The Application of Sparse Reconstruction to High Spatio-Temporal Resolution Dynamic Contrast Enhanced MRI of the Prostate: Initial Clinical Experience with Effect on Image and Parametric Perfusion Characteristic Quality

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Introduction: Dynamic contrast enhanced MRI (DCE-MRI) is an important component of multiparametric evaluation of the prostate, which in combination with T2 weighted and diffusion imaging demonstrates excellent sensitivity and specificity for detection, localization, and characterization of intermediate and high grade prostate cancer [1]. There is a common tradeoff among spatial, contrast, and temporal resolutions in DCE-MRI sequences, with each having its merits. The evolving literature on the value of pharmacokinetic modeling in prostate evaluation is conflicted but promising [2], particularly in the developing clinical applications of monitoring response to therapy and detection of recurrence after non-surgical treatment [3]. Perfusion analysis and generation of semi-quantitative and quantitative parametric maps (K*trans*, K*ep*, V*e*, iAUGC, among others) is dependent on high temporal resolution of DCE-MRI. We investigated the performance of an iterative sparse reconstruction method [4,5] applied to a Cartesian Acquisition with Projection-Reconstruction-like sampling (pCAPR) sequence [6] adapted for high spatiotemporal prostate DCE-MRI.

Methods: The protocol was IRB-approved. 19 consecutive patients suspected of prostate cancer were enrolled. Imaging was done at 3 T (Signa 7502, GE Healthcare, Waukesha WI). As part of the standard multi-sequence exam the pCAPR sequence was used. Relevant parameters included T1-weighted 3D spoiled gradient acquisition; 12° flip angle; TR/TE=5.6ms/2.2ms; 256x256x38 matrix (L/RxA/PxS/I); 1.14x0.86x3.00 mm^3; L/R FOV of 22 cm with no phase wrap; 2D SENSE acceleration 2.5 (L/R) x1.5 (S/I); frame time of 6.5 sec per phase; 55 phases acquired over ~5.5 minutes. A modular vendor-provided 12-element receiver coil was used. IV injection of gadoterate meglumine (Dotarem, 0.1 mmol/kg) at 3 mL/sec was initiated 20 sec after starting pCAPR sequence. Two sets of images were generated from the same raw DCE-pCAPR data using: 1) standard SENSE reconstruction; and 2) sparse reconstruction. Total variation-based sparse reconstruction was performed using an alternating direction method-of-multipliers (ADMM) algorithm [5]. Both image sets were used to generate perfusion parameters using DynaCAD 3.3 (InVivo, Gainesville, FL).
Experiment 1: Two experienced GU radiologists independently reviewed both standard SENSE and sparse reconstruction versions of the DCE pCAPR images, and the perfusion color maps (K*trans*, K*ep*, V*e*, iAUGC, and "Primary" which is K*trans*/V*e*). Standard and ADMM images were viewed in direct comparison using relative five-point scale [-2 (sparse reconstruction significantly worse) to +2 (sparse reconstruction significantly better)] grading: Signal-to-Noise Ratio, Sharpness, Artifacts, Delineation of Lesions, Delineation of the prostate and rectal boundaries, and Quality/Homogeneity of the Pharmacokinetic Color Maps. Also, subjective reader preference between the standard and sparse reconstruction was rated -1 (standard preferred), 0 (neutral), +1 (sparse reconstruction preferred). Experiment 2: One reader generated a lesion ROI in 9 cases where there was a discrete prostate lesion. This ROI was exactly propagated between the standard and sparse reconstruction version of pCAPR and the resulting color maps, with quantitative results were recorded.

Results: Experiment 1: Results are shown in the histograms of Fig. 1. For 4 of the 6 comparisons (SNR, Delineation of Lesions, Delineation of Prostate/Rectal Boundaries, Quality of Pharmacokinetic Maps) sparse reconstruction results were assessed as being superior to the standard results. This was with minimal reduction in sharpness (Fig. 1B) and no change in artifact level (Fig. 1C). Sparse reconstruction was preferred in 34/38 of the 38 comparisons, preference was neutral in 3/38, and standard preferred in 1/38. Experiment 2: The mean % signal change and standard deviation (SD) for the identical ROIs was 369.61 +/- 77.37 for standard reconstruction and 352.28 +/- 53.63 for sparse reconstruction. Mean K*trans* values and SD were decreased in 7 of the 9 cases with sparse reconstruction. V*e* mean values were not significantly changed but the SD decreased in all cases (0.15 compared to 0.11). Normalized values (SD/mean) decreased in 7 of 9 patients with K*trans* (0.58 to 0.49) and 8 of 9 for V*e* (0.28 to 0.21). K*ep* mean values showed no consistent change between methods but did show decreased measurement SD with sparse reconstruction. Sample results are shown in Fig. 2.

Conclusions: There was a strong reader preference for the sparse reconstruction results, with improvement in SNR, delineation of lesions, and subjective quality of the resulting pharmacokinetic color maps. It is expected that tuning of the sparse reconstruction regularization parameter can retain this performance while also maintaining sharpness. The application of sparse reconstruction to the pCAPR DCE-sequence results in more robust and accurate pharmacokinetic modeling, with less intensity fluctuation between time points resulting in more homogeneous color maps as reflected by decreased SD of all perfusion parameters.

References: [1]. Hegde et al. J MRI 37:1035-54. [2] Vos et al. Eur Urol 64:448-55. [3] Barrett et al. Magn Reson Med 67:778-85. [4] Trzasko et al. Magn Reson Med 2011; 66:1019-1032. [5] Trzasko et al. Asilomar SSC 2014; MP8a2-3. [6] Haider et al. Magn Reson Med 2008;60:749-760.

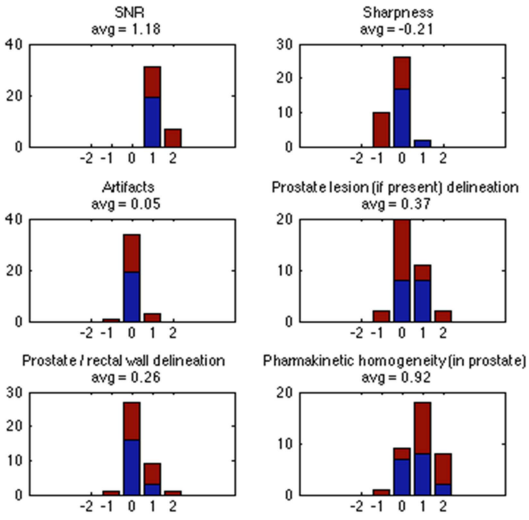

Figure 1. Histograms of both readers' scoring by parameter (reader 1 in red, reader 2 in blue).

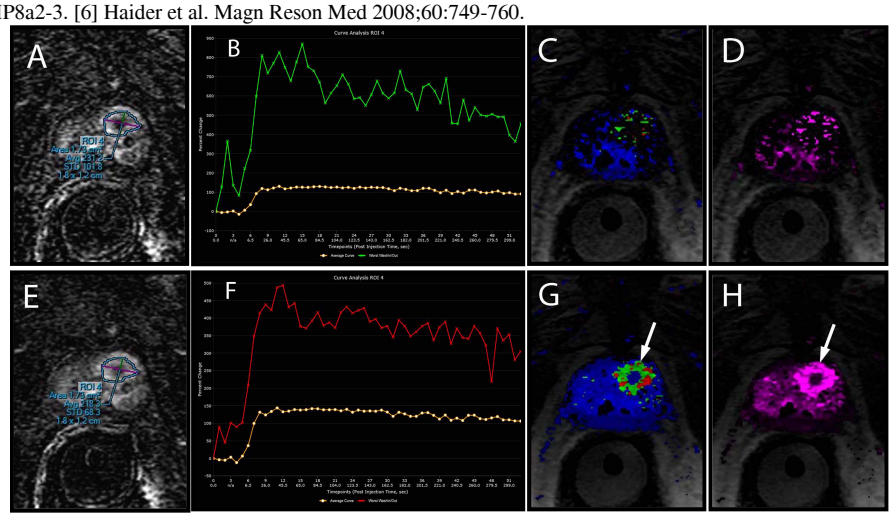

Figure 2. 75-year-old man with elevated PSA of 9.4 ng/mL. (A) Subtracted DCE-pCAPR image at the mid gland of the prostate with an ROI over a hyperenhancing lesion in the left anterior transitional zone. (B) Corresponding curve analysis generated from DCE-pCAPR images. (C-D) Corresponding Primary (C) and K*trans* (D) color maps. (E) Corresponding subtracted DCE-pCAPR image after sparse reconstruction (F) Corresponding curve analysis of DCE-pCAPR sparse reconstruction increased the amplitude when compared with original DCE-pCAPR. (G-H) The lesion has become more conspicuous on corresponding Primary (G) and K*trans* (H) color maps (arrow). Subsequent targeted biopsy confirmed prostate adenocarcinoma Gleason 3+3.