Whole-body concept for integration of hybrid PET/MR imaging into radiation therapy treatment planning

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Target Audience: Researchers and physicians who are working in the field PET/MR hybrid imaging or in the field of radiation therapy planning.

Purpose: Magnetic resonance (MR) imaging and positron emission tomography (PET) have become important imaging modalities in radiation therapy (RT) treatment planning. MR, on the one hand provides excellent soft tissue contrast and highly specific anatomical information and PET, on the other hand enables highly specific metabolic information. Both modalities improve the accuracy of target volume delineation for precise RT treatment planning. Whole-body hybrid PET/MR scanners combine both modalities [1] and might play an important role in modern RT planning. A first intensity-modulated radiotherapy (IMRT) treatment planning with ^{68}Ga-DOTATOC-PET/MR has been performed and evaluated [2], but without dedicated RT equipment, which is necessary for reproducible patient positioning at all imaging modalities. It includes a flat RT table overlay, positioning aids and RF coil holders for MR or PET/MR imaging, since the RF coils should not touch the patient's body as they do in routine MR imaging using RF surface coils. Furthermore, for all RT hardware components placed in the PET field-of-view, attenuation correction (AC) needs to be performed to provide correct tracer quantification in the target lesions. First PET/MR RT equipment was presented and evaluated for head imaging on a hybrid PET/MR system [3], but thus far not as a whole-body concept. Thus, this study introduces new RT equipment for a hybrid PET/MR system allowing for whole-body imaging. AC of all hardware components is provided by the modular concept of a umap generator. The devices are tested for PET and MR compatibility and are evaluated with a phantom scan as well as with a first patient study.

Methods: Prototype RT devices (Qfix Systems, Avondale, PA, US) have been developed that allow for whole-body imaging on a hybrid PET/MR system (Biograph mMR, Siemens AG, Erlangen, Germany) for integration of PET/MR into RT treatment planning. (1) A flat RT table overlay, equipped with a Varian Exact® style indexing system and small bore holes at the head part for fixing a thermoplastic facemask is placed on top of the spine array RF coil of the hybrid PET/MR scanner (see Fig. 1A). (2) Two RF body bridges (BBs) each fixing a body matrix RF coil (6-channels) at any predefined z-position by using the indexing system (Fig. 1B). The BBs are adjustable in three different heights allowing for individual positioning of the RF coils depending on the patient's size. Positioning accuracy of the BBs has been evaluated using ^{68}Ge rod-sources attached to the surface of the body matrix RF coil and the set has been mounted and unmounted 5 times. PET image quality and quantity was evaluated using a homogenous PET phantom and a first ^{18}F-FDG study on a patient has been included. For both acquisitions, a scan without the BBs was performed as a standard of reference. AC of all RT devices has been included using a umap generator that produces a specific umap depending on the mounted RT devices and the position, direction, and height of the BBs as illustrated in Fig. 2.

Results: Both devices are MR compatible. No MR signal was detected and the MR shim was not disturbed. Position accuracy of the BBs using ^{68}Ge rod-sources was within 1 mm in all three dimensions, when mounted accurately. PET attenuation in the phantom due to one BB (with the body matrix RF coil attached) was calculated to be 15.5±2.8% in the top part close to the BB. In the center of the phantom, the deviation was calculated to be 7.3±2.3%. When the BB is considered in AC using a CT-based umap, the error is reduced to 3.7±1.5% in the top part and 0.1±1.7% in the center. A transaxial slice of an MR 2D spin echo sequence is shown in Fig. 3A for the routine PET/MR setup and 3B for the RT setup. The overall umap of the patient scan, including MR-based umap of the patient and CT-based umap of all used hardware components is shown in Fig. 4A and a superimposed PET/MR image of the patient's left foot showing an increased FDG uptake is shown in Fig. 4B. If the BBs are disregarded in PET AC, the standard uptake value (SUV_{mean}, 50% max contour) is decreased about 13.8% in the increased FDG uptake of the patient compared to the scan without BBs. With AC of the BBs the error is reduced to 4.0%, which is comparable to the phantom scan.

Discussion: Handling of the new RT equipment was easy and the indexing system, in combination with the height adjustability of the BBs allows for exact positioning of the RF body matrix coils for individual patient sizes. A slight loss of MR signal intensity was observed with the RT setup, but image quality was comparable to the routine PET/MR setup. The signal loss was expected due to the larger distance between RF coils and patient, which is necessary, because they should not deform the patient's body. The loss of PET signal due to the BBs was calculated to be around 15% in the region close to the BBs, which is comparable to former studies with the body matrix RF coil only. With the CT-based AC of the BBs the underestimation is reduced to below 4%, which shows the accuracy of the generated umap. The remaining 4% might result from disregarding the cable of the RF coil with its baluns, which has a different position in each scan and is thus not included in PET AC [4].

Conclusion: The new RT devices for integrating PET/MR into RT treatment planning are PET/MR compatible and enable whole-body RT imaging on a hybrid PET/MR system. The RF body bridges can be adapted in height and mounted at different standardized z-positions of the RT indexing system allowing for individual patient sizes and scan regions.

References:

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[4] Kartmann et al. Med. Phys. 2013;40(8):082301

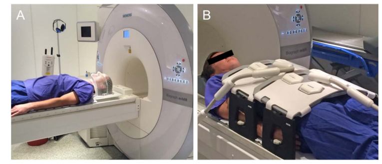

Fig. 1: *(A) RT setup with an individual thermoplastic facemask attached to the flat RT table overlay on a hybrid PET/MR scanner. (B) Setup with two BBs each fixing a body matrix RF coil mounted on the flat RT table overlay.*

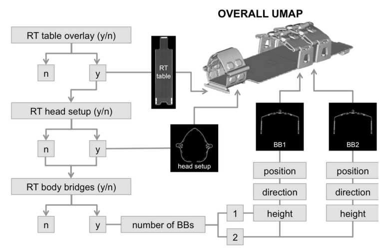

Fig. 2: *Drawing of the umap generator for a whole-body RT concept on a hybrid PET/MR system. Each device can be added separately and the BBs are added depending on their height, orientation, and position.*

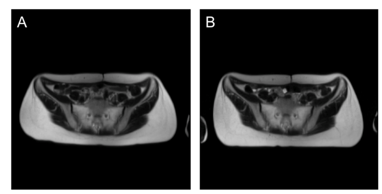

Fig. 3: *Transaxial slice of an MR 2D spin echo sequence comparing the routine PET/MR setup (A) and the PET/MR RT setup (B). Note the flat back of the patient with the RT setup, while slightly curved with the routine setup. MR image quality is comparable between both scans.*

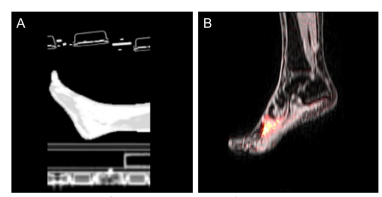

Fig. 4: *(A) Overall umap of the patient scan (one bed position), including MR-based umap of the patient and CT-based umap of the BBs, the patient table, and the spine RF coil. (B) Superimposed PET/MR image of the patient with increased FDG uptake in the left foot.*