Integration of PET/MR hybrid imaging into radiation therapy treatment planning

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

Purpose: Magnetic resonance (MR) imaging has become an important part in radiation therapy (RT) treatment planning. Excellent soft tissue contrast and the potential use of functional imaging can improve the accuracy of target volume delineation [1]. Furthermore, positron emission tomography (PET) is increasingly used as an additional imaging modality [2]. Integrated PET/MR combines both modalities and might play an important role in future when it comes to exact RT planning [3]. For accurate patient positioning during PET/MR acquisitions, a flat RT overlay and positioning aids are necessary that have to be MR- and PET-compatible. While carbon fiber-based tabletops used for CT imaging are not MR compatible, MR tabletops mostly consist of high attenuating glass fibers, which dramatically reduce the PET signal and might produce PET image artifacts. Furthermore, local radiofrequency (RF) coils have to be used for high quality MR imaging without touching and deforming the surface of the patient. Thus, coil holders (CH) are usually used in MR-based RT planning that have to be optimized towards photon attenuation if used in PET/MR imaging.
In this work, a flat prototype RT overlay and CHs for head imaging are introduced that are suitable for patient positioning in hybrid PET/MR imaging. Both devices have been evaluated towards PET and MR compatibility. MR image quality has been tested and compared to the actual PET/MR setup. PET photon attenuation has been evaluated by phantom scans and attenuation correction (AC) methods of both devices are presented. Usage of the new RT setup in PET/MR imaging has also been illustrated with an *in vivo* study on two patients.

Materials and Methods: Prototype RT devices (Qfix, Avondale, PA, USA) have been developed for an integrated PET/MR hybrid system (Biograph mMR, Siemens AG Healthcare, Erlangen, Germany) and evaluated towards MR and PET compatibility. (1) RT overlay that consists of plastic with a foam core and a Varian Exact® Sytle Indexing system. The overlay is placed on top of the spine array RF coil of the scanner and fits into the fixation system of the head part on the patient table (Fig. 1A). (2) Two coil holders that each fixes one flexible body matrix RF coil into a C-shape (Fig. 1B) to use it for head imaging as shown in Fig. 1C.
Disturbance of the MR shim and potential signal detection of both devices have been evaluated by a field sequence and a gradient echo sequence with a very short echo time (TE = 2.21 ms), respectively. MR SNR measurements of the RT head setup (two 6-channel body matrix RF coils, Fig. 1C) with a homogeneous phantom and a healthy volunteer are compared with the actual PET/MR setup (16-channel head/neck RF coil). Furthermore, the PET compatibility has been evaluated with active PET phantom scans, one for the RT overlay and another for the CHs (Fig. 1C/D). CT-based μ-maps for both devices have been generated and tested. The accuracy of repeated CH positioning, necessary for appropriate PET AC has been evaluated with ^{68}Ge rod-sources attached to the CHs. The setup was mounted and taken off several times and a PET acquisition was performed between each cycle. To illustrate the implementation of the RT devices into the PET/MR system, an ^{18}F-FDG *in vivo* study on two initial patients has been included, where a scan without the CHs was performed as a standard of reference.

Fig. 1: *(A) RT overlay, (B) RT coil holder with a RF coil, (C) RT head setup, and (D) active phantom setup for PET measurement of the RT overlay used in an integrated PET/MR system.*

Results: MR measurements show that both devices, RT overlay and RT coil holders are MR compatible. No MR signal was detected from the devices and the MR shim was not disturbed. SNR maps of the phantom for the RT head setup and for the actual PET/MR setup are shown in Fig. 2. SNR is calculated to be around 20% higher with the standard head/neck RF coil. MR Images of both setups with a MPRAGE sequence are shown in Fig. 3. The positioning accuracy of the CHs was calculated to be around 4 mm, which is approximately the PET resolution. PET phantom measurements result in 4% – 6% photon attenuation by the RT overlay and around 15% signal loss by the CHs including the RF coils. When considering the RT devices in PET AC, the difference bias is reduced to around 1% for the RT overlay and to around 2% for the CHs. Difference images of the activity concentration of the patient's brain are shown in Fig. 4 for disregarding the CHs in AC (top) and considering it in AC (bottom). As evaluated with the phantom scans, activity concentrations deviate by around 15% if CHs are not attenuation corrected, while only small deviations are observable after AC of the CHs.

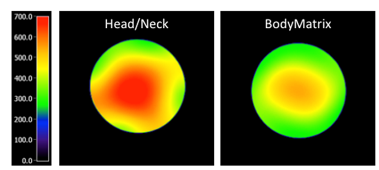

Fig. 2: *MR SNR maps of a homogenous phantom for the new RT setup (2 x 6-Ch body matrix RF coils, left) and the actual PET/MR setup with the head/neck RF coil (16-Ch, right).*

Discussion: Both RT devices are MR compatible, but a slight loss in SNR was measured for the RT head setup compared to the actual PET/MR setup with the head/neck RF coil. This was to be expected since the distance of the body matrix RF coils to the head is larger than with the head/neck RF coil. This is also observable in the MR images of the volunteer, however no other significant differences are observable. PET measurements yield a relatively low attenuation by the RT overlay (4%) but a higher attenuation (15%) by both CHs with RF coils, which is also observable in the patient study. Positioning accuracy was measured to be around the PET resolution of 4 mm, which is in the range of acceptance for the CHs and the flexible body matrix RF coil as reported in former studies [4]. Thus AC of the CHs and the RT overlay can be performed and shows very good results with 1% deviation to the reference scan for the RT overlay and 2% deviation for the CHs.

Conclusion: The newly developed RT devices are compatible for MR and PET imaging and thus PET/MR hybrid imaging can be integrated into RT treatment planning. Handling of the RT overlay and the CHs in clinical practice is straightforward. Planning the RT and AC of the accessory RT devices can be performed by using CT-based μ-maps.

References:

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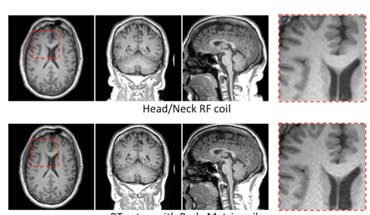

Fig. 3: *MPRAGE images of a healthy volunteer with the actual PET/MR head setup (16-ch head/neck coil) and with the RT setup (two 6-ch body matrix RF coils).*

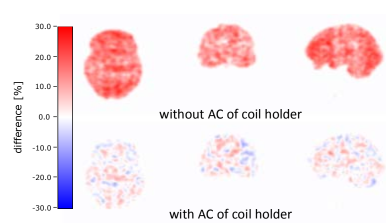

Fig. 4: *PET difference images (in percent) of the activity concentration without (top) and with (bottom) AC of the CHs. The reference scan was acquired without CHs.*