Accuracy Assessment of q-ball Imaging with Phantom Models

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

[1]Interdisciplinary MRI/MRS Laboratory, DEPT. 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 be used to estimate intravoxel complex fiber coherence by measuring orientation distribution function (ODF) within each MR voxel [1]. In clinical machine, QBI with 200 encoding points has shown the feasibility to map fiber crossing. However, due to the clinical gradient limitation, QBI resulted in a poor accuracy on either coherent or complex fiber mapping [2]. Furthermore, criteria of QBI parameter selection have not been proposed. In this study, by using MR phantom models, we evaluated the accuracy of QBI in mapping complex fiber coherence without gradient limit. The effects of diffusion time and SNR on QBI accuracy were further clarified. The results showed that QBI with 92 encoding points and b-value = 2500 s/mm^2 could map coherent and crossing fibers accurately with angular error 4.67°±0.36° and 1.07°±5.13°, respectively. With higher b-value encoding, the angular resolution of QBI might be better improved but the request of SNR might be more severe. Furthermore, to map fiber orientation accurately, longer diffusion time for water molecules to space the restrictive boundaries is necessary. This study implied that QBI with 92 encoding points, along with adequate diffusion time and SNR, could map complex fiber coherence accurately in clinical system.

Materials and Methods

In phantom studies, both coherent and 90° crossing fibers were designed. Plastic capillaries with I.D. = 20 μm and O.D. = 90 μm were filled with water and well organized. MR images were acquired by diffusion stimulated echo sequence at 9.4 Tesla MRI system (Bruker, Germany) with TR/TE = 1000/15.8 ms, diffusion duration (δ) = 4 ms, and in-plane resolution = 0.78x0.78 mm^2. In the case of coherent fibers, three diffusion times, 50, 150 and 250 ms, were studied to evaluate the effect of diffusion time. B-values from 700 to 8000 s/mm^2 were considered in each diffusion time with NEX=1 which yielded to SNR of null image = 10. QBI with NEX=16, which resulted in SNR=40, and Δ=250 ms was also acquired as a reference. In crossing fibers study, QBI with SNR=40 was acquired with NEX=16, Δ=250 ms and b-value = 2500 s/mm^2.

The QBI was encoded with 92 sampling points (3-fold tessellated icosahedron) in q-space, which gave an angular resolution of 23°. To exclude cross-term effect, cross-term correction was performed prior to ODF reconstruction [3]. 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 a linear fashion of distance function from data points while reconstructing ODF. The primary orientations of ODF were defined as the fiber orientations. For each MR voxel, deviation angle and numbers of primary ODF orientations were calculated.

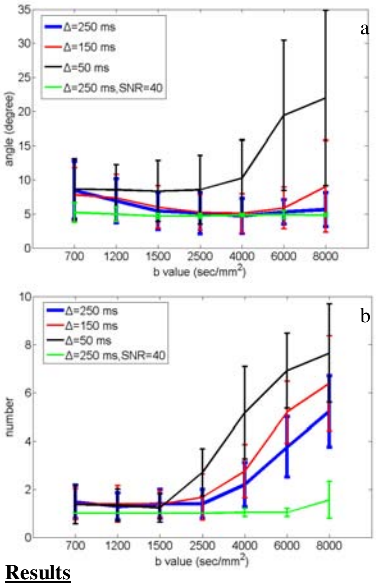


Fig. 1, Evaluation of QBI deviation angle (a) and numbers of ODF peaks (b) with various Δ, b value, and, SNR. Sufficient Δ is necessary for QBI to map fiber orientations. With SNR=10, b value between 1500-6000 s/mm^2 is capable to map fiber orientation accurately. However, as shown in fig. 1b, other pseudo orientations might be emerged if SNR is not enough.

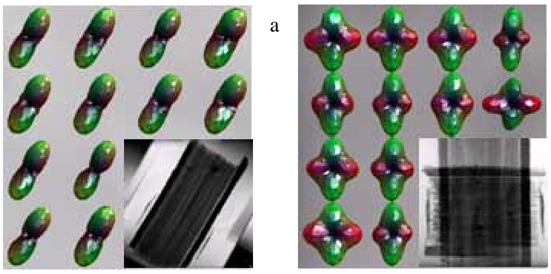
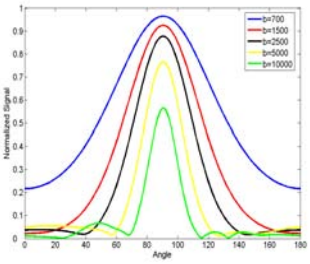


Fig. 2, ODF of both coherent and crossing fibers with image SNR=40, b=2500 s/mm^2, a) the angular error is 4.67°±0.36° for coherent phantom model with no pseudo orientation emerge. b) angular error = 1.07°±5.13° for the 90° phantom model.



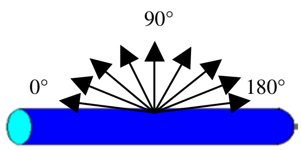


Fig 3. Normalized diffusion signal with various b-values and encoding angles from Monte-Carlo simulation.

Results

Figure 1 shows the deviation angle (Fig. 1a) and numbers of primary ODF orientations (Fig. 1b) of QBI in mapping coherent fibers with various b-values and diffusion time. While SNR=40, Δ=250 ms (green), Figure 1a shows a deviation error of 4.67° with b-value from 1500 to 8000 s/mm^2. With SNR=10, both cases of Δ= 150 and 250 ms could map coherent fiber accurately with b-value from 1500 to 6000 s/mm^2 and the deviation error = 5.09°. In Figure 1b, QBI with SNR = 40 and Δ=250 s/mm^2 is capable of delineating fiber coherence accurately with b-value between 700 and 6000 s/mm^2. However, with SNR=10, the results of Δ= 50, 150, and 250 ms shows other pseudo ODFs, which are more severe while b-value increases. Figure 2 shows the ODF of coherent and crossing fibers with SNR=40 and b=2500 s/mm^2. The deviation angle of both phantom models were 4.67°±0.36° and 1.07°±5.13°, respectively.

Conclusion

The results showed that longer diffusion time for water molecules to space the restrictive boundaries is necessary for accurate mapping of fiber orientation in QBI. With b = 2500 s/mm^2, both coherent and crossing phantom models showed deviation error within 5°. This error might be decreased with more encoding points in q-space. With b-value from 1500 to 6000 s/mm^2 and image SNR=10, QBI could define coherent fiber with error of 5.09°. However, other fake ODF orientations were emerged while b-value increases. These pseudo orientations might come out due to SNR decrease while b-value increases. As shown in Figure 3, QBI's tolerance to noise is decreased while b-value increases since the signal contrast of diffusion signal between different encoding directions is in inverse proportion to b-value. Figure 3 also implies that angular resolution would be improved while b-value increases, which induces the bandwidth to decrease. In conclusion, this study suggests that selection of diffusion time is required for molecules to space the restrictive boundaries. To improve angular resolution, higher b-value or more encoding points with adequate SNR is suggested. Furthermore, with 92 encoding points, QBI is capable of mapping complex fiber coherence accurately within acceptable error level.

Acknowledgements

The authors are grateful to David S. Tuch for helping on content discussion. The authors acknowledge support from National Science Council grant NSC 94-2752-H-010-004-PAE.

Reference

[1] D.S Tuch et al, Neuron 2003, 40, p885. [2] M. Perrin et al, Philos Trans R Soc Lond B Biol Sci, 2005, 360, p881. [3] M. Neeman et al, MRM 1991, 21, p183.