Pushing X-ray CT out of the equation: In vivo RASOR MRI-based seed detection for post-implant dosimetry in LDR prostate

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Introduction: Postimplant dosimetry is a crucial quality assurance measure for permanent seed low dose rate (LDR) prostate brachytherapy as it facilitates efficacy prediction, outcome evaluation and treatment optimization. Recently, a correlation between the D90 (minimal dose on 90% of the prostate) and biochemical control was established based on postimplant dosimetry[1], underlining the importance of treatment optimization. In recent years, X-ray CT has been the modality of choice for the visualization of brachytherapy seeds for postimplant dosimetry. However, nowadays these CT images are preferentially fused to MR images, since CT faces difficulties in accurate contouring of the prostate due to poor soft tissue contrast, whereas MRI exhibits superior soft tissue contrast[2]. Although image fusion exploits the best of both modalities, it may introduce registration errors related to interscan movement. Furthermore, such an approach is cost inefficient since it requires multi-modal imaging and laborious processing. Therefore, it would be favorable if MRI could be used to both accurately depict the seeds and delineate the prostate, enabling fully MRI-based postimplant dosimetry. The feasibility of MRI to accurately depict brachytherapy seeds located in phantom setups was recently demonstrated by our group, using a method called center-out radial sampling with off-resonance reconstruction (co-RASOR). Here, the feasibility to depict brachytherapy seeds *in vivo* using co-RASOR, eventually aiming at fully MRI-based postimplant dosimetry, will be investigated and qualitatively compared to conventional X-ray CT.

Methods: *Imaging sequence:* The original co-RASOR imaging technique was a fully frequency encoded radial center-out 3D ultrashort TE (UTE) acquisition method, which incorporated a non-selective block pulse to obtain a large excitation bandwidth[3]. By introducing a frequency offset, Δf_0, to the central reception frequency, f_0, either during signal reception[3] or retrospectively during reconstruction[4], small paramagnetic objects such as brachytherapy seeds can be visualised at their exact location with high positive contrast[3,4]. *Sequence optimization:* To optimize the imaging sequence for *in vivo* use, accounting for *in vivo* conditions including breathing (varying dB_0), inhomogeneous tissue (water-fat, flow), the large FOV and time constraints, several aspects of the original co-RASOR technique were reconsidered. The aspects investigated included the excitation pulse, the 3D center-out sampling scheme and ultrashort TE, readout BW, image contrast (balanced), the number of averages and fat suppression (TFE factor and direction). *Optimal imaging parameters:* 3D Stack-of-Stars balanced Turbo Field Echo (bTFE) with SPAIR fat-suppression (220Hz offset) and full profile sampling; TFE factor = 30 (in slice dir.); TR/TE =3.3/1.6ms; BW = 1085 Hz; NSA = 2; density of angles = 90%; total scan time = 3min24sec.Other imaging parameters included a field strength of 3T (Philips Achieva TX), FOV = 250x250x90 mm, scan matrix 250x250x45; recon. matrix = 512x512x90; flip = 25. *Processing:* Off-resonance reconstructions were obtained retrospectively using Δf_0=2KHz[4]. To demonstrate the effect of RASOR reconstruction, the relative signal increase was calculated by dividing the off-resonance image (Fig. 1b) by the onresonance image (Fig. 1a), as presented in Fig. 1c. The final background-suppressed (bs) RASOR image (Fig. 1d) was obtained by subtracting the onresonance image twice from the offresonance image. For visualization purposes, orthogonal maximum intensity projections (MIP's) were made from the bs-RASOR data after rigid registration to the CT data, as depicted in Fig. 2b I, II, III. For comparison, orthogonal maximum intensity projections (MIP's) were made from CT images of the same region. *Patients:* Four patient who underwent permanent seed prostate brachytherapy and standard dosimetry (CT and MRI based) at 1 month postimplant received 1 to 3 additional MRI scans for sequence optimization according to the methods just described.

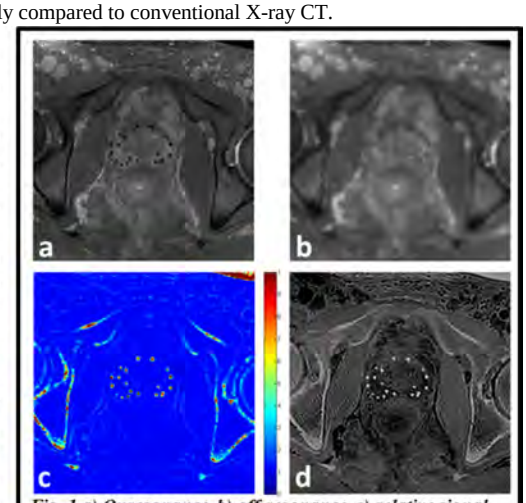

Fig. 1.a) Onresonance, b) off-resonance, c) relative signal increase (scale 0-10) and d) background-suppressed RASOR image of the prostate after permanent seed brachytherapy.

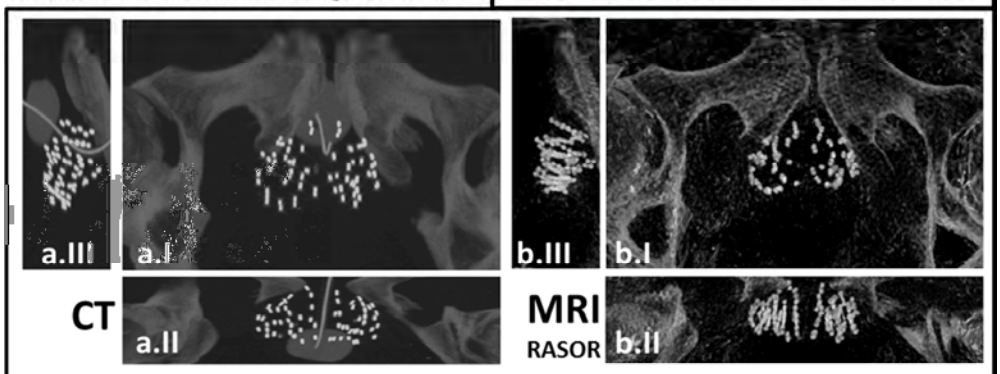

Fig. 2. a I,II,III) Orthogonal MIP's of a 3D CT dataset, depicting seeds, bone and a urinary catheter. b I,II,III) Orthogonal MIP's of a 3D background-suppressed RASOR dataset rigidly registered to the CT data using the bone structures, also depicting both the seeds and the bone in a fluoroscopic representation.

Results & discussion: Sequence optimization resulted in the following parameter choices: slab-selective excitation was chosen to reduce the excited volume, limiting back-folding and the total acquisition time. As a consequence, a radial stack-of-stars sampling scheme was applied with full profile sampling instead of center-out sampling and no UTE. The relatively longer echo time in combination with a 'balanced' gradient scheme and SPAIR fat-suppression resulted in high SNR and particularly well localized and sharp signal voids at the locations of the seeds. Fat suppression prevented water-and-fat related out-of-phase signal voids which could be misinterpreted as seeds after RASOR processing. For SNR purposes two signal averages were chosen. The optimized RASOR imaging sequence enabled accurate depiction of the brachytherapy seeds with high positive contrast and high specificity. The effective background suppression enabled seed visualisation in a fluoroscopic way (Fig. 2.b). Interestingly, the bs-RASOR technique depicted bone structures with relatively high values, enabling 3D rigid registration of MRI (fig. 2b) to CT (Fig. 2a). Whereas bone structures were successfully registered, the MIP's in Fig. 2 clearly show differences in the positioning of the seeds in MRI and CT, most likely related to differences in bladder and rectum filling volume and interscan patient position. When fusing CT and MRI for postimplant dosimetry, these differences will most likely cause discrepancies between the actual dose pattern and the dose estimate. If and to what extent this is true, is currently under investigation. An MRI-only approach would not suffer from these differences, since the onresonance image (Fig. 1a) of the exact same scan can be used for prostate delineation, facilitating perfect registration. The fact that a seed is depicted as a 'dumbell-shaped' hyperintensity, as thoroughly described and demonstrated in previous work[3,4], should be taken into account when performing fully MRI-based postimplant dosimetry. Finally, a highly favourable property of the presented imaging technique is its ability to visualize bone structures, enabling MRI to CT image registration.

Conclusions: This study demonstrates the feasibility of *in vivo* MRI-based localisation of implanted brachytherapy seeds with positive contrast and high specificity, using a robust, clinically available imaging sequence with RASOR reconstruction and straightforward post-processing.Other applications of this technique may be bone and fiducial imaging for MRI-based treatment planning in external beam radiotherapy, bone imaging for dose calculation and attenuation correction in PET-MRI.

References: [1]Henry AM et al. Int.J.Rad.Oncol.Biol.Phys.2010;76,1,50–56., [2]Brown AP et al. Brachytherapy. 2013;12(5):401-7., [3]Seevinck PR et al. Magn Reson Med. 2011;65(1):146-56., [4]de Leeuw H et al. Magn Reson Med. 2013;69(6):1611-22.