MLAA-Based RF Surface Coil Attenuation Estimation in Hybrid PET/MR Imaging

Thorsten Heußer, Christopher M. Rank, Martin T. Freitag, and Marc Kachelrieß

German Cancer Research Center (DKFZ), Heidelberg, Germany

Introduction

Attenuation Correction (AC)

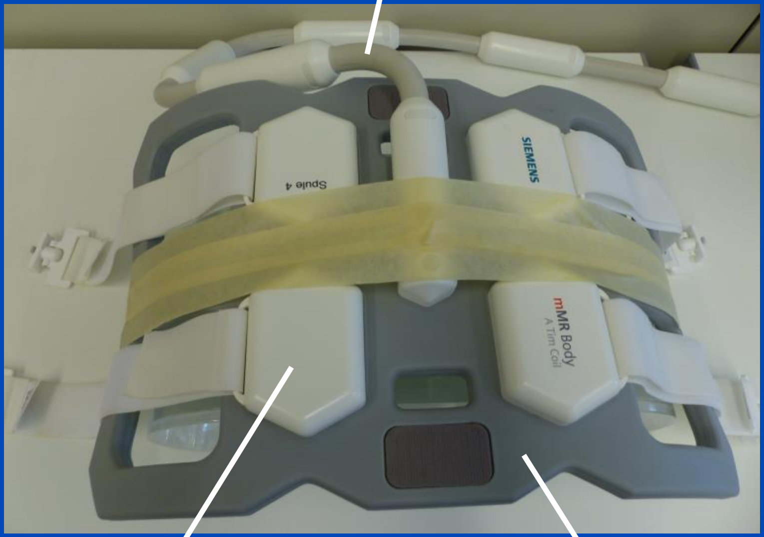
- Patient AC
  - Standard MR-based AC (MRAC) underestimates activity distribution
  - Recent approaches to improve MRAC
    - » Atlas-based methods
    - » Dedicated MR sequences (e.g., UTE, ZTE)
    - » Emission-based methods

- Hardware AC
  - Stationary components
    - » Patient table
    - » MR head coil
    - » Considered during AC using pre-acquired CT-based templates
  - Flexible components
    - » RF surface coils
    - » MR-safe headphones
    - » Positioning aids
    - » Not considered during AC in current clinical practice

Introduction

Radiofrequency (RF) Surface Coils

- **In (PET/)MR imaging, signal receiving RF surface coils are used to improve MR image quality**
  - **Standard equipment provided by the vendor**
  - **3 to 5 partially overlapping RF coils to cover entire torso**



Introduction

RF Coil Attenuation

- RF coils contribute to photon attenuation

Transversal | Coronal | Sagittal

CT

- RF coils are not visible in MR images

⇒ MRAC neglects RF coil attenuation

⇒ Activity is underestimated by up to 18%[1]

⇒ PET quantification is significanly impaired by the use of RF surface coils

[1] Paulus DH, Tellmann L, and Quick HH, "Towards improved hardware component attenuation correction in PET/MR hybrid imaging," *Phys Med Biol* 58(22):8021-40 (2013).

Introduction
Aim

- Improve PET quantification by emission-based estimation of the RF coil attenuation
- Joint estimation of attenuation and activity
  - Iterative approach based on the MLAA algorithm[1]
- Attenuation map only updated outside patient body outline
  - Only (flexible) hardware attenuation is estimated
  - Patient attenuation map is not modified
  - The proposed algorithm is called external MLAA (xMLAA)

[1] Nuyts J, Dupont P, Stroobants S, Benninck R, Mortelmans L, and Suetens P, "Simultaneous maximum a posteriori reconstruction of attenuation and activity distributions from emission sinograms," *IEEE Trans. Med. Imaging* 18(5), 393-403 (1999).

dkfz.

xMLAA[1]

Objective Function

- Objective function *Q*

$$Q(\boldsymbol{\lambda},\boldsymbol{\mu}) = L(\boldsymbol{\lambda},\boldsymbol{\mu}) + \beta_{\mathrm{S}} L_{\mathrm{S}}(\boldsymbol{\mu}) + \beta_{\mathrm{L}} L_{\mathrm{I}}(\boldsymbol{\mu})$$

- Log-likelihood *L*

$$L(\boldsymbol{\lambda},\boldsymbol{\mu}) = \sum_j \left(p_j \ln \hat{p}_j - \hat{p}_j\right)$$

with $\hat{p}_j = \frac{a_j}{n_j}\sum_i M_{ij}\lambda_i + \frac{s_j}{n_j} + r_j$

and $a_j = e^{-\sum_i \mu_i l_{ij}}$

- Smoothing prior L_S with weight β_S
- Intensity prior L_I with weight β_I

$\boldsymbol{\lambda}$	Activity
$\boldsymbol{\mu}$	Attenuation

i	Voxel index
j	LOR index
p_j	Measured projections
$\hat{p}_j$	Estimated projections
a_j	Attenuation factor
n_j	Normalization factor
s_j	Scatter
r_j	Randoms
M_{ij}	System matrix element
l_{ij}	Intersection length

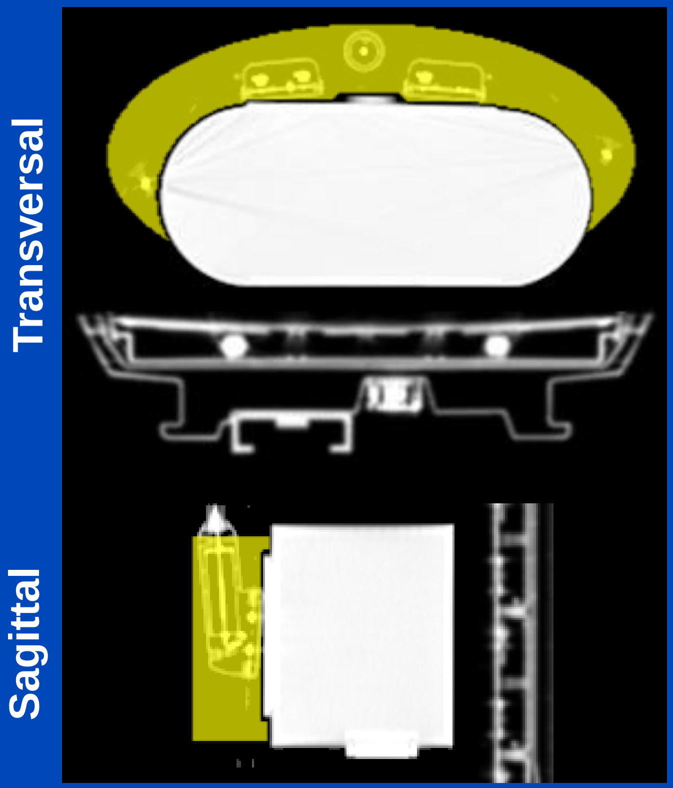
[1] Heußer T, Rank CM, Berker Y, Freitag M, and Kachelrieß M, “MLAA-Based Attenuation Correction of Flexible Hardware Components in Hybrid PET/MR Imaging,” accepted for publication in *EJNMMI Physics*.

dkfz.

xMLAA

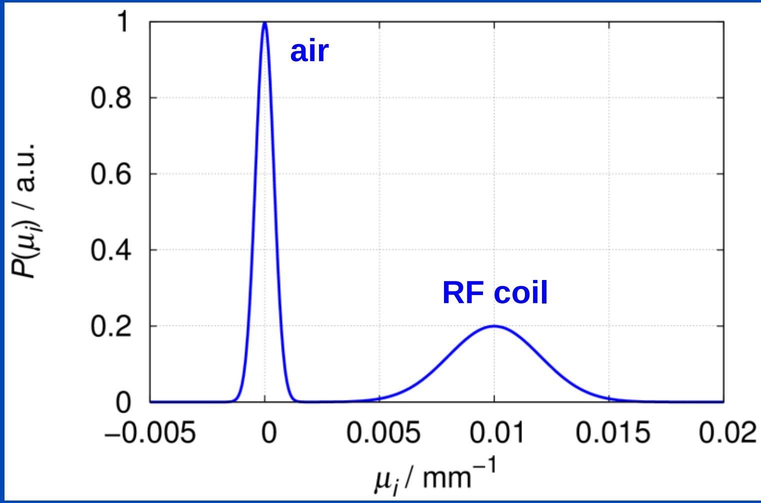
Hardware Mask

- Manually defined region where RF coil is assumed to be located
- Attenuation update only performed within region defined by hardware mask



Prior Expectations

- Intensity prior L_I
  - Favors the occurrence of pre-defined attenuation coefficients
  - Realized as bi-modal Gaussian probability distribution
    - » μ_{air} = (0.00 ± 0.0001) mm^{-1}
    - » μ_{RF} = (0.01 ± 0.0020) mm^{-1}
  - **Aim:** Suppress non-zero attenuation coefficients in the background while allowing for attenuation coefficients corresponding to the RF coil



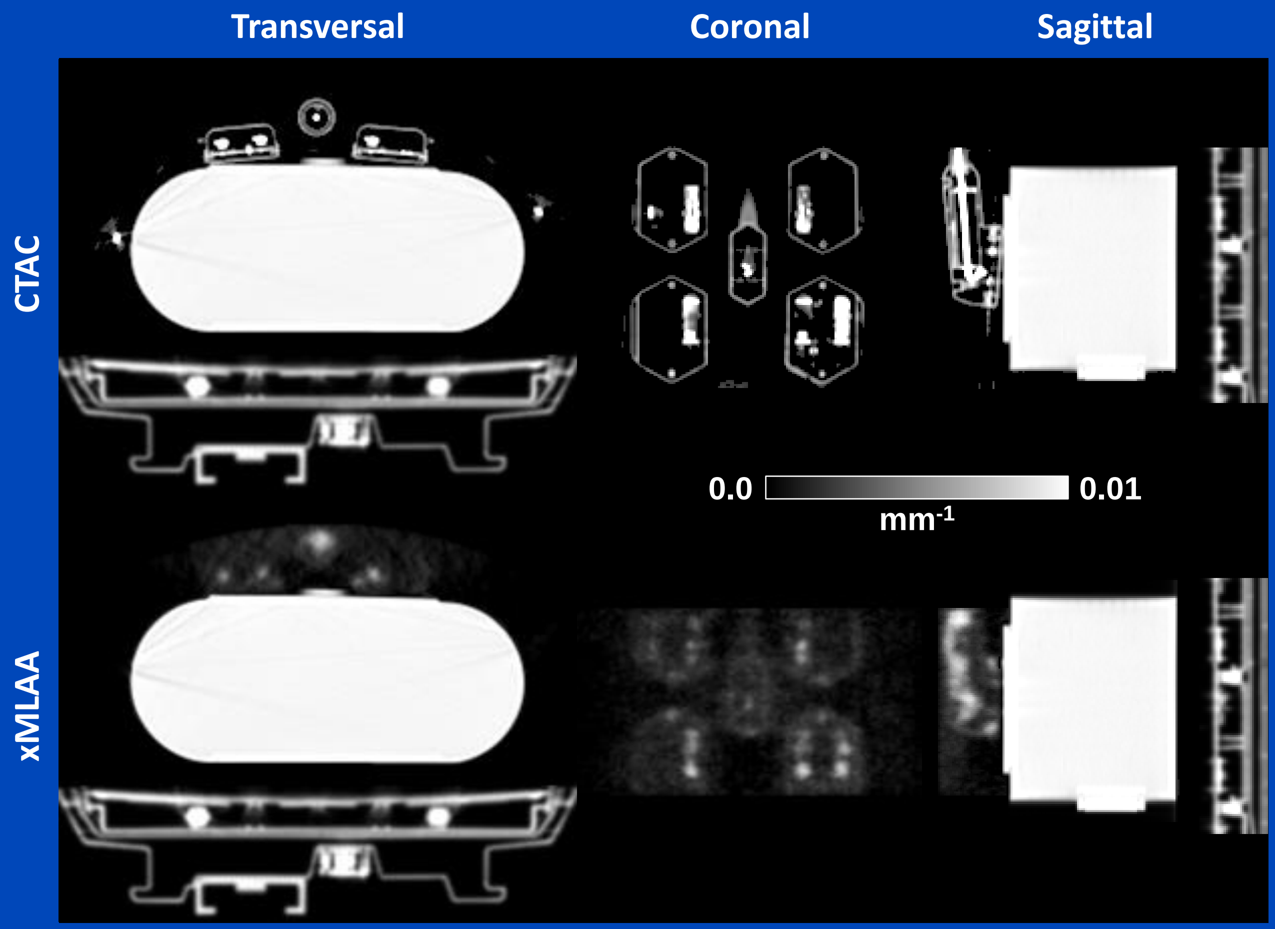
Phantom Data

Experiments

- **Pelvis phantom**
  - Plastic housing filled with water (11 L)
  - 55 MBq ^{68}Ga dissolved
  - Torso RF surface coil fixed with adhesive tape
- **PET/MR measurement**
  - Siemens Biograph mMR
  - Single bed position
  - 62×10^6 acquired counts
- **CT-based attenuation map**
  - With RF coil in identical position, the phantom was scanned with a clinical CT device (Siemens SOMATOM Definition Flash)

Phantom Data

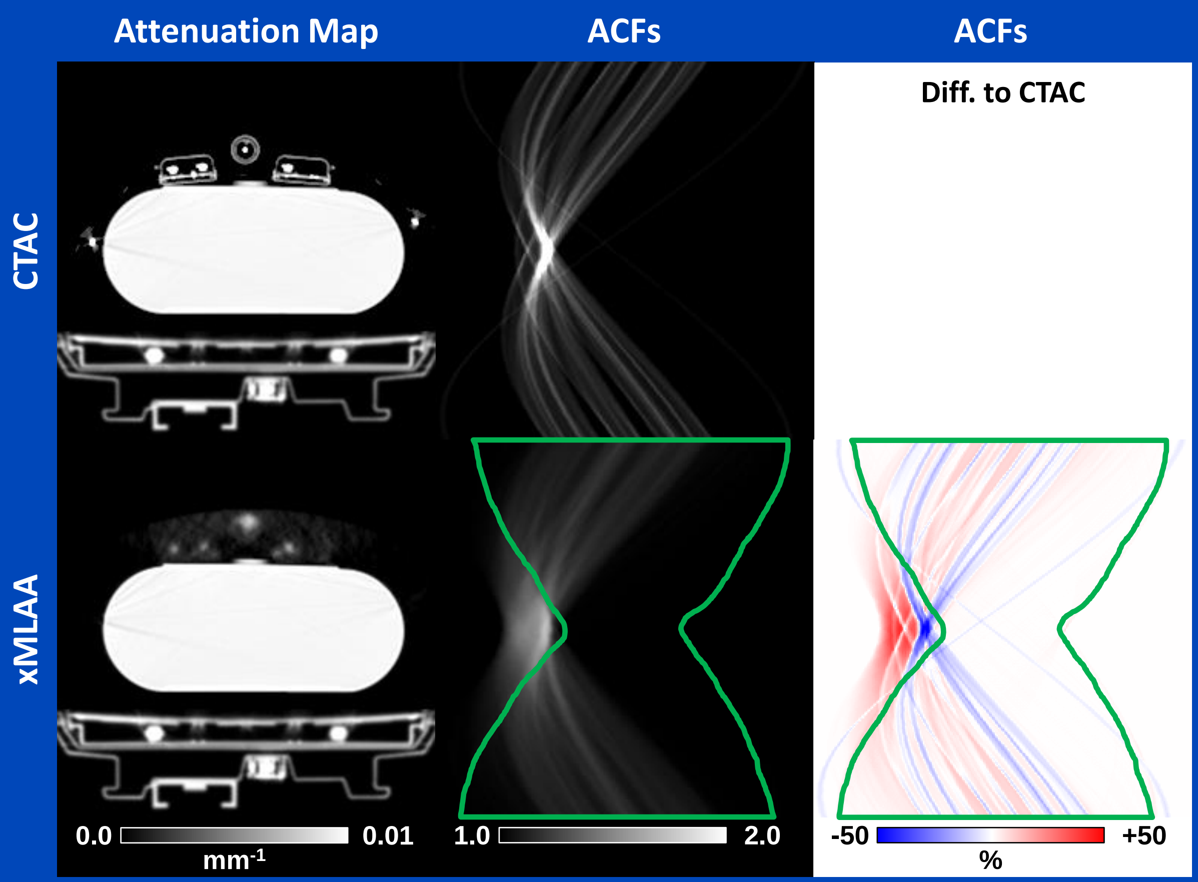
Attenuation Maps

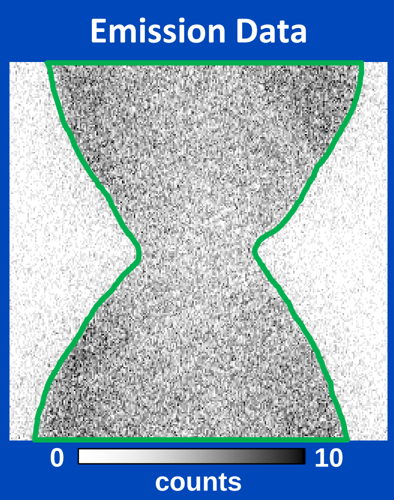


dkfz.

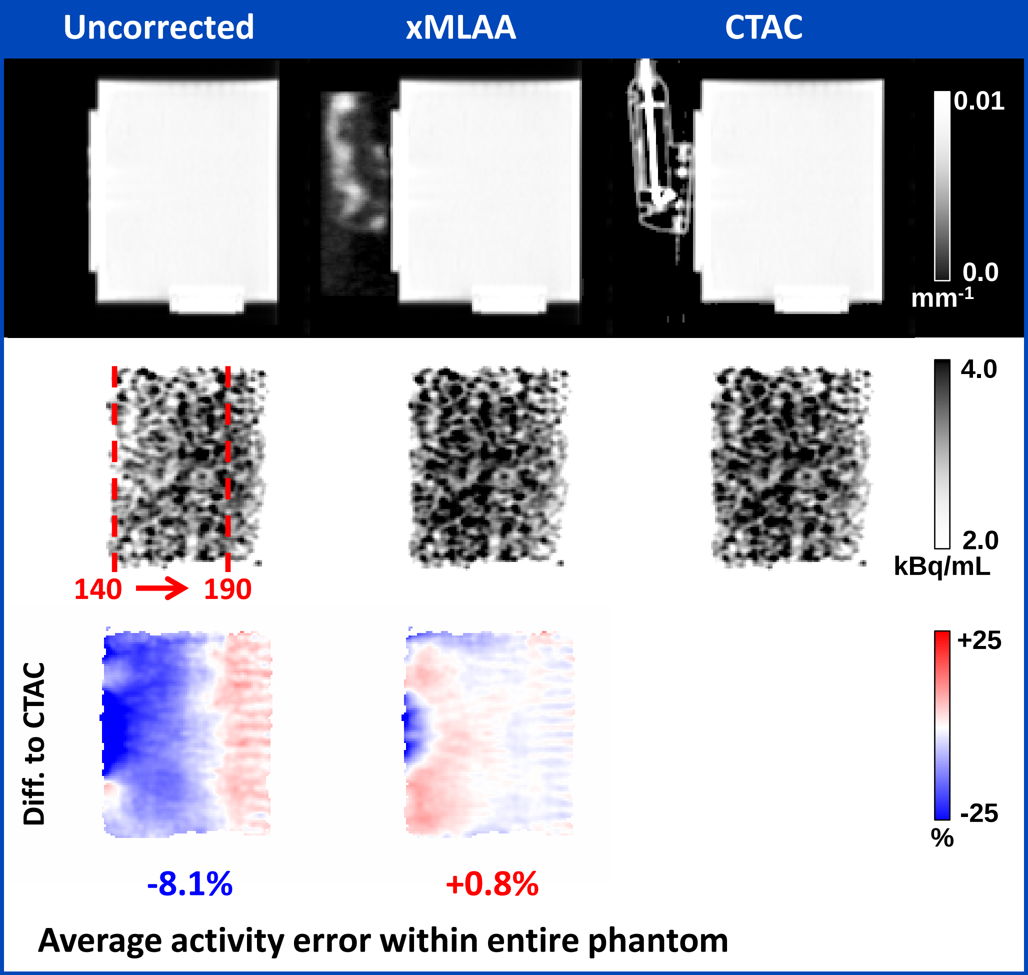
Phantom Data

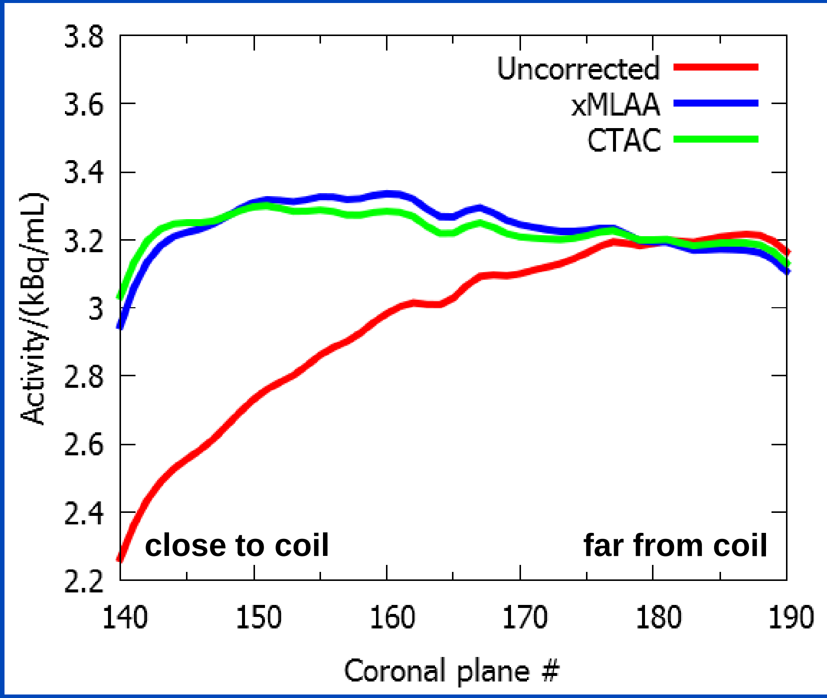
Attenuation Correction Factors





Phantom Data
Activity

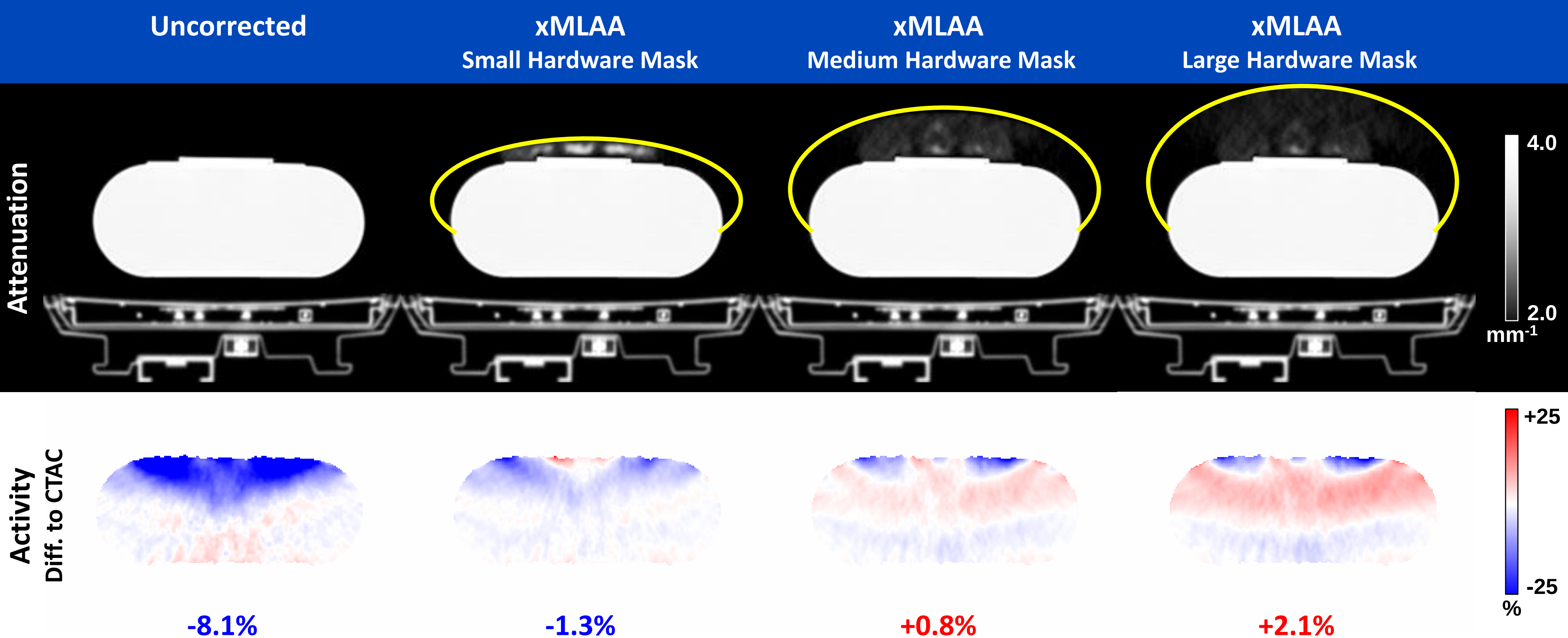




dkfz.

Phantom Data

Impact of Hardware Mask

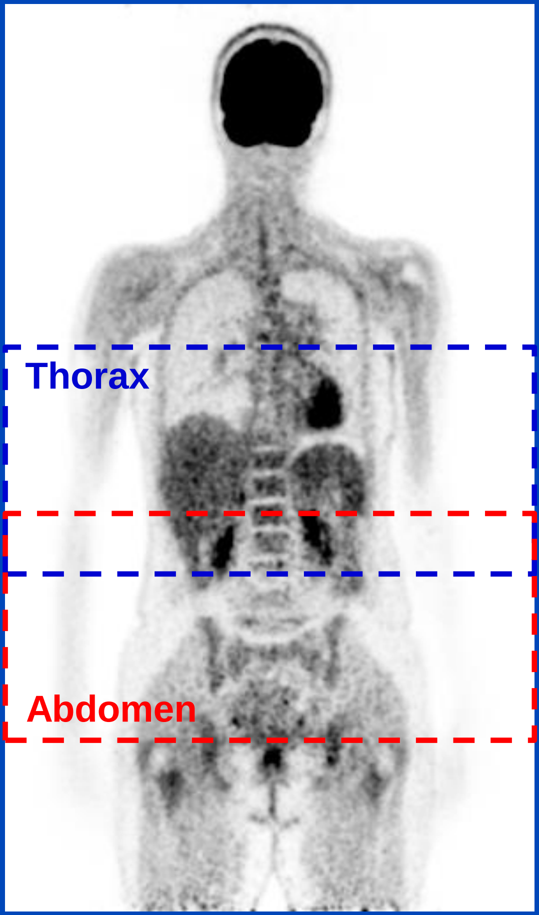


Average activity error within entire phantom (compared to CTAC)

Patient Data

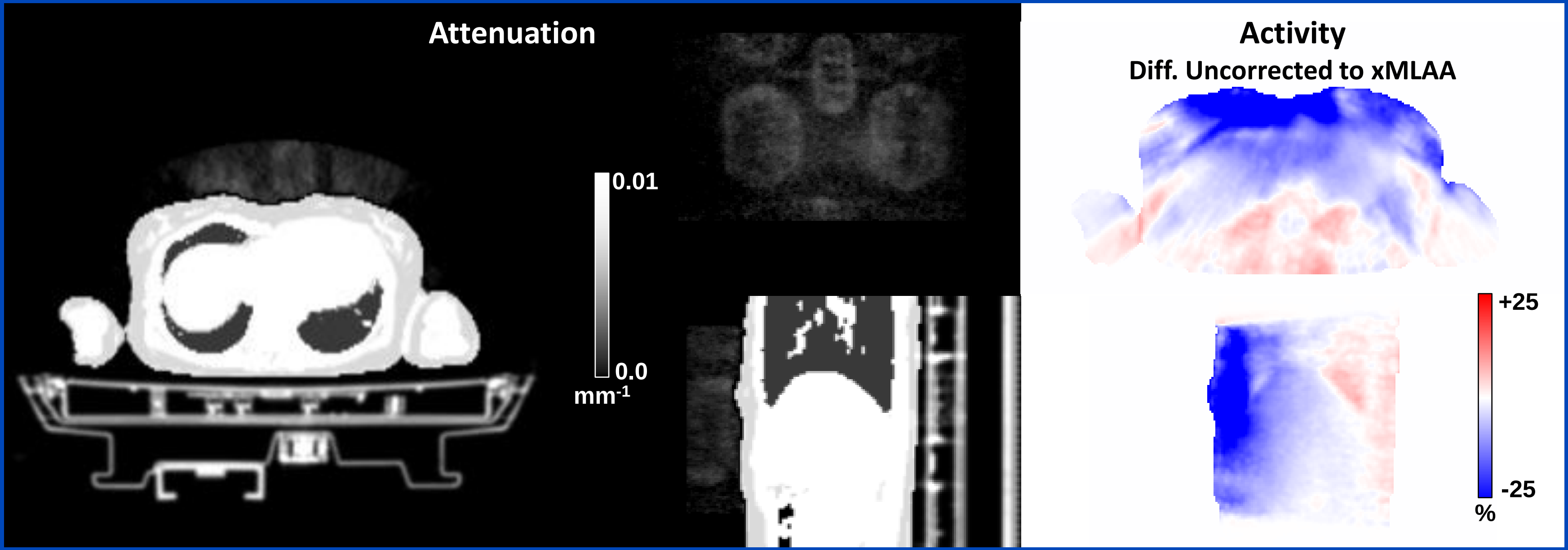
Data Sets

- **Five ^{18}F-FDG patients**
  - **Data acquired with Siemens Biograph mMR**
  - **4 min data acquisition per bed position**
  - **Only single bed positions investigated**
    - » **Lower Thorax ($65 \pm 8 \times 10^6$ counts)**
    - » **Abdomen ($64 \pm 6 \times 10^6$ counts)**
  - **Vendor-provided MR-based attenuation maps used for patient AC**
  - **CTAC not available for comparison**



Patient Data

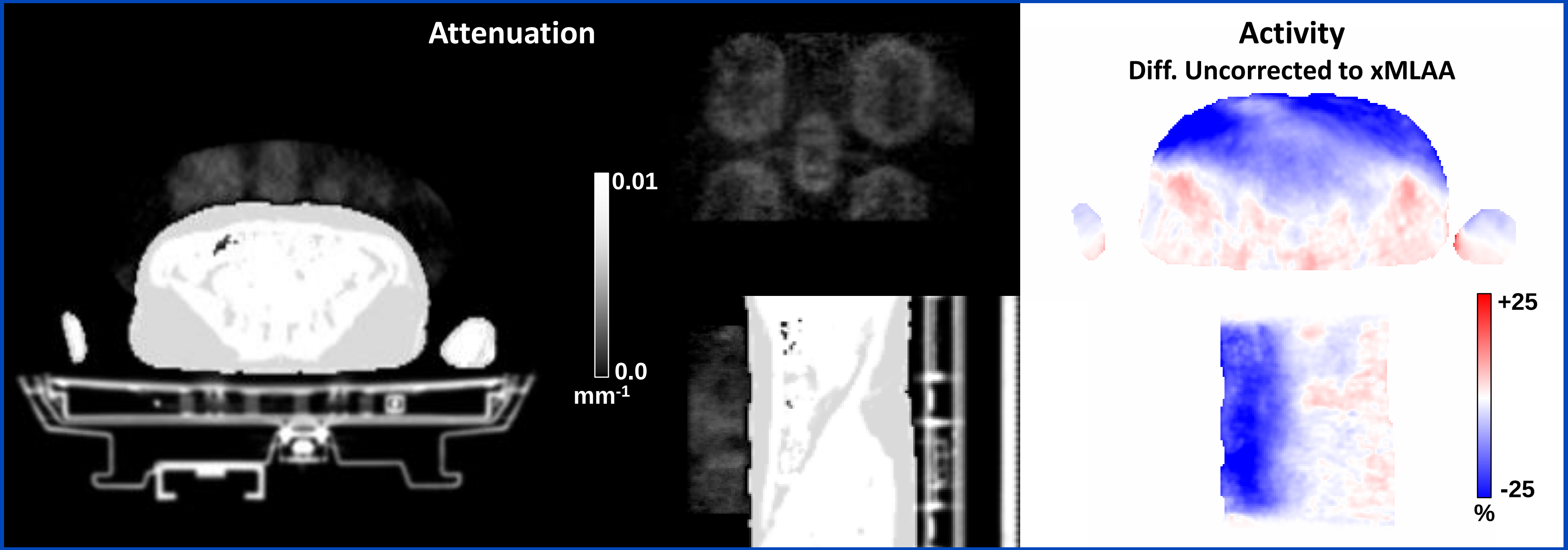
Results Thorax



- **Average activity underestimation across five patients when neglecting RF coil attenuation (uncorrected) to xMLAA: -5.3±1.2%**

Patient Data

Results Abdomen



- **Average activity underestimation across five patients when neglecting RF coil attenuation (uncorrected) to xMLAA: -6.1±0.9%**

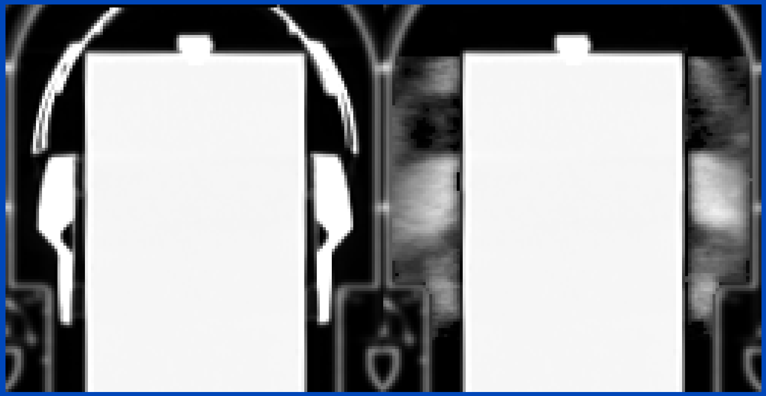
Conclusions

- **Phantom experiments**
  - **MRAC: -8.1 % average activity error compared to CTAC**
  - **xMLAA: +0.8 % average activity error compared to CTAC**
- **Patient data**
  - **Similar trends observed for clinical patient data**

$\Rightarrow$ **xMLAA for RF surface coil attenuation estimation can be employed to improve quantification in hybrid PET/MR imaging**

Outlook

- Quantitative evaluation of xMLAA for clinical data required (e.g. comparison with registration-based methods)
- xMLAA is also applicable for attenuation estimation of other hardware components (e.g. MR-safe headphones[1])



[1] Heußer T, Rank CM, Freitag M, and Kachelrieß M, "MLAA-Based Headphone Attenuation Estimation in Hybrid PET/MR Imaging," *IEEE Medical Imaging Conference Record,* M10B-1 (2016).

Thank You!

This presentation will soon be available at www.dkfz.de/ct

Job opportunities through DKFZ's international PhD or Postdoctoral Fellowship programs (www.dkfz.de), or directly through Marc Kachelrieß (marc.kachelriess@dkfz.de).

This work was supported by the Helmholtz International Graduate School for Cancer Research, Heidelberg, Germany.

Parts of the reconstruction software were provided by RayConStruct® GmbH, Nürnberg, Germany.

dkfz.