Estimating in vivo Spatial Resolution of Magnetic Resonance Images Using Radiofrequency Tagging Pulses

W-T. Wang[1], C. H. Meyer[1]

[1]Biomedical Engineering, University of Virginia, Charlottesville, Virginia, United States

Introductions: In magnetic resonance imaging (MRI), the image spatial resolution is usually specified by using nominal spatial resolution, which is the field-of-view (FOV) divided by the image matrix size, or by using the width of the point-spread function (PSF) simulated based on the sampling scheme. Alternatively, the spatial resolution can be measured by using a resolution phantom. These methods, however, do not provide the true spatial resolution because they take into account only some or none of the image quality degradation factors, including partial k-space sampling, B_o-, B_1-field inhomogeneity, T_2 blurring and susceptibility effects.

The goal of this work is to use radiofrequency (RF) tagging pulses to measure the true spatial resolution of in vivo MR images. The RF tagging pulses have been used to spatially label an image with stripes or grids, known as tags, to study a specific physical or physiological property, such as intra-myocardial motion and deformation [1], or to evaluate imaging trajectories, such as measuring reduction of image distortion and artifacts [2]. This work investigates the feasibility of using tag width to estimate the true spatial resolution. Tag width is further used as an indicator of improvement in spatial resolution for spiral images with off-resonance correction.

Methods: Applying tagging RF pulses prior to the imaging sequence is equivalent to convolving the modulated magnetization M_z with the PSF of the sampling scheme. That is, $h \otimes p = g$, where *h* is the modulation function of M_z, *p* the PSF to be estimated, and *g* the measured tag function. For most MR imaging, the PSF is a *sinc* function which in Fourier domain is a *rect* function spanning from $-f_h$ to f_h, where f_h is the highest frequency sampled by the imaging sequence. Ideally, if *h* is a *sinc* function that is narrower than *p*, then *g* is equal to *p*. That is, measuring the tag width is equal to measuring the width of the PSF. When *h* is not a sinc function, p can be estimated by deconvolving g with *h* as long as the highest frequency of FT{h} is larger than or equal to f_h. For the RF hard pulse used in this work, $h(z)=1-2(\bar{\gamma}\tau B_1)^2\, sinc^2(\bar{\gamma}\tau(B_1^2+(zG)^2)^{0.5})$, where B_1 is magnetic field of the RF pulse, *G* is the slice-selection gradient, and $\bar{\gamma}$ is the gyromagnetic ratio divided by 2π. To explore the feasibility of estimating *p* via *g*, we applied a single tag line of different modulation widths (0.4, 0.8, 1.6, and 3.2 mm) to images obtained from a uniform cylinder phantom. The imaging parameters of the gradient-echo sequence included an FOV of 256 mm, a matrix size of 256×256, TE/TR/flip-angle(FA)=3ms/1000ms/90˚. The tag line width was measured by applying a nonlinear curve fitting technique to fit the intensity profile of the tag line, which was taken from the four-fold Fourier interpolated images. The nonlinear curve fitting was performed with and without prior deconvolution of the tag line profile with the modulation function *h*. The estimated PSF width is then compared with the ideal PSF width.

The tag lines are further used to demonstrate the improvement in spatial resolution of spiral images by using off-resonance correction. To this end, a group of 40 RF hard pulses were applied prior to the spiral sequence. The FA of the RF pulses is 90° and the rectangular pulses have duration of 100 us with an interpulse gap of 200 us. Tag lines were applied to the spiral data acquired from a volunteer with the following imaging parameters: 14 interleaves with 8192 data points/interleaf, FOV=240mm and TE/TR/FA=2.06ms/500ms/90˚.

Results and Discussion: In Figure 1, the measured spatial resolution and the ideal PSF width (the dotted line) is plotted against the width of the modulation function. The measured spatial resolutions were obtained with (the solid line) and without (the dashed line) deconvolution. It shows that, for the modulation width of 0.4, 0.8 and 1.6 mm, the tag width is an excellent measure of the true spatial resolution (ideal PSF width) when deconvolution was performed before the curve fitting. The corresponding percentage error is 0.3%, 0.5%, and 1.4%. For the modulation width of 3.2 mm, which is wider than twice the ideal PSF width, the true spatial resolution can not be derived from the tag width. When the true spatial resolution is estimated without deconvolution, the results are still a good indicator of the spatial resolution as long as the modulation width is narrower than the ideal PSF width, which is indicated by the dotted line in Figure 1. The percentage error is 0.9%, 2.1%, 31.1% for the modulation width of 0.4, 0.8, and 1.6 mm, respectively. The prior deconvolution allows an accurate estimation of the ideal PSF width using a wider tag width, but it requires knowledge of the functional form of the modulation. On the other hand, measurement without deconvolution gives good estimates as long as the modulation width is less than the ideal PSF width.

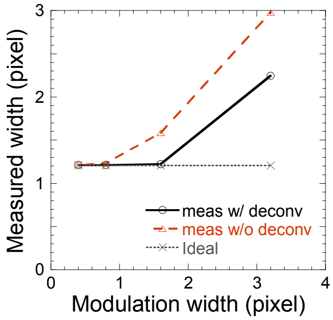

Figure 1. The ideal PSF width (dotted line) is compared to the measurements obtained using curve fitting with (solid line) and without (dashed line) deconvolution.

For in vivo images, the resultant tag function is further convolved with additional functions, including those of anatomical structures and the image degradation factors. In general, the functional forms of these additional functions are not known, rendering the deconvolution difficult to apply. The spatial resolution can be estimated using curve fitting without deconvolution or direct measurement of the tag width. Figure 2 shows the comparison of the brain images reconstructed from spiral data without (A) and with (B) off-resonance correction. The images are four-fold interpolated using Fourier zero-padding. In (C), the intensity profiles, taken along a line segment indicated in (B), are compared. With off-resonance correction, the width of the tag lines decreases and the visualization is improved.

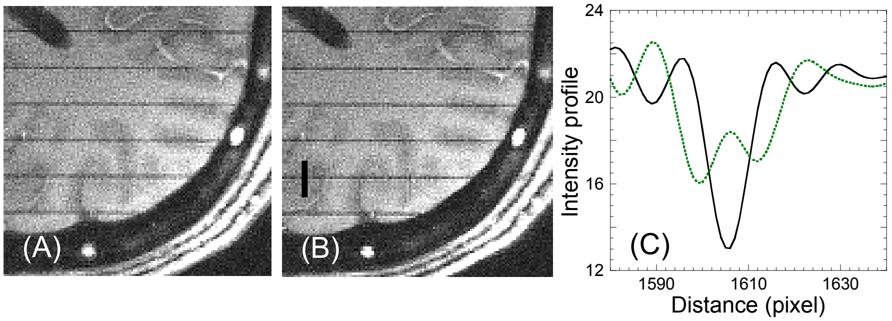

Figure 2. The zoomed-in phantom image reconstructed from the spiral data without (A) and with (B) off-resonance correction. The intensity profiles, taken along the line segment shown in (B), are compared in (C). The intensity profile are obtained without (dotted line) and with (solid line) off-resonance correction.

Conclusion: In this work, we demonstrate the use of tags to measure the spatial resolution of MR images. It is shown that, for visualization and quantification of the spatial resolution, a good estimation can be obtained when the width of the modulation function is narrower than the spatial resolution to be measured. We employed the tags to demonstrate the spatial resolution improvement of a spiral image provided by off-resonance correction. In conclusion, the true spatial resolution can be estimated using tags with a thin modulation width. As a rule of thumb, using tags whose modulation width is one half of the best possible spatial resolution can provide both an accurate quantitative and a quick visual estimation of the true spatial resolution.

References:

[1] Wu et al., MRM 48:389-393, 2002.
[2] Kim et al., MRM 50:813-820, 2003