Comparison of Compressed Sensing and Keyhole Methods for Fat-Water Separation

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Introduction

Chemical shift imaging methods require multiple scans with differing chemical shift contrasts[1], which requires long acquisition times. This makes the class of techniques too expensive for monitoring steatosis, despite its many advantages over other imaging modalities[2]. In prior studies, keyhole methods and compressed sensing (CS) have been used to decrease the amount of data that must be collected to properly decompose chemical species[3,4]. Here we compare these image acquisition methods in terms of their effect on the quantification of chemical species following decomposition[5] with our new accelerated VARPRO-ICM algorithm, which requires 3 source images.

Methods

Undersampled k-space data were created by skipping certain phase encoding (PE) lines. Two keyhole methods were used, namely true keyhole (TK) and zero-padded keyhole (ZPK). In TK, one of the three source images is acquired fully, whereas only the center lines of the other two source images are acquired. Then, the outer lines of k-space are copied from the fully sampled source image to the other two. In ZPK, the unsampled parts of k-space are simply zero-padded[3] to obtain three source images of the same size and resolution. We calculate sampling ratio (SR) as the number of lines of k-space that are used in the reconstructions, divided by the number of lines available in the full resolution data set. No k-space filtering was performed in creating both types of keyhole reconstructions.

Compressed Sensing (CS) can also be used to shorten acquisitions by highly undersampling k-space. A number of CS regularization parameters are used to balance artifact removal and spatial resolution preservation[6]. Total Variation (TV) weight is the most effective parameter for modulating image quality. A fast compressed sensing algorithm, RecPF [7], was used in this study, with an optimal TV weight value of 5×10^{-4} (found by visual inspection). The undersampling of each source image was performed using a previously described sampling scheme[8].

The quantification error was calculated by first calculating the lipid fraction, as previously defined[9], by dividing the magnitude of the fat estimate by the sum of the magnitudes of the fat and water estimates. We then found the pixel-wise difference between a reference decomposition lipid fraction map (LFM) and the undersampled source decomposition LFM. Finally, we took the absolute value of this difference, and found the mean of manually masked pixels. We performed this analysis on 3 data sets, and present the average findings below.

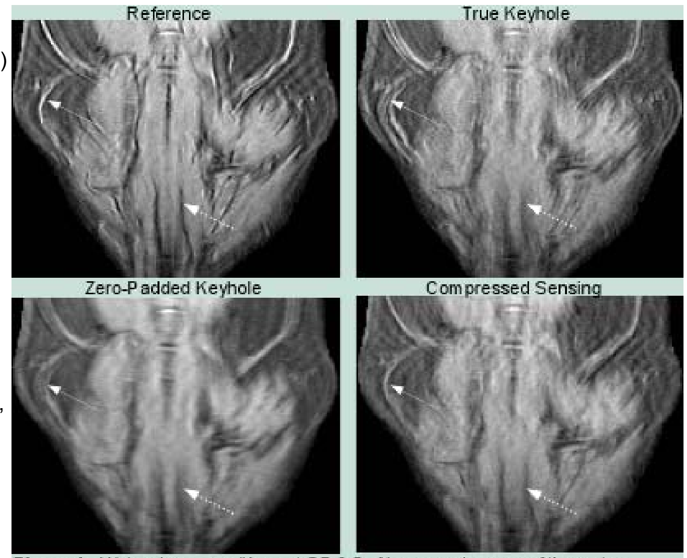

Figure 1: *Water decompositions at SR 0.5.* Above are images of the water parameter maps which were calculated from each type of source data set (all except reference decomposition had source data with 0.5 sampling ratio). Visually the compressed sensing-sourced decompositions were observed to have reduced artifacts (solid arrows) and blurring (dotted arrows) (see discussion).

Results

At low SRs, the CS method allowed the lowest quantification error (see figure 1). At high SRs, TK and ZPK slightly outperformed CS (see discussion below). The mean quantification error (averaged over three data sets) as a function of SR is plotted in figure 2.

Discussion

At very low SRs (less than .5), CS clearly yields a much smaller quantification error than either TK or ZPK. This is expected because at these low SRs, ZPK and TK have very small amounts of new information in the second two scans. At very high SRs, CS does not perform quite as well as the keyhole methods, because the keyhole methods will yield exactly the same decompositions as the reference data set at an SR of 1, while CS capabilities such as denoising might show up as errors at high SRs, when actually improving the decompositions.

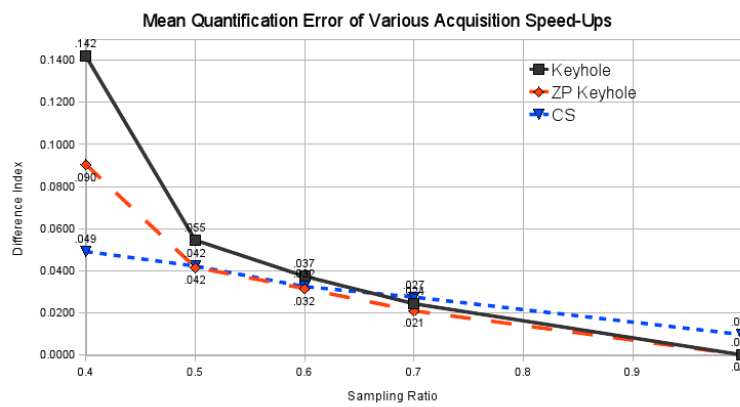

Figure 2: *Quantification Error Comparison of Undersampling Methods.* This plot presents the quantification error of the True Keyhole, Zero-Padded Keyhole, and Compressed Sensing methods, averaged over three data sets. At low sampling ratios, CS-sourced images yield the lowest quantification error, whereas the keyhole methods perform slightly better at higher sampling ratios (see discussion).

We would expect CS to be the best method because this method allows us to reconstruct full k-space source images that are not zero-padded or filled in with incorrect data. Better source data should lead to better decompositions, and further improvements to complex CS reconstruction methods should allow the relative advantage of CS to grow. We would expect TK to be the worst method because zero-padding does not contain incorrect phase information, whereas copying data from one image to another when the chemical shift weighting is not constant does insert incorrect phase information into the source images. So, while the source (magnitude) image quality is worse with ZPK than TK, the decompositions should look better with ZPK than TK.

Based on the experimental results, we recommend the use of CS for the acquisition of chemical shift data for fat-water separation.

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