CNR-based Variable Resolution Reconstruction for Black Blood MRA

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Introduction

In MRI, the theoretically achievable spatial resolution is characterized by the extent of *k*-space used for image reconstruction. Spatial resolution increases with the extent of *k*-space sampled. Since noise in MRI data is "white" (uniformly distributed across the *k*-space), sampling more *k*-space results in adding more noise to the image. Contrast resolution is the contrast at which an object can be discriminated from the background and depends on the object size and image noise. Therefore, increasing *k*-space coverage to improve spatial resolution might make the image noisy and thus reduce contrast resolution of the low contrast-to-noise (CNR) structures. In this study, we propose an extension of the variable resolution reconstruction technique [1], by utilizing the local CNR value to improve the visibility of low intensity objects such as vascular structures in black blood MRA (BB-MRA).

Theory

The relationship between the noise standard deviation and the fraction of *k*-space data, β, used for reconstruction is given by, $\sigma_\beta=\beta^{1/2}\sigma$, where σ and σ_β are the noise standard deviation of the images reconstructed using the entire and β fraction of *k*-space, respectively. Since a vessel is predominantly a one-dimensional structure, it is mainly blurred in two dimensions orthogonal to the vessel long axis when a fraction of *k*-space data is used for reconstruction. It can be shown that if the vessel cross-section occupies one voxel in the image reconstructed from the complete *k*-space data, the fraction of the voxel occupied by the vessel is reduced to $\beta^{2/3}$ when the image is reconstructed using only β fraction of *k*-space. Similarly, the contrast of a single vessel voxel changes from C_0 to $\beta^{2/3}C(\beta)$ when the fraction of k-space used in reconstruction reduces from 1 to β. Therefore, the CNR of a single vessel voxel as a function of β is given by:

$$CNR(\beta)=\frac{\beta^{2/3}C_0}{\sigma_\beta}=\beta^{1/6}\frac{C(\beta)}{\sigma} \qquad (1)$$

In BB-MRA images, the vessel intensity distribution can be modeled by a Rayleigh distribution (assuming complete suppression of the blood signal), whereas the background tissue intensity distribution can be described by a Gaussian distribution due to its high SNR [2]. The contrast between vasculature and tissues in BB-MRA is given by $C(\beta)=\mu_b(\beta)-\mu_v(\beta)$; where $\mu_b(\beta)=\mu_b$ is the mean of the background tissue distribution and $\mu_v(\beta)$ is the mean of Rayleigh distribution which is given by $\mu_v(\beta)=(\pi/2)^{1/2}\sigma_\beta$. Eq. [1] for a single voxel is simplified to obtain the CNR for BB-MRA, as a function of β as follows:

$$CNR(\beta)=\beta^{1/6}\left(\frac{\mu_b}{\sigma}-\sqrt{\frac{\beta\pi}{2}}\right) \qquad (2)$$

Given μ_b and σ, a unique value of β where $CNR(\beta)$ is maximum, β_{max}, is given by

$$\beta_{max}=\frac{\left(CNR_0+\sqrt{\pi/2}\right)^2}{8\pi} \qquad (3)$$

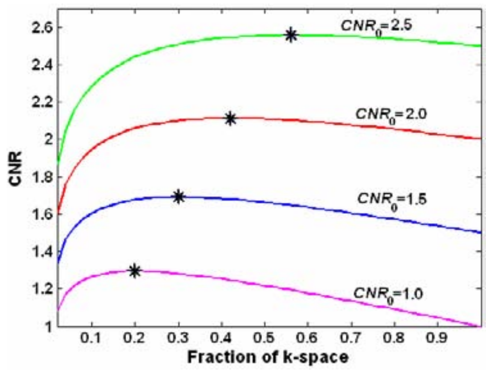

Fig 1. Dependence of the $CNR(\beta)$ on the fraction of *k*-space used for image reconstruction for CNR_0=[1.0, 1.5, 2.0, 2.5]. Symbols on the curves indicate the maximum achievable by $CNR(\beta)$ for the given CNR_0.

where CNR_0 refers to the CNR at β=1 $\{CNR_0=(\mu_b/\sigma-(\pi/2)^{1/2})\}$. From the Eq. [3] it follows that CNR between the vessel with a single voxel cross-section and the background tissues can be improved by using reduced fraction of k-space in reconstruction only if $CNR_0 < 2(2\pi)^{1/2}-(\pi/2)^{1/2}=3.76$.

<u>The main steps of the algorithm:</u>

1. Create a set of image volumes with different fractions of *k*-space zero-filled to the acquired volume. E.g.: reconstruct nine different image volumes I_i, i=0,1…8; using different fractions of *k*-space β_i calculated using Eq [3] for CNR_0 =0.0:0.5:3.76. (Note: I_8 denotes the image reconstructed with full *k*-space)
2. Compute CNR_0 values for each voxel **r** in I_8 (i.e.β=1) as follows:

$$CNR_0(\mathbf{r})=\frac{\mu_e(\mathbf{r})-I_8(\mathbf{r})}{c}$$

where $\mu_e(\mathbf{r})$ is the estimate of the surrounding background mean in a (5x5) neighborhood of **r**.

3. Construct the final image ***F*** by using the CNR values at each voxel **r** using:

$$F(\mathbf{r})=\begin{cases} I_0(\mathbf{r}) & CNR_0(\mathbf{r})\le 0 \\ I_i(\mathbf{r}),\ \text{where}\ i=\text{round}(2\cdot CNR(\mathbf{r})) & 0<CNR_0(\mathbf{r})<3.76 \\ I_8(\mathbf{r}) & CNR_0(\mathbf{r})\ge 3.76 \end{cases}$$

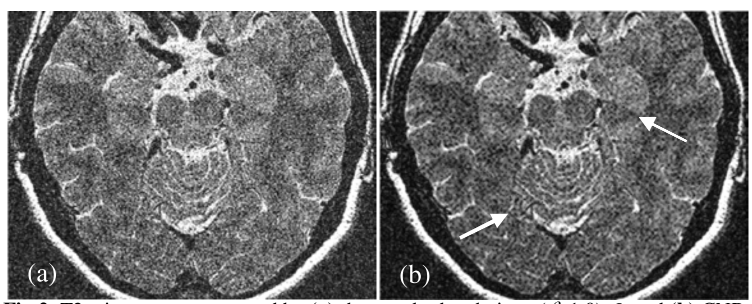

Fig 2. T2w image reconstructed by **(a)** the standard technique (β=1.0), I_8 and **(b)** CNR-based variable resolution reconstruction, ***F***. The white arrows indicate regions of improved small vessel details and lower noise in Fig 2(b) when compared to Fig 2(a).

Results

The proposed technique was validated using data from a black blood MRA study acquired on a 1.5 Tesla GE SIGNA Lx 8.4 MRI scanner (GE Medical Systems, Waukesha, WI) using a quadrature head coil. The acquisition parameters for dual contrast 3D FSE were: TR=1600 msec, TE_{PD}=13 msec, TE_{T2}=93 msec, ETL=12, Rbw=±31.5 kHz, FOV=230×153.3 mm, acquisition matrix= 384×256, 16 slabs, 6 slices/slab, 0.6 mm slice thickness. Fig. 1 illustrates the dependence of the $CNR(\beta)$ for CNR_0=[1.0,1.5,2.0,2.5] and the symbols indicate the value of $CNR(\beta_{max})$. A slice obtained by reconstructing the T2w volume using β=1 fraction of *k*-space is shown in Fig. 2(a) and the same slice in the T2w volume reconstructed using the proposed CNR-based variable resolution method is shown in Fig. 2(b). It can be seen that the image reconstructed using our algorithm (Fig 2 (b)) has less noise and better delineation of small vessel details (indicated by the arrows).

Discussion and Conclusions

In this work, we have shown that the theoretical knowledge of vessel and background tissues intensity distributions in MRA datasets can help in formulating a variable resolution reconstruction algorithm to improve the quality of the BB-MRA images. This analysis demonstrates that the amount of *k*-space required for optimal visualization of vessels in BB-MRA images depends upon the CNR of the vessel voxel and that the CNR of vessel voxels can be improved by using a variable resolution reconstruction algorithm.

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References: [1] Kholmovski EG, et al. ISMRM 2001, p. 786. [2] Gudbjartsson H, et al. MRM 1995; 34:910-914.