Orthogonal Super Resolution Reconstruction for 3D Isotropic Imaging in 9.4T MRI

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Purpose

High resolution isotropic 3D scanning for MR imaging is practically limited by the length of the scan for *in vivo* applications. The common practice for acquiring 3D volumes in MRI is to acquire 2D slices and stack the slices to get a 3D volume. However, the through-plane resolution in these 3D volumes is typically much less than that achieved in-plane. The goal of this research is to apply a super resolution (SR) reconstruction technique to create isotropic 3D MRI images from 2D multislice stacks of images. This algorithm combines 2D multislice stacks obtained in three orthogonal directions, axial, sagittal and coronal, to reconstruct isotropic images in 3D. The evaluation of this technique was performed in an *ex-vivo mouse model where the results of the SR reconstruction were compared to an isotropically acquired 3D image of the same specimen*. CNR (Contrast to Noise ratio) measurements were used for quantitative comparison and the ability to identify specific biological structures in 3D was used for the qualitative comparison. Finally, the SR technique was applied in live animal model to demonstrate efficacy in *in- vivo* imaging.

Methods

Data Acquisition:

MR imaging was done using a Bruker Biospin 9.4T horizontal bore magnet and a quadrature volume coil of diameter 35mm. 2D multi-slice images of a recently sacrificed mouse were acquired using a T1-weighted RARE imaging sequence (TR=1570 ms, TE=7.5 ms, Rare Factor=4, avg=4, FOV=30mm x 30mm, matrix =128 x 128, in-plane resolution = 234µm x 234µm, slice thickness = 1 mm). A 3D isotropic image of the same mouse was acquired using a T1-weighted TurboRARE sequence with same imaging parameters as above except with a through-plane resolution of 234 µm. The orthogonal set of images of a live mouse were acquired using a respiratory-gated T1-weighted RARE imaging sequence (TR=1200 ms, TE=7.5 ms, Rare Factor=4, avg=4, FOV=28mm x 28mm, matrix =128 x 128, in-plane resolution = 109µ x 109µ, slice thickness = 1 mm).

SR algorithm:

Orthogonal super resolution approach based on acquisition of three orthogonal low resolution image volumes was originally presented by Souza and Senn [1]. Using this approach, a high resolution volume is created from low resolution images acquired in the axial, coronal, and sagittal orientation. IBP (Iterative Back Projection Algorithm) is used for reconstructing the super resolution data set from the low resolution volumes.

Results

The CNR between high and low intensity (CNR_{H-L}), high and medium intensity(CNR_{H-M})and medium and low intensity (CNR_{M-L}) regions (each with window size 9x9x9) are calculated for *ex-vivo* case and are tabulated along with acquisition times in Table1. Gastrointestinal walls (highlighted by arrows in the fig) in the abdomen are better resolved in the SR image (Fig. 1b) when compared to the interpolated image in through-plane direction (Fig 1c). The structure of kidney is more clear in the SR image (Fig. 1d).*In-vivo* case has more noise due to motion artifacts. The interpolated image looks more blurry and structures are not clear when compared to SR image. To compare the sharpness of edges in *in-vivo* case, intensities of pixels are plotted (Fig 2) over a line profile (line profile is highlighted in the Fig 1d&1e).

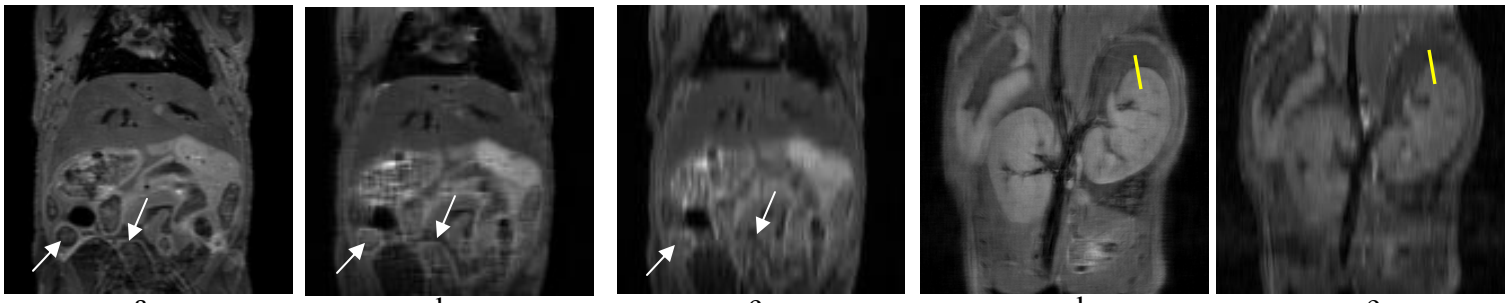

Fig 1 a) ex-vivo isotropically acquired 3D image, b) ex-vivo SR image c) ex-vivo interpolated image in through-plane direction, d) in-vivo SR image, e) in-vivo interpolated image in through plane direction

Table 1) CNR tabulation

Acquisition Geometry	CNR_{H-L}	CNR_{H-M}	CNR_{M-L}	Acquisition time
3D isotropic	10.57	9.31	8.34	1hr 17 min
Orthogonal	8.36	7.23	6.8	6 min 9 sec
Interpolated Image	6.29	5.47	5.31	2 min 3 sec

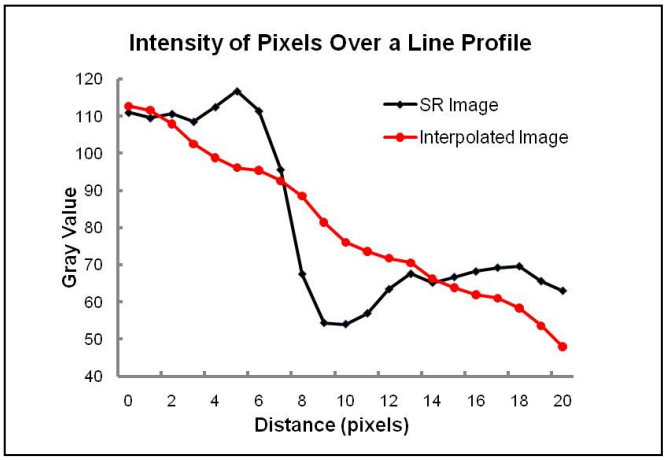

Fig 2) Plot showing the Intensity of Pixels over a line profile in SR and interpolated image for *in-vivo* case

Conclusions

The structural detail observed in the through-plane direction of the super resolution reconstructed MR images was comparable to that observed in the isotropically acquired 3D scans. CNR for the orthogonal SR reconstructed isotropic images is only 18-22% less than the isotropically acquired 3D data set as opposed to 37-42% reduction observed in interpolated image. The SR reconstructed data set took ~13 times less scanning time when compared with isotropically acquired 3D scan in *ex-vivo* case. Despite the noise caused by motion artifacts, in *in-vivo*, SR algorithm resolves the structures clearly. The loss of visual information is less in SR image when compared to the interpolated image, in both *ex-vivo* and *in-vivo* cases. The plot shows that the edges of the structures are sharp in SR image, whereas the edges are blurry and smoothened in interpolated image. For the first time SR algorithm is successfully used to reconstruct *in-vivo* 3D isotropic volume in Ultra high field MRI.

References

1. Souza, A. and R. Senn, *Model-based super-resolution for MRI.* Conf Proc IEEE Eng Med Biol Soc, 2008 2008;p. 430-4