AJNR

Tetrahedral Gradient Diffusion-Encoding Scheme with Line Scan Imaging

Pradip M. Pattany

AJNR Am J Neuroradiol 2003, 24 (1) 2-3
http://www.ajnr.org/content/24/1/2

Tetrahedral Gradient Diffusion-Encoding Scheme with Line Scan Imaging

MR images that represent water diffusion through tissue can be produced by analyzing spin dephasing and signal intensity loss caused by random motion along magnetic field gradients. Diffusion-weighted imaging has been shown to enable detection of stroke early after the thromboembolic event, and anisotropic diffusion in white matter is of particular interest in studying the structural integrity of the axons in certain pathologic conditions.

Using conventional clinical imagers, three sets of diffusion-weighted images are obtained by applying diffusion encoding along each of the three orthogonal axes of the imager individually. One set of images without diffusion encoding is also obtained. The data are then used to generate apparent diffusion coefficient maps for quantitative analysis. The b values attained with this scheme are dependent on the length of the diffusion-encoding gradients being applied, the time between the leading edge of the two diffusion-encoding gradients, and the maximum gradient strength available on the imager. To use the high b values (>1500 s/mm^2), with the gradients being the limiting factor, the TE has to be increased. Longer TE results in a poor signal-to-noise ratio, which can be improved by increasing the number of averages, although that also increases the overall acquisition time.

For conventional image acquisition, the use of echo-planar imaging reduced the total acquisition time considerably when compared with spin-echo imaging. Both these methods use frequency and phase-encoding gradients to generate a 2D Fourier transform image. It is well known that any physiological motion or flow that occurs during data acquisition results in artifacts that are propagated in the phase-encoding direction with the 2D Fourier transform method. Also, echo-planar imaging does not work well in regions of the body that have excessive field inhomogeneity due to susceptibility and physiological motion. These artifacts are further exacerbated when diffusion encoding is performed.

Several acquisition methods have been proposed, but they require powerful gradient hardware and faster image acquisition methods, such as echo-planar imaging. Over the years, several new approaches have been investigated to overcome the problems of diffusion imaging in the regions of the body in which physiological motion and magnetic susceptibility are prevalent. One such method uses tetrahedral diffusion encoding (tetrahedral gradients) with line scan imaging, proposed in this issue of the *AJNR* by Bammer et al; with this method, they were able to quantify mean diffusion values in the spinal column by using high b values and short TEs.

The tetrahedral gradient scheme uses all three orthogonal gradients at the same time. With this scheme, the direction of diffusion encoding is angled equally to all three orthogonal axes of the magnet. The tetrahedral gradient scheme uses the combined strength of the three gradients, assuming the maximum gradient strength is equal in all three axes, and it produces $\sqrt{3}$ (1.732) times the input of an individual orthogonal gradient. The higher gradient strength enables one to considerably shorten the TE needed to achieve a given maximum b value, resulting in improved signal-to-noise ratio and shorter acquisition time compared with conventional diffusion-weighted imaging methods. Unlike the conventional diffusion-weighted imaging method, with which four sets of images (three with and one without diffusion encoding) are acquired. With the tetrahedral method, there are four possible directions in which diffusion encoding can be applied, hence the term *tetrahedral diffusion encoding* (1). As a result, this method requires five sets of images (four with and one without diffusion encoding). The direction of tetrahedral gradient is altered by changing the sign of one or more diffusion-encoding gradients for a given axis. Because the tetrahedral gradient scheme enables one to get higher b values, one can measure the extracellular water diffusion by fitting the values obtained at lower b values (≤ 1000 s/mm^2) and intracellular water diffusion by fitting the values obtained with higher b values. This is accomplished by fitting the diffusion-weighted imaging data by using a bi-exponential model.

The line scan technique overcomes the problem of physiological motion artifacts commonly seen on conventional 2D Fourier transform images, because it does not use the phase-encoding gradient to generate the image. The basic concept of the line scan spin-echo method is as follows; to obtain an axial section, a selective 90-degree RF excitation pulse is applied while the z gradient is turned on; however, when the selective 180-degree RF refocusing pulse is applied, the y gradient is turned on. This results in a row of spins that experience both RF pulses. From this row of spins, a line of data is acquired by applying a frequency-encoding gradient along the x axis. Subsequent lines of data are acquired by shifting the frequency of the 180-degree RF pulse so as to excite adjacent rows of spins. When all the lines of data are acquired, the image can be formed. There are several methods proposed to excite multiple lines of data in a given TR, but the basic concept of line scanning remains the same. This method uses spin-echo to generate the signal intensity; hence, it is not affected by the susceptibility artifacts. Because the line scan method does not use the phase-encoding gradients,

the artifacts caused by physiological motion and flow are kept to a minimum.

The tetrahedral diffusion-weighted line scan method used by Bammer et al shows that this method is robust and can be used effectively for imaging of the spine. This method enabled them to use high b values ($\leq$3005 s/mm^2) while maintaining the TE of 65. It would not have been possible had they used the conventional diffusion-encoding method. They were able to quantify mean diffusion values in vertebral bodies, nuclei pulposi, and annuli fibrosi. The results showed that the diffusion-weighted signal intensity was bi-exponential in vertebral bodies and that the signal intensity followed a mono-exponential course for nuclei pulposi and annuli fibrosi. With the bi-exponential fit, they were able to quantify the values for slow (intracellular) and fast (extracellular) diffusion in the vertebral bodies. Their results indicate that the method is robust and that it provides excellent image quality.

It is certain that many new diffusion-encoding schemes along with an image acquisition method will be developed in the future, which will enable imaging parts of the body where physiological motion and magnetic field susceptibility are prevalent. The tetrahedral diffusion-weighted line scan method is showing good promise that diffusion-weighted imaging data can be obtained from these regions of the body.

PRADIP M. PATTANY
Department of Radiology
University of Miami
Miami, Florida

References

1. Conturo TE, McKinstry RC, Akbudak E, Robinson BH. **Encoding of anisotropic diffusion with tetrahedral gradients: a general mathematical diffusion formalism and experimental results.** *Magn Reson Med* 1996;35:399–412