# Evaluation of minimal angular discrimination for q-ball imaging: a phantom study

**K-H. Cho[1], C-H. Yeh[2], H-C. Lin[2], J-H. Chen[1], and C-P. Lin[2,3]**

[1]Interdisciplinary MRI/MRS Lab, Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan, [2]Institute of Radiological Sciences, National Yang-Ming University, Taipei, Taiwan, [3]Institute of Neuroscience, National Yang-Ming University, Taipei, Taiwan

## Introduction

Q-ball imaging (QBI) can estimate complex fiber coherence by measuring orientation distribution function (ODF) within each MR voxel [1]. The function of QBI for mapping multiple fibers has been validated on 90° crossing phantom at a clinical machine [2] and the accuracy of QBI for mapping single fiber coherence has also been evaluated by phantom model [3]. However, the minimal angular discrimination of QBI in distinguishing two crossing fibers has not been proposed because of the time-consuming work to acquire enough QBI data sets and the obstacle task to find out in vivo crossing fibers with different crossing angles. In this study, a method was proposed to estimate the minimal angular discrimination of two crossing fibers for QBI. By 1-D signal distribution of unidirectional phantom, 1-D ODF distribution was calculated and FWHM (full width at half magnitude) of 1-D ODF profile was evaluated as the angular discrimination. The results showed that FWHM at b-value of 6000 s/mm$^2$ was 44.1° ± 9.6°. From the results of QBI on 45° crossing phantom at b-values higher and lower than 6000 s/mm$^2$ respectively, the reliability of the angular discrimination obtained via this method was also demonstrated.

## Materials & Methods

All MR images were acquired at a 9.4 Tesla MRI system (Bruker Companies, Ettlingen, Germany). The FOV (field of view) was 25 mm × 25 mm with an acquisition matrix of 32 × 32 pixels, which yielded in-plane resolution of 781 μm × 781 μm. Stimulated echo-pulsed gradient sequence was used for DWI acquisition with TR = 3000 ms, diffusion gradient duration = 3ms and TE = 13.8 ms. For sufficient diffusion anisotropy, the diffusion time was set to be 100 ms, which resulted in RMS (root-mean-square) of diffusion distance of 20 μm.

In the study, a unidirectional phantom model and a crossing phantom model with crossing angle of 45° were built by water-filled plastic capillaries with internal and external diameters of 20 μm and 90 μm respectively. Figure 1 showed how the diffusion gradient direction changed to obtain 1-D signal distribution of unidirectional phantom. 9 different b-values were set to be from 700 to 17000 s/mm$^2$ and the direction of diffusion gradient was changed from 0° to 180° in 31 steps. Based on assumptions that diffusion signals with oppositely applied diffusion gradients are theoretically identical and distribution of diffusion signal of coherent fibers should be cylindrical symmetry along fiber orientation, a simple estimation of 1-D ODF distribution was as follows,

$$ODF(A) = \frac{1}{2A}\int_{\pi/2-A}^{\pi/2+A} signal(t)dt \qquad (1)$$

where *A* is the angel away from the phantom orientation and *signal* represents 1-D signal distribution function of unidirectional phantom. The angular discrimination of QBI can be obtained by calculating FWHM of 1-D ODF profile. For 45° crossing phantom, two HARDI data sets were acquired at b-value of 4000 and 8000 s/mm$^2$ respectively. For sufficient angular sampling resolution, QBI was encoded with 162 sampling points (4-fold tessellated icosahedron) in q-space, where the angular resolution was 17°. To exclude cross-term effect, cross-term correction was performed prior to ODF reconstruction [4]. The ODF reconstruction was performed at 642 orientations (8-fold tessellated icosahedron), which provided an angular resolution of 8°. 60 points on each equator were interpolated by spherical radial basis function interpolation while ODF was constructed. The primary orientations of ODF were defined as the fiber orientations.

## Results

Figure 2a showed 1-D ODF distribution with 9 different b-values. The result of FWHM of 1-D ODF profile in Figure 2b showed that the variation of bandwidth increased while the average of bandwidth decreased along the increase of b-value. It could be sure that critical b-value with bandwidth of 45° was approximated to 6000 s/mm$^2$. Figure 3 showed ODF results of QBI acquired on 45° crossing phantom model. The resolved crossing angle was 30.1° ± 11.3° for b = 4000 s/mm$^2$ (Figure 3a) and 45.0° ± 0.0° for b = 8000 s/mm$^2$ (Figure 3b).

## Discussion

The phenomenon of larger variation of bandwidth with higher b-value may be resulted from the decay of diffusion signal at high b-value and the diffusion signal was seriously polluted by noise. Therefore, b-value of 4000 and 8000 s/mm$^2$ were selected for experiments on 45° crossing phantom after considering the variation of bandwidth. According to Figure 2b, the FWHM at b = 6000 s/mm$^2$ was 44.1° ± 9.6° and QBI at b = 4000 s/mm$^2$ should not be able to solve 45° crossing but QBI at b = 8000 s/mm$^2$ could. However, QBI at b-value of 4000 s/mm$^2$ detected two crossing fibers but the crossing angle was far from 45°. It is to say that QBI can not resolve 45° crossing with this parameter. Therefore, the experiments of QBI on crossing phantom support the results of FWHM of ODF distribution. ODF bandwidth may be affected by different external environment, say diameter of fibers, permeability and so on, because ODF bandwidth is a diffusion-based property. In future, this method might be applied on different subjects to study angular discrimination of QBI in various environments.

## Conclusion

A simple and time-economic method was proposed to estimate the angular discrimination by acquiring 1-D signal profile on unidirectional phantom. By the results of QBI at b = 4000 s/mm$^2$ and b = 8000 s/mm$^2$ on 45° crossing phantom, the result of ODF FWHM was more reliable. Further, the result also showed QBI at b-value of 8000 s/mm$^2$ could precisely map 45° fiber crossing with phantom model.

## References

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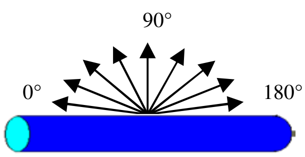


Figure 1. Illustration of various crossing angle between diffusion gradient and phantom orientation.

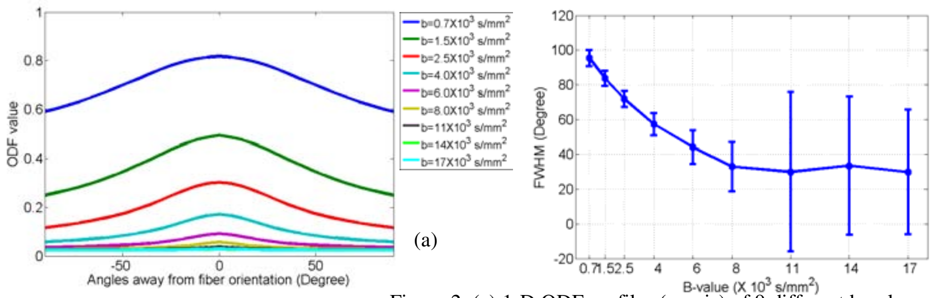


Figure 2. (a) 1-D ODF profiles (y-axis) of 9 different b-values, plotted as a function of crossing angle between ODF orientation and fiber orientation. The direction of 0° is parallel to fibers. (b) The plot of FWHM obtained from ODF profiles versus different b-values.

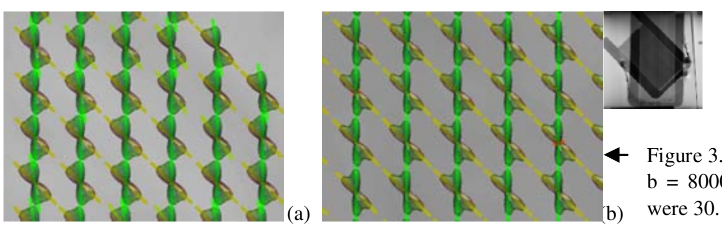


Figure 3. ODFs obtained using QBI with (a) b = 4000 s/mm$^2$ and with (b) b = 8000 s/mm$^2$ on 45° crossing phantom model. The crossing angles were 30.1° ± 11.3° (a) and 45.0° ± 0.0° (b) respectively.