

Accurate real-time position verification of an Ir-192 source for dynamic MR-guided single fraction HDR prostate brachytherapy.

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Introduction Low-dose-rate (LDR) brachytherapy has become an accepted, effective and safe therapy for localized prostate cancer. However, treatment with temporary high-dose-rate (HDR) brachytherapy with iridium-192 as a monotherapy is gaining interest. As compared to LDR, HDR dramatically decreases treatment time and enables dose distribution control by intra-procedural source position optimization. This means that independent treatment verification for HDR brachytherapy is needed to ensure that the treatment proceeds as prescribed, in particular if a high dose is given as in single fraction therapy. From the long history of LDR brachytherapy it can be learned that fluoroscopy and X-ray CT imaging allow excellent seed localization, however, prostate visualization and tumour delineation are poor on these modalities. Therefore in LDR brachytherapy CT images are often combined with the excellent soft tissue contrast provided by MRI, to enable dose distribution verification [1]. For the same reasons, MRI-guidance would be extremely useful for dose distribution optimization in HDR brachy monotherapy, and even more if MRI-guidance would provide intra-procedural feedback on the exact location of the source with respect to tumour and critical organs. Therefore, MRI-guided single fraction HDR brachy monotherapy for localized prostate cancer is being developed in our institute. In a dedicated treatment suite equipped with an HDR afterloader and a 1.5 T MR scanner, patient treatment and MR imaging can be combined. In this work, we investigate the feasibility of real-time Ir-192 source position verification using MRI. To this aim, the co-RASOR imaging technique will be exploited, which has recently been demonstrated to be capable of depiction of small paramagnetic structures with high positive contrast and high accuracy [2].

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 spherically symmetric signal pile-up typical for 3D radial center-out sampling, since distortions manifest in the direction of the read gradient (all directions). By applying the frequency offset, the signal pile-up around the magnetic field perturber can be shifted and eventually focused into the exact center of an object at the optimal frequency offset [2]. The off-resonance introduced during reception can also be introduced during reconstruction [3].

Phantom An HDR source was introduced parallel to B_0 in a 7-cm-thick highly inhomogeneous piece of porcine tissue containing fat, connective tissue, and bone. The source consists of a non-radioactive Iridium cylinder (0.65×3.6mm) in an AISI 316L steel capsule (0.9×4.5mm) connected to a steel cable (diameter 0.7mm)[4].

Imaging The phantom was subjected to a CT scan with the following parameters: thickness and increment 1mm, voltage 120kV and 450mAs. Co-RASOR imaging was performed on a 1.5T clinical scanner (Philips Healthcare, Best, The Netherlands) with the following scan parameters: excitation with a broad excitation block-pulse (BW 10kHz), field of view 192×192×60mm³, resolution 1mm isotropic, echo time 0.14ms, repetition time 6.1ms, flip angle 20°, density of angles 70% and read-out bandwidth 890 Hz/voxel resulting in a scan duration of 1.39 min [5]. After on-resonance acquisition, 50 frequency offsets were applied in steps of 250Hz to the acquired data, using homebuilt software written in Matlab (The MathWorks, Inc, Natick, MA). Reconstruction required approximately 1sec/ frequency offset for the 192×192×60 dataset. The optimal frequency was determined visually. The images reconstructed at the optimal frequency were thresholded and the resulting positive contrast images were merged with the on-resonance acquired image. The CT and co-RASOR images were rigidly registered using elastix [6].

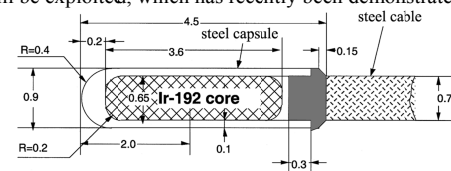


Figure 1: Schematic illustration of the radioactive Iridium cylinder [4].

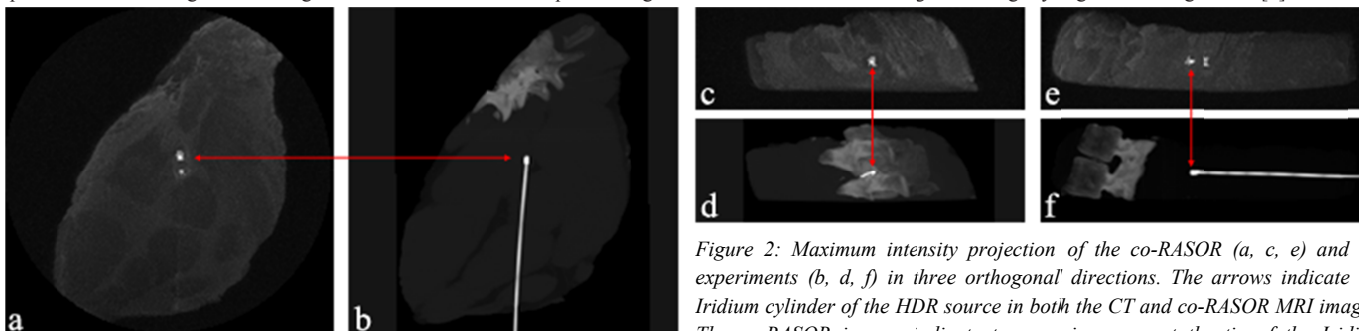
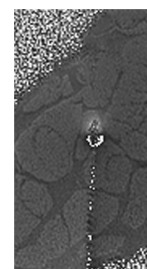


Figure 2: Maximum intensity projection of the co-RASOR (a, c, e) and CT experiments (b, d, f) in three orthogonal directions. The arrows indicate the Iridium cylinder of the HDR source in both the CT and co-RASOR MRI images. The co-RASOR images indicate two maxima, one at the tip of the Iridium cylinder and one at the end of the steel cable.

Results&Discussion: Results of co-RASOR imaging of the Iridium HDR source in the inhomogeneous porcine tissue are shown in Figure 2. The distal high signal spot in the co-RASOR images corresponds within 1 mm to the tip of the source, as measured in the registered CT images. The co-RASOR image shows two positions with a signal pile-up. The signal maximum at the tip of the Iridium cylinder is obtained at a frequency offset of 5.75 kHz, while the signal maximum at the end of the steel cable is obtained for a frequency offset of -5.0 kHz. This difference in optimal frequency offset can be applied to selectively depict the Iridium source during, for example, an HDR treatment. The need for the difference in frequency offset is also reflected in the signal phase, as shown in Figure 3. The phase is positive at the Iridium source (negative frequency offset) and negative at the steel cable. The phase wraps near the steel cable show the extremely strong field disturbance of the cable. For real time imaging and position verification, imaging and reconstruction should be applied within a few seconds, which is in the range of the source dwell times in a single fraction monotherapy HDR prostate treatment. Data can be acquired faster by applying a smaller number of radial spokes at the cost of SNR and reducing the FOV. Data acquisition using 2 single slices within 3 seconds is feasible, but might result in image distortion in the through-plane direction and additional signal loss due to larger echo times and smaller excitation bandwidths needed for such acquisitions.

Figure 3: Signal phase at the Iridium source



Conclusion We have shown that 3D UTE acquisition with 70% density of angles and off-resonance reconstruction is able to generate geometrically accurate maximum intensity projection images of an HDR brachytherapy Iridium source within 1.35min.

References [1] M.A. Moerland et al. R&O, 91:202-206, 2009 [2] P.R. Seevinck et al. MRM, 65:146-156, 2011 [3] H. De Leeuw et al. Proc ISMRM:2940, 2010 [4] G.M. Daskalov, Med Phys, 25(11):2200-2208,1998 [5] P.R. Seevinck et al. Proc ISMRM:3762, 2011 [6] S. Klein et al. IEEE TMI, 29(1): 196-205, 2010