Background

Positron emission tomography (PET) and multiparametric magnetic resonance imaging (mp-MRI) are increasingly explored in radiation oncology. The clinical implementation of these complementary imaging modalities is hampered by the need of PET-MR image registration and potentially impaired by uncertainties in geometric information. The introduction of hybrid PET/MR scanners overcomes these issues but introduces new challenges. To assure similar patient positioning during imaging and therapy, specially manufactured flat table tops (FTT) are used. However, they cause additional attenuation and scatter which is not accounted for during PET image reconstruction. Thus, PET image quality (IQ) is significantly degraded. The goal of this phantom study was to evaluate the impact of a FTT on PET/MR IQ and to investigate possible correction methods.

Materials and Methods

PET images of a 12l canister filled with 40 MBq [18F]-FDG in an aqueous solution; (0.9% NaCl and 0.2mmol/l Gd-DOTA-butil) were acquired on a Siemens Biograph TrueV PET/CT and a Siemens Biograph mMR PET/MR. Measurements were performed with the canister positioned with and without the MR-compatible FTT. A transmission scan (PET-TS) of the FTT was performed on a GE Advance PET. MR markers visible also on PET were used for co-registration between modalities. An attenuation map (μMap) was derived from PET-TS and used to modify the MR-μMap for an additional reconstruction. All images were evaluated visually and by computing the uniformity index using a sliding window approach with a 5x5 voxel ROI (volume of 0.8ml) on a slice-by-slice basis. The result of the uniformity measurement was averaged over 20 central slices. Similar measurements were performed with a modified NEMA phantom (all spheres of the same volume 11.3ml) filled with FDG with in 8.1 activity ratio, and with a round cylinder. Activities measured in the spheres of the NEMA phantom and longitudinal activity profiles in the cylinder were compared between PET/CT and PET/MR. To assess the influence of the FTT on the MR image the signal to noise ratio (SNR) was measured using a Siemens sphere phantom filled with 7.3 liter solution of Bayol-Oil and Macrolue blue, positioned in the magnetic isocenter. Ten T1w acquisitions (AQ) were performed with and without the table. The SNR defined as $\frac{\text{Signal}}{\Sigma \text{standard deviation of background}}$ was calculated voxelwise and convoluted with a 3x3x3 averaging kernel.

Results

The best IQ was found in PET/CT without FTT (non-uniformity: 17%, Fig. 2A). Compared to these images, PET/MR images were degraded (non-uniformity: 25%, Fig. 2C). PET/CT with FTT exhibited attenuation artifacts (non-uniformity: 22%, Fig. 2B). In PET/MR scans both scatter and attenuation artifacts were observed (non-uniformity: 46%, Fig. 2D). IQ could be improved significantly by the FTT’s PET-TS μMap (non-uniformity: 26%, Fig. 2E).

The ratio $\frac{\text{MAX}_{\text{PET/MR}}}{\text{MAX}_{\text{PET/CT}}}$ of the mean activity measured in the six spheres of the modified NEMA phantom were as follows (without and with the FTT respectively): in PET/CT 1.7% and 6.2%; in PET/MR 2.6% and 6.8%. The longitudinal activity profiles measured in the cylinder are shown in Fig. 3. The measured activity dropped in the proximity of the FTT compared to the cylinder center by 22.5% in the PET/CT and by 33.2% in PET/MR. Additionally, 12.2% activity deficit was recorder in the top part of the cylinder, in the close vicinity of the phantom’s wall.

Conclusion

Although the non-uniformity measure provides an indication for IQ, it is of limited use for evaluating systematic artifacts caused by incorrect corrections. The incorrect attenuation visible in PET/CT images is caused by the transformation from CT attenuation to PET attenuation that is not valid for materials used in the FTT. A PET-TS can be used to derive a μMap and to reduce artifacts in PET/MR. Further improvements are currently explored by improving the quality of the PET-TS μMap and by its better integration into the reconstruction.

Outlook

We hypothesize that in PET/MR the attenuation correction based on PET-TS μMap results in significantly higher IQ than if a CT based μMap is used. Appropriate comparative studies are ongoing.

The financial support by the Federal Ministry of Science, Research and Economy and the National Foundation for Research, Technology and Development is gratefully acknowledged.

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