Fast and reliable localization of brachytherapy seeds using undersampled co-RASOR

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Introduction Prostate brachytherapy by Iodine-125 seeds is a common treatment modality for localized prostate cancer. An important aspect in such a treatment is intra-operative and post-implant dose evaluation, which relies on accurate localization of implanted seeds relative to the surrounding organs. In current clinical practice, the seeds are localized intra-operatively using ultrasonography (US)[1]. However, seed localization is difficult on US and therefore post-implant dosimetry is a valuable tool in maintaining a high quality implant program[2]. Post-implant dosimetry is based on CT imaging because of excellent seed localization. Prostate visualization and delineation, however, are poor on CT and it is therefore often combined with MRI[1,3], which does provide excellent soft tissue contrast. To eventually enable post-implant dosimetry, the different imaging systems need to be calibrated or some kind of co-registration step needs to be performed[1,3]. Both methods are error-prone and time-consuming. Furthermore, if possible, the use of X-ray should be minimized to reduce the integral radiation dose. The ideal imaging method should therefore not involve X-ray radiation, should provide both excellent soft tissue contrast as well as a good localization of the implanted seeds, preferably in an acquisition time as short as possible, to prevent the influence of movement. Ultimately, this method would allow accurate seed localization in real-time MR guided interventional procedures making post-implant dosimetry superfluous[4].
Our group has recently presented an MR imaging technique capable of depicting small paramagnetic structures with high positive contrast and high accuracy. This imaging method, center-out RAdial Sampling with Off-Resonance reception (co-RASOR)[5], is a 3D imaging technique which in its current form takes at least several minutes, depending on the image resolution and the field-of-view. The aim of this work is to investigate the use of undersampling to reduce imaging time while preserving the high positive contrast necessary to accurately localize the implanted seeds. X-ray CT images will be acquired as a reference.

Methods *Imaging sequence* The co-RASOR imaging technique is a fully frequency encoded 3D ultrashort TE (UTE) acquisition method, which utilizes a large excitation bandwidth and off-resonance reception. Without off-resonance reception, the magnetic field disturbance induced by a small paramagnetic object causes a sphere-shaped signal pile-up typical for 3D radial center-out sampling. By manually introducing an offset, Δf_0, to the central reception frequency, f_0, the radial signal pile-up caused by the magnetic field disturbance can be shifted towards the source of the field disturbance, resulting in a hyperintense signal at the exact location of the small paramagnetic object[5]. *Phantom* Brachytherapy seeds were introduced in a 7-cm-thick highly inhomogeneous piece of porcine tissue containing fat, connective tissue, and bone, submersed in agarose gel, and doped with 32 mg/ml $MnCl_2$ to adapt the T_1 value. Four brachytherapy seeds were introduced in such a way that two seeds were aligned with B_0 and two perpendicular to B_0. The brachytherapy seeds measure 0.8x4.5 mm and consist of a silver core in a titanium tube with hemispherical ends, as schematically demonstrated in Fig. 1. The paramagnetic titanium ends induce the strongest susceptibility effects and represent two magnetic centers. *Imaging* Co-RASOR imaging was performed on a 3T clinical scanner (Philips Healthcare, Best, Netherlands) as described in ref [5], using an f_0 offset of 1214Hz, which is equal to one pixel shift. A water-fat in-phase echo time was chosen, leading to the following timing parameters: TR/TE1/TE2 = 5.8/0.08/2.3 ms with scan time = 179 s when applying a density of angles (DoA) of 100% with a scan matrix of 128^3, reconstructed to a voxel size of 0.8 mm (160^3). Long T_2^* suppression was accomplished by subtracting the echo from the UTE image. To investigate the feasibility of undersampling, the exact same scan was repeated with DoA = 60% and 20%, leading to scan times of 106 s and 36 s. Finally, to really speed up the acquisition, single echoes were acquired (TR/TE = 3.2/0.07 ms) with DoA = 20% and 10%, leading to scan times of 21.8 s and 11.5 s for the 3D dataset. Co-RASOR images were qualitatively compared with high resolution X-ray CT images acquired on a 64-slice clinical CT scanner (Brilliance, Philips Healthcare, Best, The Netherlands) with a tube voltage of 120 kV, detector slice thickness of 0.625 mm and reconstructed voxel size of 0.258x0.258x0.5 mm^3. Maximum intensity projections of the acquired slices were used for visualization purposes (To depict all four seeds simultaneously).

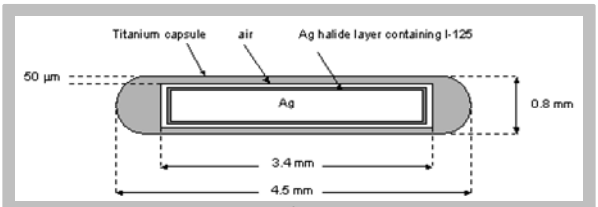

Fig. 1. Schematic representation of a brachytherapy seed, depicting the silver (Ag) core surrounded by the titanium capsule and ends.

Results In Fig. 2 maximum intensity projections over 5 mm and 32 mm for coronal (row I and II) and transversal (row III and IV) images, respectively, are shown which depict all four seeds simultaneously. Column a) of Fig. 2 clearly demonstrates that co-RASOR imaging acquired with a DoA=100% enables excellent depiction of brachytherapy seeds with high positive contrast, independently of their orientation with respect to B_0. Long T_2^* suppression by echo subtraction (row III and IV) increased contrast-to-noise ratio even more. Although reducing the DoA to 60% (column b) and 20% (column c) increases noise levels and enhances streaking artifacts, the brachytherapy seeds remain perfectly visible, while scan time is reduced by a factor of 1.7 and 5.0, respectively. Interestingly, after long T_2^* suppression the seed intensities are not affected, although the noise level strongly increases. Scan times were reduced even more by omitting acquisition of a 2nd echo, while undersampling with DoA´s of 20% and 10% (column d), resulting in total scan times of 21.8 s and 11.5 s respectively (scan time reduction factors of 8.2 and 15.6). Brachytherapy seeds are still visible on these images with extreme undersampling.

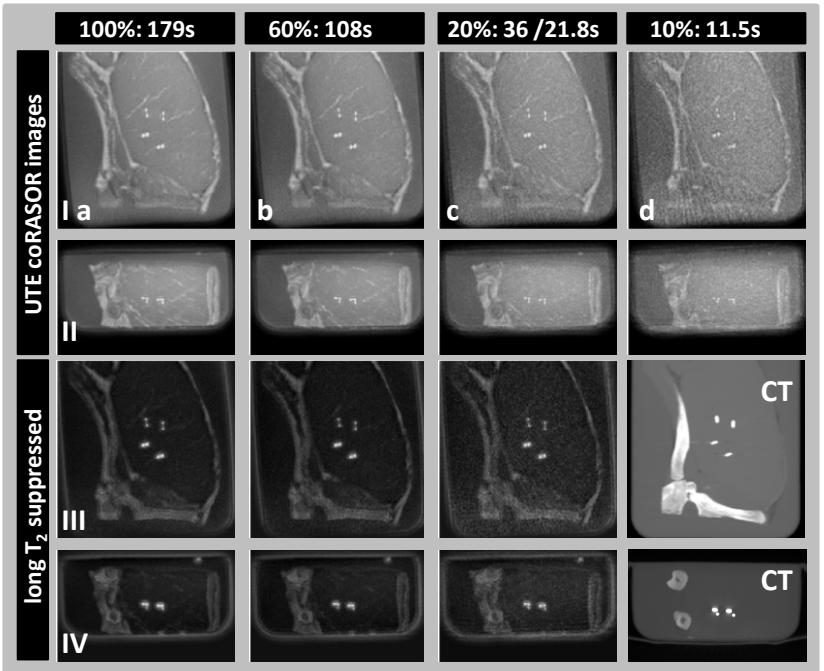

Fig. 2. Depiction of brachytherapy seeds implanted in porcine tissue. Both coronal (I and III) and transversal (II and IV) images are depicted with (I and II) and without (III and IV) long T_2^* suppression using DoA of 100% (a), 60% (b), 20% (c) and 10% (d). CT images are shown for validation (d III and IV).

Conclusions Undersampled co-RASOR imaging was demonstrated to reduce scan times up to a factor of 15, while preserving the capability to localize brachytherapy seeds. Anticipating on the use of smart iterative reconstruction methods, which have been demonstrated to reduce streaking artifacts and noise in undersampled radial MRI[6], we foresee that 3D co-RASOR imaging could enable intra-operative near real-time monitoring and dosimetry of interventional brachytherapy procedures.

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