Super-resolution in Layer-Specific MRI of the Retina

E. R. Muir[1], T. Q. Duong[1], and G. Nair[1]

[1]Yerkes Imaging Center, Emory University, Atlanta, GA, United States

Introduction Super-resolution (SR) algorithms are post-processing methods that are used to improve spatial resolution by combining information contained in a set of multiple images. In SR, many low resolution images with sub-pixel shifts are used to reconstruct a high resolution image. The first attempt to apply SR techniques to MRI implemented the sub-pixel shifts by shifting the field of view (FOV) in the frequency- and phase-encoding directions (1), but this method has been criticized, and it has been demonstrated that little new information is gained by shifting the FOV in Fourier encoded directions. Therefore, SR in MRI has since been applied almost exclusively to the slice-select direction. SR in the frequency- and phase-encoding directions could be implemented using physical shifts of the object being imaged, but this method has remained unexplored. In this study, we apply in-plane SR to in vivo MRI of the rat retina using natural slow drift of rat's eye to obtain the sub-pixel shifts, instead of shifting the FOV.

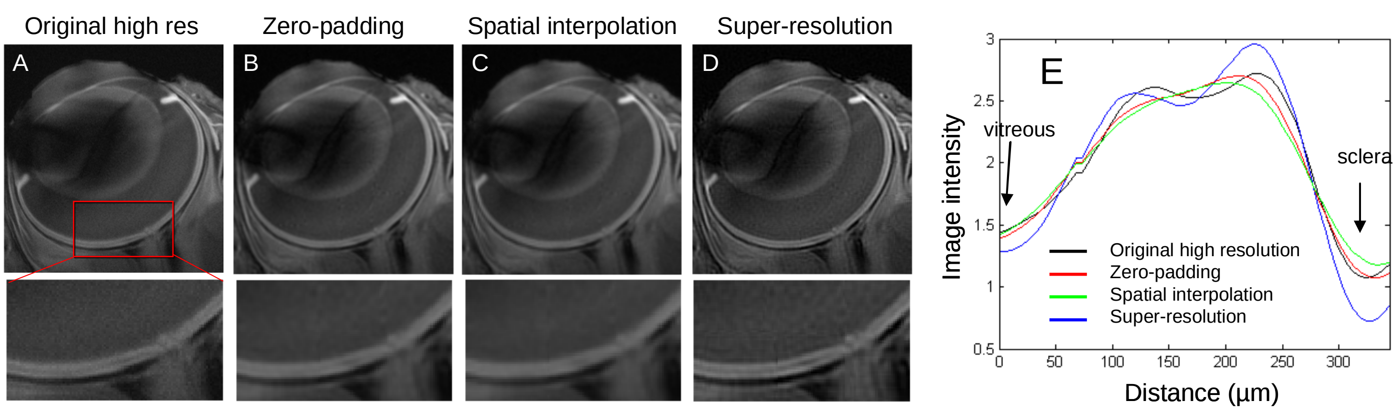
Methods Manganese-enhanced MRI was performed on rats under ~1% isoflurane. MRI was performed on a 7T/30cm scanner using a small surface coil over the eye. Images were acquired using FLASH with a 7.5x7.5 mm FOV, 256x256 matrix, 0.8 mm slice, 100 ms TR, and 6.5 ms TE, and 16 images were acquired in time series.

The original images were down-sampled by a factor of 2 in k-space to obtain a set of low-resolution images. Image registration was done with a block matching algorithm to find local motion to sub-pixel accuracy (2). Four types of images (same matrix size) were computed and compared: 1) original high-resolution image obtained by co-registration and averaging the original images, 2) images obtained by zero-padding (k-space) with co-registration and averaging, 3) images obtained with bilinear (spatial) interpolation with co-registration and averaging, and 4) SR images reconstructed using an iterative back-projection algorithm (3) from the downsampled images.

Results Three layers, two bright and one dark, are present in the original (high-resolution) images, as shown in **Figure A** (images were co-registered and averaged). After downsampling, the middle layer was almost completely gone. The downsampled images were interpolated, co-registered, and averaged using zero-padding interpolation (**Figure B**) and bilinear spatial interpolation (**Figure C**). With zero-padding the middle layer is very faintly visible and is present only along some sections of the retina. Spatial interpolation was unable to recover the middle layer, except for a few small spots. In the SR image (**Figure D**) the middle layer is distinctly visible along all but the ends of the retina. Profiles perpendicular to the retina were obtained along the length of the retina and averaged for each image. **Figure E** displays the profiles of each of the four images shown in **Figures A-D**. The middle layer is present in the original images and SR image, but only a single bright layer is present in the interpolated images.

Discussion and Conclusions Well resolved, layer-specific retinal MRI is difficult to obtain because of the extremely thin layers in the retina, so post-processing techniques to enhance resolution, such as super-resolution, could be quite useful. Unfortunately, applying super-resolution techniques to enhance resolution in MRI has been problematic due to the acquisition of data in k-space. A set of shifted images is required for SR, and in MRI this has been attempted by shifting the FOV, which is equivalent to a phase shift in the frequency domain. The consensus is that little or no new information is added by doing this, so in-plane SR is usually not attempted in MRI. Physical motion of the object being imaged, such as the natural drift of the eye utilized in this study, can be used for SR MRI, but this approach has not previously been studied. We demonstrated that the spontaneous drifting motion of the eye under anesthetic can effectively be used for SR in MRI.

In conclusion, this study showed that SR techniques offered significant improvement in resolving retinal layers compared to interpolation. SR algorithms should be particularly useful for studying diseases of the retina which result in retinal degeneration, such as retinitis pigmentosa and diabetic retinopathy.



Figures. Images of the retina: (A) original high resolution, (B) zero-padded, (C) spatial interpolation, (D) super-resolution reconstruction and (E) image intensity profiles across the retinal thickness.

References 1) Mayer et al, MRI 2007, 25:1058. 2) Schultz et al, J Vis Comm Image Rep 1998, 9:38. 3) Irani et al, J Vis Comm Image Rep 1993, 4:324. Supported in part by NIH/NEI R01EY014211