for optimum intrinsic alignment + benefits



SPECT/CT: the past



Bucher et al.
General camera mounted anatomical X-ray tomography.
Eur J Nucl Med 27: 819-27, 2000



Buck et al.
SPECT/CT
J Nucl Med 49: 1305-19, 2008

SPECT/CT = Routine attenuation correction



Image fusion objectives



→ (Co-)localization



→ Added diagnostic benefit



→ Examination time



"The world is more than the sum of its parts." (Aristotle)

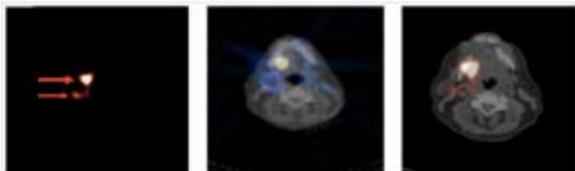


SPECT/CT: the promise



"CT is potentially more useful for SPECT than for PET."

Balloy DL. Is PET the future of Nuclear Medicine? Eur J Nucl Med Mol Imaging 30: 1045-6, 2003



SPECT

Hawkeye

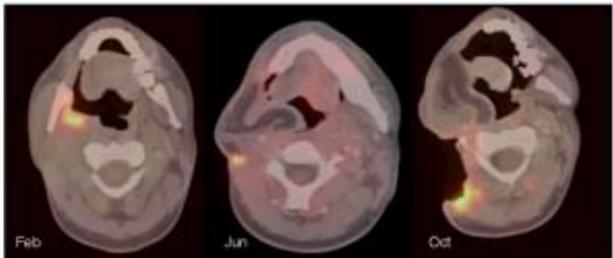
Precedence

Courtesy J.Mortensen, Copenhagen

SPECT/CT = Routine attenuation correction + Fusion



PET/CT



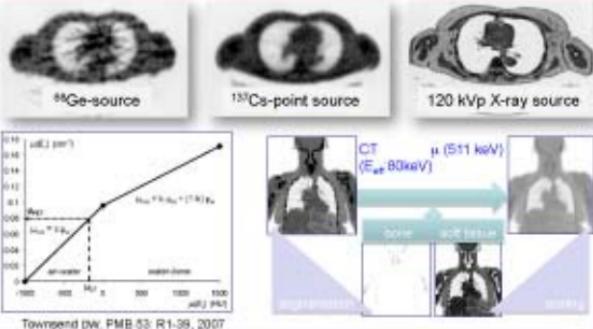
Bleyer et al. A combined PET/CT scanner for clinical oncology. J Nucl Med 41: 1369-80, 2000

Townsend DW. Multi-spatiality imaging of structure and function. Phys Med Biol 55: R1-39, 2008

PET/CT = Image fusion in oncology



PET/CT quantification

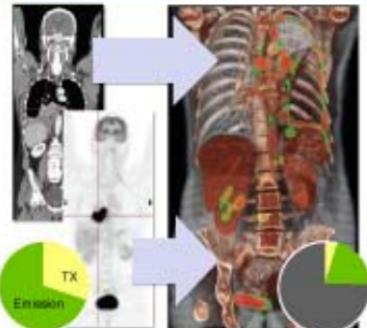


Townsend DW. PMB 53: R1-39, 2007

CT-AC: low-noise, post-injection attenuation correction



PET/CT: technical advances



Higher resolution ✓

Increased sensitivity ✓

Time-of-flight ✓

Resolution recovery ✓

Cont. table motion ✓

Gating ✓

CT dose modulation ✓

„A technical evolution leading to a medical revolution.“ J Czernin



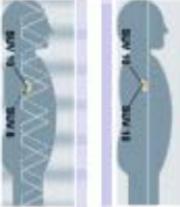
PET/CT: the near future



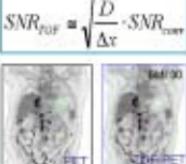
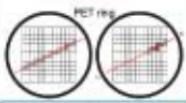
High volume sensitivity
(Larger axial FOV)



Optimized workflows
(Continuous table motion)



Increased SNR
(Time-of-flight PET)



Exploring the full technical potential of PET and CT



MR-compatible PET detectors



"A few years from now, when Geiger-mode APDs have been further researched and optimized, SiPMs might drastically change current PET detector technology. They will most likely be the technology of choice for combined PET/MRI scanners and [...] combined PET/CT, serving as a dual detector for PET photons and CT x-rays."

2007: pre-clinical APD technology used for human PET/MR

	PMT	APD	SIPM
Active area (mm ²)	2-10 ⁵	100	10
Gain	10 ³	10 ²	10 ²
Qu. Efficiency (%)	25	80	40
Block timing (ps)	550	5'000	600
Bias voltage (V)	2'000	1'500	50
Compactness	-	+	++
Susceptibility	yes	no	no

PMT: Photo multiplier, APD: Avalanche photodiode,
SIPM: silicon photo multiplier or Geiger-mode APD

Pichler et al., Latest Advances in Molecular Imaging Instrumentation, J Nucl Med 49: 55-238, 2008



Standard MR-AC



Integrated



Co-planar



Integrated



PET/MR system design



System parameters

PET field-of-view (cm)	18 x 67	26 x 58	25 x 60
PET detector	PMT+LYSO	APD+LYSO	SIPM+LSB
PET spatial resolution (mm)	≥ 5	≥ 4	≥ 4
Time-of-flight (TOF-PET)	yes (525 ps)	no	yes (386 ps)
MR	3T	3T	3T
MR field-of-view (cm)	50 x 50 x 45	50 x 50 x 50	50 x 50 x 50

Whole-body PET/MR with state-of-the-art performance



Standard MR-AC



"If history repeats itself, and the unexpected always happens, how incapable must Man be of learning from experience."

George Bernard Shaw
(1856 - 1950)
Irish dramatist & socialist



PET/CT was history



1st PET/CT (SMART) @ UPMC
300 patients 1998-2001



cancer patients. Conclusion: A combined PET and CT scanner is a practical and effective approach to acquiring co-registered anatomical and functional images in a single scanning session.

Objectives

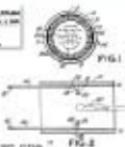
1. Fusion = Function + Anatomy
2. CT-based attenuation/scatter correction

Reality

1. CT-based attenuation/scatter correction
2. Localization of PET findings on low-dose CT
3. Fusion of CT and PET images



PET/MR is history



Bruker Hammer
"Two images are better than one."
Physics World 23-24, 1997



Objectives

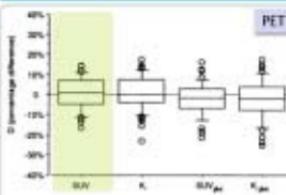
1. Fusion = Function + Anatomy (PET/MR>PET/CT)
2. none

Reality

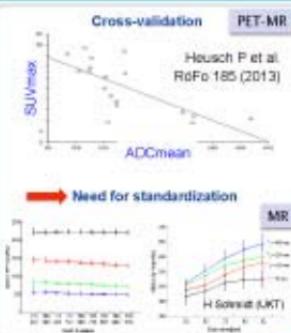
1. MR-based attenuation correction
2. Localization of PET findings on low-quality MR
3. Usefulness of PET/MR versus PET/CT?



Pushing fusion II



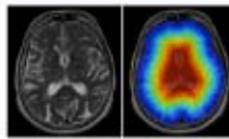
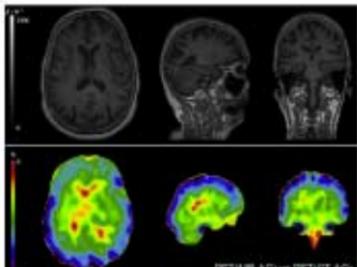
- Intra-patient reproducibility
 - FDG PET: SUV, K₁
 - Highly-reproducible quant. params
 - Metabolic endpoints: ASUV
- WA Weber, JNM 40(11) 1988



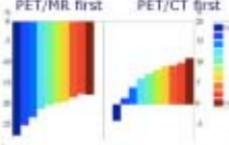
Ensure repeatability/reproducibility → Standardization



PET/MR quantification



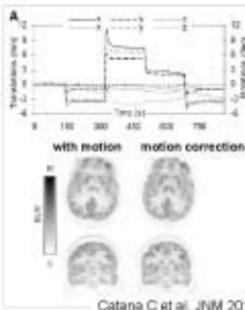
%Diff PET following MR-AC with DWFS and CT-AC



Ignoring bone in MR-AC: Gradient effect in AC-PET



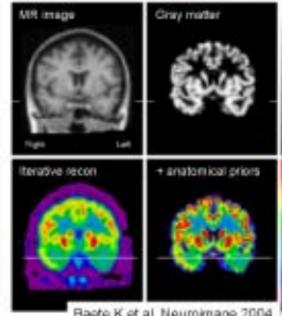
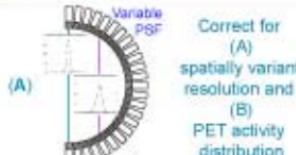
MR-based motion correction



Routine motion correction (+PVC +IDIF) vs. System costs

Digitized by srujanika@gmail.com

MR-based PVC



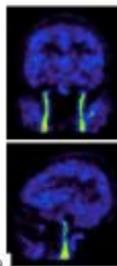
Corrections challenged by segmentation, motion, PSF model

6

Image-derived input function (IDIF)



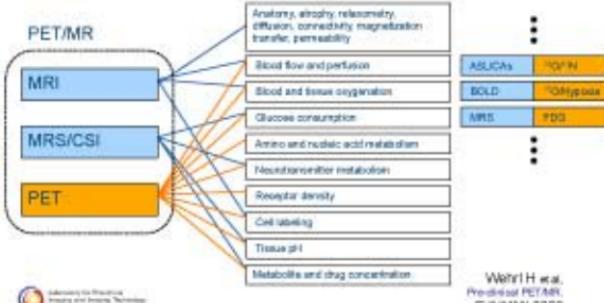
- Extracted from large arteries close to the organ-of-interest
 - IDIF in PET: Use carotids
 - Benefits
 - No arterial cannula
 - No dispersion of input function
 - Drawbacks
 - Poor temporal resolution
 - Need to correct IDIF for PVE



PET/MRI: Potential for routine adoption of IDIF concept

三

Cross-modality



Wehrli H et al.
Precision PET/CT
EJNMMI 2009

From dual-modality to multi-parametric imaging

1

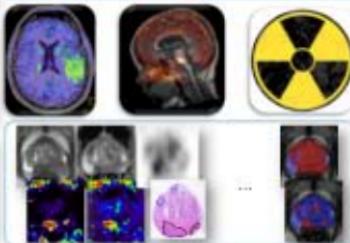
Key applications of PET/MR



International expert panel „The real work has just started.“

Key application (Definition)

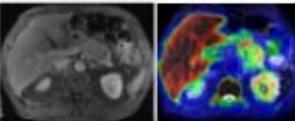
Producing an image or result that provides new or substantially more information and clarity than anything else can provide today.



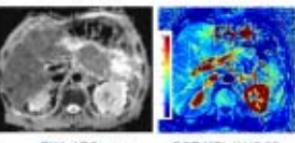
PET/MR: the near future



Pancreatic CA before CTx

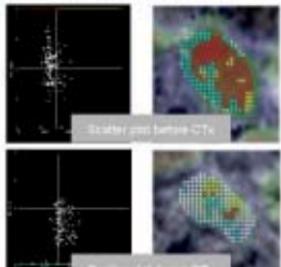


T1w fs + Gd [18F]FLT-PET/MR



DWI ADCmap DCE-MRI IAUC 90

Multi-parametric analysis

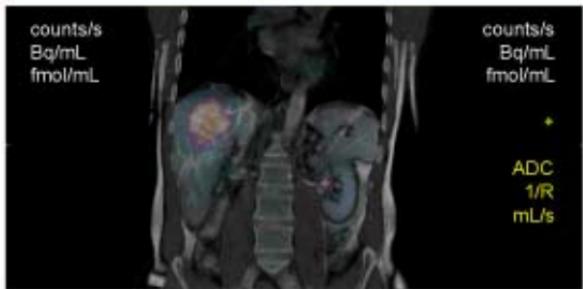


Courtesy of A. Beer and Stefan Neidhart, TU Munich

Multi-parametric imaging of tumour biology



Visual image fusion



Courtesy Timor Kadir, Mirada Medical, Oxford, UK

Navigating through multiple parameters from fusion examination

Hardware and software



PET

Dynamic PET
Static PET

modeling

MRI

DCE
spectroscopy
DWI

maps

MR morphometry
MRI sequences
T1-T2-T2* maps

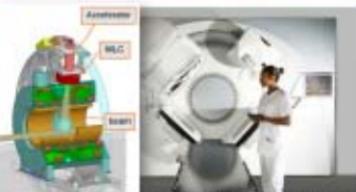
Software tools: Fifi, Matlab, PMOD, VINCI, Workstation (TrueD, Tissue4D etc.)

Bailey DL et al. Mol Imaging Biol 16, 2014

Hardware fusion mandates sensible software fusion



Fusing imaging and therapy



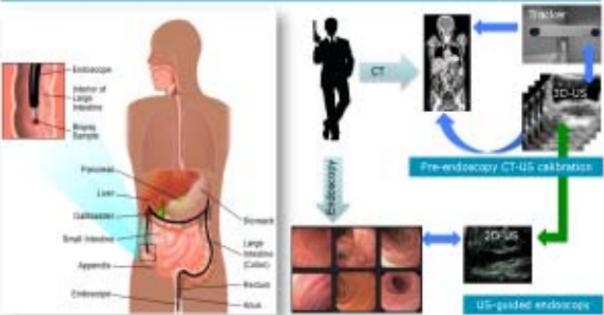
Langerak JAW et al. Radiat Oncol 05: 25-9, 2003



Kerkhoff M et al. Radiat Oncol 08: 241-8, 2006

To move from retrospective off-line to semi-synchronous RT(P)

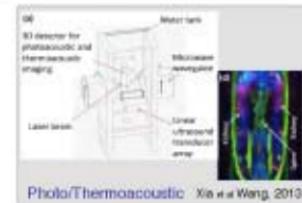
US - guided fusion



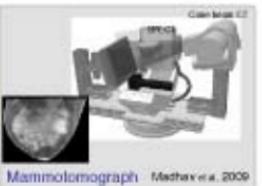
Kaarn M, Hummel J et al. Automatic patient alignment using 3D-US. Med Phys, 2013

US-guided image fusion of endoscopy and CT

More hardware fusion



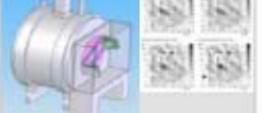
PhotoThermoacoustic Xie et al. Wang, 2013



Mammolomograph Madabh et al. 2009



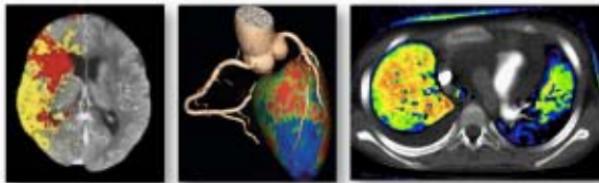
X-ray/Ultrasound Goodlett et al. 2008



SPECT/MRI Wagenknecht et al. 2006

Fusion 2020

In 2000 radiology claimed to do image fusion.

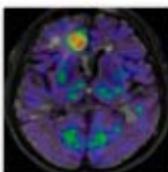


Mono-modal image fusion

Fusion 2020



In 2010 nuclear medicine claimed to do image fusion.



Anato-metabolic image fusion



Cooperation



"EANM and ESR recognise [that it] is important to provide adequate and appropriate training ... in order to offer proper service to the patient using hybrid systems. ..." Bischof Delabye A, EJNMMI, 2007

PROPOSED plan for initiation of an interdisciplinary training programme being developed on a European level together by the ESR and the EANM and the interested ESR/FNMRI partners!



Cuscoolo and Brattström, EJNMMI 2009

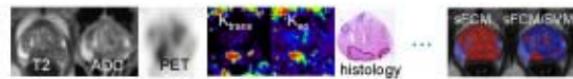
Training multi-modality imaging professionals



Fusion 2020



In 2020 multi-disciplinary image fusion will take over.



Gaddie S et al, Radiology, Tübingen, Germany, 2014

Fusing images requires cooperation of professionals



thomas.beyer@meduniwien.ac.at