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Comparison of different compressed sensing algorithms for low SNR 19F application --- imaging of transplanted pancreatic islets with PFCE labeled

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Introduction: Transplantation of pancreatic islets is a possible treatment option for patients suffering type I diabetic disease. However, the outcome of islet transplantation largely depends on the site of transplantation. Thus, monitoring the fate of transplanted islets using noninvasive imaging technique is necessary. Thanks to its high specificity without any background signal in biological tissue and potential for quantification of cell numbers, ^{19}F MRI is emerging as a useful tool for cell tracking[1]. Our previous study shows perfluorocarbon (PFCE) based particles have no significant effect on pancreatic islets' function and morphology. One major concern of ^{19}F MRI is the often essential long acquisition time due to the low concentration of the ^{19}F contrast agents and/or cell numbers. As the feasibility of using compressed sensing (CS) to accelerate ^{19}F MRI has been demonstrated by Zhong et al.[2], by applying different newly developed CS reconstruction algorithms, we want to validate the application of CS for imaging of perfluorocarbon (PFCE) labeled islets both in vitro and in vivo after subcutaneous transplantation.

Methods and Materials: The rodent pancreatic islets were obtained from Wistar rats (female, 8-10 weeks) using the collagenase digestion method[3]. Then the isolated islets were incubated overnight with cationic PFCE particles, which were prepared according to Dewitte et al.[4]. After washing with PBS three times, these pre-labeled islets were picked and separated equally for either making agar phantom or subcutaneous transplantation (each 200 islets). All MRI experiments were performed on a 9.4T Bruker Biospec small animal MR scanner (Bruker Biospin, Ettingen, Germany) equipped with a home built coil tuneable and matchable to both the ^{19}F and ^{1}H resonances. An 2D RARE sequence was used for both in vitro and in vivo ^{19}F acquisition with some parameters modification: TE/TR = 15.9 ms/1 s, FOV = 6.4 cm*6.4 cm/8 cm*4 cm, matrix size = 64*64/50*50, NA = 1000, slice thickness = 2.5 mm.
Different algorithms including SparseMRI[5]: a traditional convex based method for MRI application served as golden standard in this study; orthogonal multimatching pursuit[6] (OMMP): a recently proposed greedy algorithm; compressive sampling matching pursuit[7] (CoSaMP): a balanced algorithm between the faster greedy algorithm and more accurate convex algorithm; L1-reweighted minimization[8] : a slower non-convex algorithm with better accurate; two-level l1 minimization[9]: which approximates the reweighted L1 minimization method piecewise-linearly to generate similar results with faster speed are applied for CS reconstruction and comparison purpose. The sampling pattern was chosen by selecting lines in both readout and phase encoding direction with central k-space emphasized, points where the selected lines intersected are considered as sampled. By doing so, Cartesian k-space under-sample scheme normally done by the hardware for 3D imaging, where two phase encoding directions are under-sampled while readout direction is fully sampled, could be simulated. Under-sample factor (UF) from 2 to 8 was used.

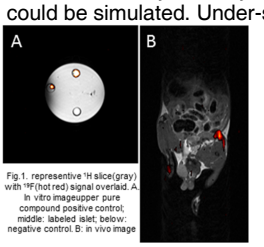


Fig.1. representive ^{1}H slice(gray) with ^{19}F(hot red) signal overlaid. A. In vitro imageupper pure compound positive control; middle: labeled islet; below: negative control. B: in vivo image

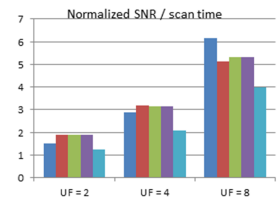


Fig.4. Normalized SNR/t value for in vivo reconstruction

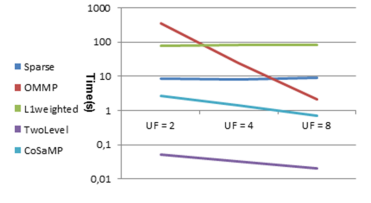


Fig.5. Computation time of diferent algorithms for in vivo image

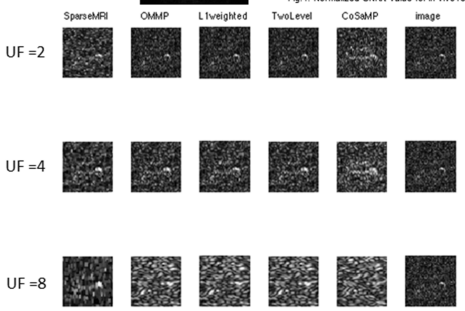


Fig.2. In vivo ^{19}F image reconstructed using different algorithm under different UFs

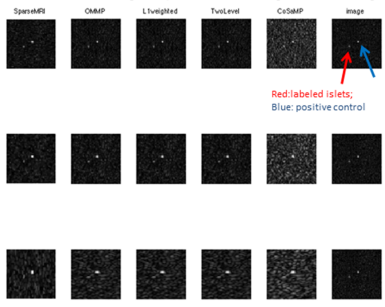


Fig.3. In vitro ^{19}F image reconstructed using different algorithm under different Ufs(left spot: labeled islets, middle spot: pure PFCE as positive control.

Results: The uptake of PFCE by islet cells was around 10^{15} ^{19}F spins/pancreatic islets according to in vitro NMR measurements. Thus, the total ^{19}F spins of 200 labeled islets is relative low considering the low sensitive of ^{19}F technique. In order to visualize the islets by ^{19}F MRI, a half hour scan time is necessary to get a 2D image with low resolution (1 mm x 1mm for in vitro & 1.6mm x 0.8mm for in vivo) resulting in SNRs of 9.86 for in vitro & 10.12 for in vivo (fig.1). Using different CS algorithms (fig.2 and 3), up to UF equals 4, for both in vitro and in vivo, signal from labeled islets could still be retrieved with a similar SNR as for the fully sampled image except for the CoSaMP method. This means that CS techniques effectively increase SNR/t (scan time) by a factor of around 3.2 (fig.4). If the detect limitation is set to SNR equals 5, for UF equals 8, there is still remaining detectable signal with some blurring noise around. Regarding the computational time of the different algorithms (fig.5), two-level methods gave the best performance, which is 10 times faster than SparseMRI.

Conclusion and Discussion: To the best of our knowledge, this study demonstrates and validates the application of CS for ^{19}F cell tracking using different CS algorithms for the first time. More importantly, in this study, we restrict the scope to the low SNR regime of ^{19}F images, which is the main concern of ^{19}F applications. Because of the low sensitivity, either huge amount of labeled cells or long scan times are needed. As for our application, increasing labeled islets requires sacrificing more animals for islets isolation and is as such not feasible; it is essential to improve the imaging approach. As we have demonstrated, several existing CS reconstruction algorithms could be applied to reduce the scan time by a factor of three or four with similar SNR and resolution. The experimentally determined acceleration rate we present here is lower than what was reported by Zhong et al.[2]. This may be partly explained by the much higher SNR level (44 vs. 10) for the fully sampled in vivo image in their study using a mouse model of localized inflammation. In addition, as the Cartesian k-space under-sample scheme was used in this study, it could affect the final reconstructed image quality. Especially for the UF = 8 reconstructed image, blurring effects happened for the signal of interested. This could be further improved by introducing non-Cartesian under-sample pattern in the future. As for both L1-reweighted and a two-level method, only L1 minimization was taken into account, the accuracy of the techniques could be further improved by importing other constrains, such as TV constrains used by SparseMRI[5]. We conclude that compressed sensing is a useful tool for accelerating ^{19}F MRI with low SNR. Among the different algorithms that we used in this study, the two-level method is preferable as it is considered the fastest method with relative good accuracy.

References: 1.Ahrens ET et al., Nature Biotechnology 2005; 23:983-987; 2.Zhong J et al., MRM 2013;69:1683-90; 3.Malaisse MWJ, Methods in Diabetes Research 1984;1:147-52; 4. Dewitte H et al.,Journal of Controlled Release 2013;169:141-149; 5.Lustig M, et al. MRM 2007;58:1182-95; 6. Liu E, et al. IEEE Trans 2012;58:2040-47; 7. Needell D, et al. Applied and Computational Harmonics Analysis 2009;26:301-21; 8. Candes EJ, et al. Journal of Fourier analysis and applications 2008;14:877-905; 9.Huang X, et al. accepted for publish in Signal Processing.