

A dual plane co-RASOR technique for accurate and rapid tracking and position verification of an Ir-192 source for single fraction HDR brachytherapy

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Introduction: Treatment of prostate cancer by single fraction High-Dose-Rate (HDR) brachytherapy potentially provides an improvement in prostate cancer treatment, but safe dose delivery is mandatory. Contrary to the fluoroscopy, US or CT guided procedures, which are used in clinical practice, a much more reliable approach would include MR imaging and MRI based intra-procedural feedback on the exact location of the source with respect to tumor and critical organs, to allow dose distribution optimization [4]. However, accurate localization of a brachytherapy source requires sufficient temporal resolution and adequate spatial resolution, which are not easily achieved by conventional MRI [5,6]. For example, the recently developed 3D co-RASOR technique [7] provides accurate spatial resolution, but lacks temporal resolution. In this *in vitro* study, we present a dual plane version of the 3D co-RASOR technique, which significantly reduces the acquisition time while maintaining the localization accuracy provided by 3D co-RASOR. Experiments in heterogeneous tissues are performed to show the robustness and the adequate spatial and temporal resolution for tracking of an HDR brachytherapy. The accuracy is verified with CT and 3D co-RASOR.

Materials & Methods: Signal pile-up induced by a field perturbing object, such as an HDR brachytherapy source, can be focused in its exact geometric center by applying a center-out read-out [7]. A 3D center-out acquisition therefore allows the center of a field perturbing object to be located accurately in 3D. Another option is to apply two, orthogonal, center-out encoded slabs containing the source. Each slab allows accurately localization in-plane, while the location in the through-plane direction is covered by the perpendicular slab. To show that the dual-plane variant of co-RASOR allows tracking in heterogeneous tissue, a phantom was used. The phantom consisted of a 4-cm-thick inhomogeneous piece of porcine tissue containing fat, connective tissue and bone. In the porcine tissue two plastic 6F Proguide needles were inserted (Elekta/Nucletron, Veenendaal, The Netherlands). One needle, the one parallel to B_0 , contained a non-active Ir-192 HDR brachytherapy source (Elekta/Nucletron, Veenendaal, The Netherlands) [8]. The source was retracted in 20 steps of approximately 5mm.

MR imaging was performed on a 1.5T whole body MRI (Philips Healthcare, Best, The Netherlands), using an elliptic surface coil with short axis 14 cm and long axis 17 cm. A 3D Free Induction Decay (FID) was acquired using a center-out radial read-out. Scan parameters included: excitation with a non-selective RF block pulse with a bandwidth of 22kHz, field of view (FOV) 176^3mm^3 , 1mm isotropic resolution, echo time (TE) 0.34ms, repetition time (TR) 5.0ms, flip angle (θ) 15° , read-out bandwidth 794Hz/pixel, 100% density of angles and one signal average, resulting in a scan duration of 5min and 12s. Subsequently, a dynamic, interleaved dual-plane 2D acquisition, consisting of a coronal and a sagittal slice, was used. The coronal scan was planned to contain both needles. The sagittal slice was planned to contain the Ir-192 source. Scan parameters included: excitation by a sinc-gauss RF pulse with a bandwidth of 4.1kHz, FOV 176^2mm^2 , slice thickness 5mm, 1mm isotropic resolution, TE 0.82ms, TR 8.3ms, θ 15° , read-out bandwidth 891Hz/pixel and one signal average, resulting in a scan duration of 3.2s per dynamic.

To demonstrate the spatial accuracy of co-RASOR, CT images were acquired on a 64-slice CT scanner (64-slice Brilliance, Philips Healthcare, Best, The Netherlands) with the following parameters: voltage 120kV, mAs 263, in-plane resolution 0.45 mm, increment 1mm. Postprocessing was performed using Matlab (The MathWorks, Natick, MA). 3D and 2D dual plane images were processed as described previously [7]. Thirty reconstructions with off-resonance frequencies from 0 to 7.5kHz, with a frequency stepsize of 250Hz were applied. The optimal frequency offset for the 2D images was selected manually to correspond to the highest signal intensity in an area in the image broadly covering the position of the Ir-192 source. The positive contrast was created by subtracting the on-resonance image from the image reconstructed with the optimal frequency offset and thresholding [7]. 2D reconstructions and postprocessing were completed well within one second. An image displaying the positive contrast, anatomical reference and the signal void caused by the sources, was obtained by overlaying the MIP of the co-RASOR image on the corresponding on-resonance MR images.

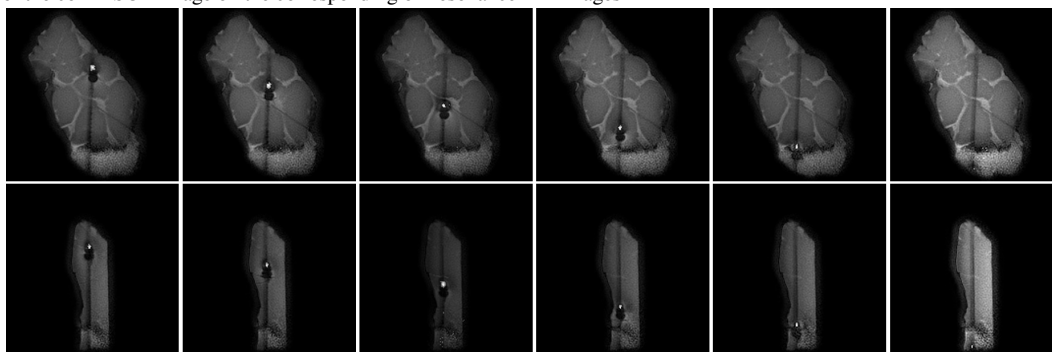


Figure 1: Coronal (top) and sagittal (bottom) slice displaying an overlay of the positive contrast co-RASOR image on the on-resonance acquired image. The hotspot represents the tip of the HDR-brachytherapy source. Shown are the results after retracting the source approximately 0, 2, 4, 6, 8 and 10cm.

Results: To test the applicability of the dual plane co-RASOR technique in heterogeneous tissue samples, experiments were performed on the phantom. After

registration, CT images and the 3D co-RASOR images depicted the same location for the Ir-192 source. To verify that the correct position was extracted from the dual-plane co-RASOR image, the location of the tip, with respect to the scanner isocenter, of the non-radioactive Ir-192 source was extracted from the 3D image, yielding: (-58; 19; 49). The results of the dynamic acquisitions are shown in Figure 1. Initially, the position of the Ir-192 source agreed to 1 mm with the position on the CT image (-; 19; 51) and (-59;-; 50) for the coronal and the sagittal image, respectively. Differences are caused by the different off-centers used for the scans (rounding errors) and by the uncertainty inherent to the co-RASOR method [7]. Distances, in steps of four subsequent dynamic acquisitions, were on average 20.5mm, with the minimum distance 18mm and the maximum distance 23mm. The coordinate along z in both 2D images agreed to within 1mm.

Discussion: Two orthogonal 2D center-out encoded slices allow 3D tracking of an HDR brachytherapy source in inhomogeneous tissue. The method was shown to provide a spatial accuracy comparable to CT, with an appropriate temporal resolution, 3seconds, for the intended application.

The main determinant of the spatial accuracy appeared to be the imaging resolution. Hence, the localization accuracy can be enhanced by increasing the resolution by increasing the scan matrix or artificially by zero filling [7]. The observed displacement of the tip at successive dynamic scans agreed well with the intended step size of the retraction. The small differences are likely caused by the uncertainty caused by the imaging resolution and might have been introduced during the manual retraction of the source. The method requires signal surrounding the source and its efficacy is reduced in areas with a low SNR. Although the interleaved method resulted in a reduced signal at the overlap of the slices, that, especially for small field perturbing structures, complicates the localization, the SNR proved to be adequate.

In literature many tracking methods have been proposed, which can be divided into active tracking and passive tracking methods [9, 10]. As active tracking would require modifications of the brachytherapy source, passive tracking is a more suited approach than active tracking. The proposed method has been designed to provide as high an accuracy as possible within approximately 3 seconds, which corresponds to typical source dwell times used in HDR brachytherapy. The tracking can be speeded up by applying methods that are used to speed up active tracking methods, such as parallel imaging techniques, e.g., SENSE, sparse imaging or using a lower imaging resolution [9, 11]. As the coordinates extracted from the co-RASOR acquisition can be converted into world coordinates, scan planes might be updated automatically in sequential acquisitions, as is done in active tracking methods [10].

In conclusion, we have shown a dual-plane 3D technique for accurate tracking of an HDR-brachytherapy source with adequate spatial and temporal resolution.

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