Synergy between k-space inverse-Hanning filtering and coRASOR reconstruction for positive contrast visualization of interventional devices

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Introduction Accurate and specific depiction of interventional devices, including needles, brachytherapy seeds and catheters, while maintaining anatomical reference is a long lasting challenge in the development of MRI-guided procedures. The non-local and non-specific blooming T_2^* contrast usually generated by (super)-paramagnetic devices in gradient echo sequences certainly does not meet the requirements. To improve the accuracy and specificity of these type of experiments, many techniques have been developed in the last decade, often expoiting the device-induced frequency perturbation either during excitation or signal reception. A different approach is based on the fact that off-resonance effects induce echo shifts, which can be exploited to generate positive contrast, either by finding the exact off-resonance for each voxel[1] or by suppressing the center of k-space by raw data filtering using an inverse Hanning window[2]. The positive contrast generated often improved specificity; however, when applied to device visualisation, these methods did not increase the accuracy since the methods merely highlight the off-resonance effects in the vicinity of the devices.

Our group has recently developed a completely different approach in which the off-resonance effects in the frequency encode direction are turned to our benefit for depiction of small paramagnetic structures with high positive contrast at the exact magnetic center of the structure[3]. This imaging method, center-out RAdial Sampling with Off-Resonance (co-RASOR), was also demonstrated to be applicable as a reconstruction method applied to on-resonance acquired data[4], preserving image quality and anatomical reference in the on-resonance image. Since k-space filtering using an inverse Hanning filter according to Eibofner et al. was shown to automatically suppress magnetically homogeneous parts[2], and coRASOR succeeds in highlighting the exact magnetic center of the field disturbing devices[3,4], we hypothesize a synergy when combining both methods. Additionally, fully frequency encoded techniques, such as coRASOR, may be expected to be favorable, since echo shifts as a result of susceptibility differences occur only in the frequency encode direction. The aim of this work is to investigate the possible synergy between k-space inverse-Hanning filtering and coRASOR for background suppressed positive contrast device visualisation.

Methods *Imaging sequence* The co-RASOR imaging technique is a fully frequency encoded center-out radial acquisition method. In 3D radial center-out sampling, as applied in this work, magnetic field disturbances induced by small paramagnetic objects cause a sphere-shaped signal pile-up[3,4]. By introducing an frequency 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 small paramagnetic objects[3,4]. *Phantom* Brachytherapy seeds were introduced in a 7-cm-thick highly inhomogeneous piece of porcine tissue submersed in agarose gel 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. The paramagnetic titanium ends are expected to represent two magnetic centers[3]. *Imaging* Co-RASOR imaging was performed on a 3T clinical scanner (Philips Healthcare, Best, Netherlands) using the following imaging parameters: TR/TE = 3.7/0.14 ms, total scan time = 216s, density of angles of 80%, readout bandwith of 1104 Hz/pix, scan matrix of 192x192x192, acquired and reconstructed isotropic voxel sizes of 1x1x1 mm^3. *Processing* On-resonance reconstruction as well as coRASOR reconstruction was applied according to De Leeuw et al.[4] using a single off-resonance of -1500Hz for the entire image, both with and without k-space filtering using a 3D inverse Hanning filter (1 - Hanning). The filter width was varied over a range from 3 to 191 and its influence was qualitatively and quantitatively assessed. For all reconstructions the contrast-to-noise ratio (CNR) was determined by dividing the signal difference of the mean of the two most hyperintense seeds and the surrounding tissue (ROI) by the standard deviation (sd) of that same ROI, measuring 7x7x7 pixels, chosen in the center of the four seeds. Subtraction of the on-resonance image from the reconstruction was investigated as well.

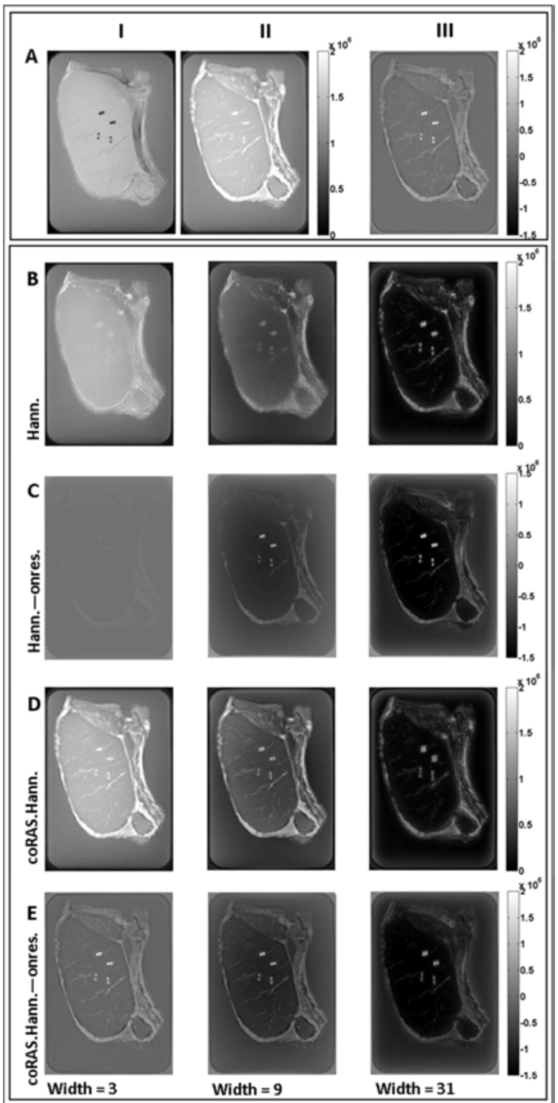

Fig. 1. MIP images (7 slices) of porcine tissue containing 4 brachytherapy seeds. A. I, II , III are onresonance (onres), coRASOR (coRAS) and difference (coRAS - onres.) images. Row B, C, D and E represent Hanning filtered reconstructions (Hann.), Hann. minus onres., combined coRAS and Hann. and combined coRAS and Hann. Minus onres. Reconstructions, respectively. Columns I, II and III present Hann. Filterwidths of 3, 9 and 31, respectively, for rows B to E.

Results Inverse-Hanning filtering of 3D center-out radially acquired k-space data is effective in suppressing background signal, however, at the cost of increased blurring, (Fig.1B.), which may be expected due to the effect of the filter in k-space on the point-spread function in image space. Magnetically homogeneous areas are increasingly suppressed when increasing the filter width, as observed in muscle tissue surrounding the seeds as well as in the surrounding agarose, for filter widths of 3, 9 and 31(Fig1B.), leading to increased CNR (Fig.2. red squares). Filter widths > 31 resulted in a further decrease in image quality due to blurring and are therefore not depicted. Areas with susceptibility deviations, such as the seeds, but also fatty tissue and the edges of the phantom, were less suppressed by the inverse Hanning filter. Interestingly, the seeds are visualized hyperintense at their exact locations in a similar way as in coRASOR reconstructions, however smeared out with respect to coRASOR reconstructions (Fig1A.,1B.). Combining coRASOR with inverse-Hanning filtering led to even more signal smear(Fig1D.), although CNR was enhanced with increasing filter width (Fig.2. blue crosses). Subtraction of the onresonance image from coRASOR, inverse-Hanning filtered reconstructions and combined reconstructions led to increased CNR in all cases. The increasing CNR at low filterwidths for Hanning filtered on-resonance reconstructions (Fig.2 orange dots) is caused by low sd. Furthermore, as it acts as a mask, subtraction confined the hyperintense signal to locations with T_2^* signal voids, visually reducing the extent of blurring in Hanning filtered reconstructions (C vs B and E vs D).

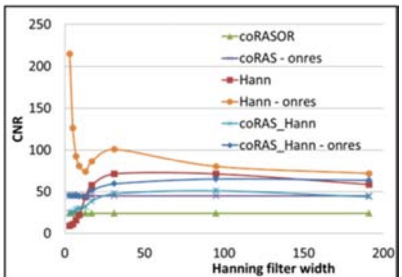

Fig. 2. CNR vs Hanning filter width

Conclusions and discussion Inverse-Hanning filtering of radially acquired k-space data is effective in suppressing background signal and increasing CNR, however, at the cost of blurring in image space. In the 3D radial acquisition this blurring effect may be expected to be symmetric, most likely causing the highlighting of the small seeds at their original location. When combining coRASOR, with the frequency offset optimized for coRASOR, and inverse-Hanning filtering, blurring becomes worse. Since inverse-Hanning filtering and coRASOR both induce a shift of signal towards the center of the magnetic perturber, it may be necessary to optimize the frequency offset for inverse Hanning filtering and coRASOR in conjunction. This remains to be investigated, as well as the applicability of the method for larger devices.

References: [1]Varma. MRM 65:1483-90, 2011; [2]Eibofner MRM 68:1399-1409, 2012; [3]Seevinck MRM 65: 149-156, 2011; [4]De Leeuw MRM epub, july 2012