# The Effects of Different Capillary Structures on BOLD Model in Functional MR Imaging

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***Abstract*** - Simulation results of Monte Carlo method to evaluate the MRI signal loss due to intravascular susceptibility difference under different capillary structure were presented in this report. These data reveal a simplified periodic structure is a good approximation to the complicated random structure when the diffusion constant of water is larger than $10^{-9}$ m²/sec for gradient echo and $2 \times 10^{-9}$ m²/sec for spin echo at typical Cerebral Blood Volume(CBV) fraction (f=5%).

## Introduction

The blood oxygenation level dependent (**BOLD**) contrast was used to interpret functional MRI phenomena[1]. The applied static magnetic field was disturbed by the capillaries that were filled with paramagnetic deoxygenated hemoglobin (deoxyHb). Therefore, the transverse signal loss (T2*) decreases as the field inhomogeneity increases. In the past, the signal loss due to intravascular susceptibility difference has been generally calculated by Monte Carlo simulations[2,3] according to the periodically distributed capillary structure. However, randomly distributed capillary seem to be a better model for the practical considerations. Here, we applied Monte Carlo method to study the effects of different capillary distributions model on BOLD MR signal loss.

## Methods

First, the magnetic field map ($h(\vec{r})$) was calculated according to different capillary structures and magnetization ($M=H_0*\Delta\chi$). The capillaries were generated for two types of structures, i.e., random and periodic structures. For random structure[4] (figure 1), capillaries with random orientation were generated in a voxel until the specified CBV fraction (f) was reached. To make sure these capillaries were uniformly distributed in the voxel, we divide the voxel into 4*4*4 subcubes and calculate CBV fraction of every subcube. For periodic structure (figure 2), the directions of all capillaries were set perpendicular to the applied static field and the magnitude of the static field is divided by 2 to compensate the influence of the capillary orientation. The distance between adjacent capillaries are evaluated by $L=\sqrt{\pi/f}\cdot R_c$ (*Rc* : capillary radius). Once the capillaries were generated, the magnetic field turbulence can be calculated by

$$\Delta H_z(r,\phi) = \frac{MR_c^2\cos(2\phi)\sin^2(\alpha)}{2r^2}$$

$$M = H_0\Delta\chi$$

$\alpha$ : the angle between the external $H_0$ and the axis of the capillary

The diffusion of water molecules can be modeled as Brownian motion in space. The displacement of the water molecule in dt is a gaussian distribution whose mean is zero and standard deviation is $\sqrt{2Ddt}$. The distribution is derived from random number generator of the ANSI C language. The time step dt may affect the results significantly if it is chosen too large compared with the capillary structure. In our simulations, the dt was chosen such that $\sqrt{2Ddt}$ is fixed at about 1 micron to get convergent results. Summing the magnetic field along the trajectory can get the phase of the spin at echo time.

## Results

64*64*64 molecules, with uniformly distributed initial positions, are considered in our simulations. The radius of capillaries (Rc) is 3 microns, and the simulation range is a cube with length 160 microns. The results of applying Monte Carlo method to different capillary structures with fixed CBV fraction (f=5%) for gradient echo and spin echo were plotted in figure 3-(a) and figure 3-(b), respectively. Obviously, the results are very different for smaller diffusion constants. This implies the periodic structure is a good approximation to random structure if the diffusion constant is large enough to average the surrounding magnetic fields.

## Discussion

The periodic capillary structure is widely used for Monte Carlo simulation due to its simplicity. Though the practical capillary structure is unknown to us and maybe be variant in different tissues, the random structure seems to be more reasonable than the periodic structure. For typical free water molecules, D is around $2.5 \times 10^{-9}$ m²/sec. These results suggested that for molecules with D higher than the criterion, the molecule can diffuse through several capillaries and two capillary structures yield quite similar results. But if the

..sion constant is small, results of both structures may be ..se.


## References

Ogawa, et al. *Biophysical Journal* **64(3)**, pp.803, 1993.

R. Fisel, et al. *Magn. Reson. Med.*,**17**, pp. 336-347, .991.

P. Kennan, J. Zhong, and J. C. Gore, *Magn. Reson. ..ed.*, **31**, pp. 9-21, 1994.

..i-Ming Tsai, and Jyh-Horng Chen, *SMRM abstract* ..94 (submitted).


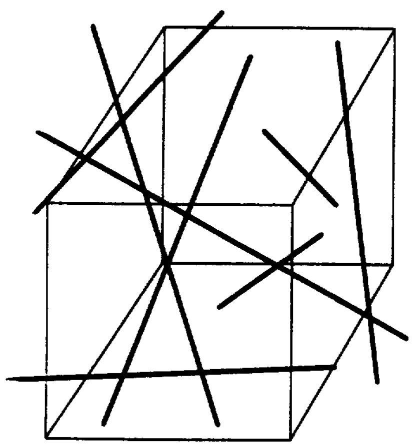
Figure 1

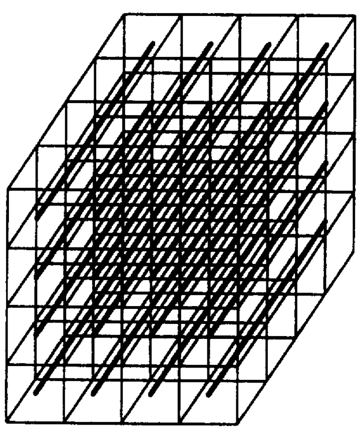
Figure 2

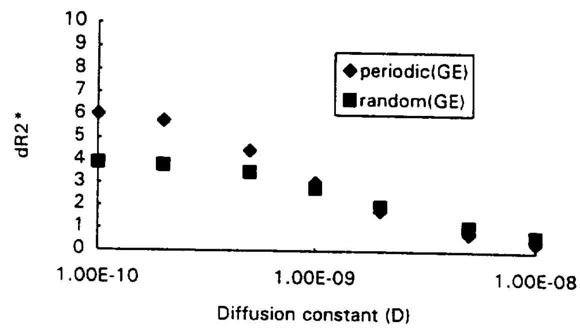

Figure 3-(a)

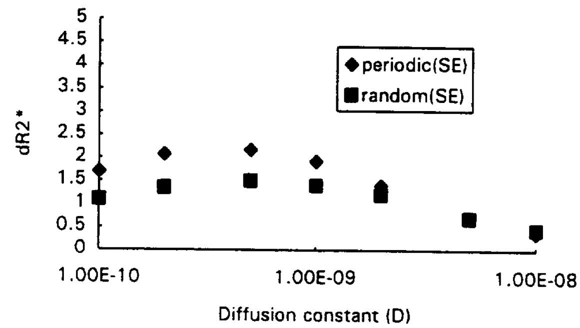

Figure 3-(b)