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Diffusion-Weighted Imaging of the Brain: Beyond Stroke

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Abstract

Diffusion-weighted imaging provides image contrast that is different from that provided by conventional magnetic resonance imaging techniques. It is highly sensitive for detection of cytotoxic oedema, and as such has gained favor in the detection of acute infarcts. However, diffusion-weighted imaging is underrepresented in the characterisation of many other disease processes. Our objective is to differentiate diseases that manifest with various neurological disorders, based on diffusion contrast and apparent diffusion coefficient values and review of hyper- and hypointense lesions on diffusion-weighted imaging.

Résumé

L'imagerie de diffusion fournit un contraste d'image différent de celui obtenu au moyen des techniques conventionnelles d'imagerie par résonance magnétique. Elle est très sensible pour détecter l'œdème cytotoxique et est donc devenue une méthode de choix pour la détection de l'infarctus aigu. L'imagerie de diffusion est cependant sous-représentée dans la caractérisation de l'évolution de beaucoup d'autres maladies. L'étude vise à différencier les maladies qui se manifestent avec divers troubles neurologiques à partir du contraste de diffusion et des valeurs du coefficient de diffusion apparent, de même que par l'examen des lésions hypointenses et hyperintenses sur les clichés obtenus par imagerie de diffusion.

Key Words: Apparent diffusion coefficient; Brain; Diffusion-weighted imaging; Magnetic resonance imaging

Diffusion-weighted imaging (DWI) is a magnetic resonance imaging (MRI) technique in which contrast within the image is based on microscopic motion of water. Thus, it is more sensitive to early changes of cytotoxic or vasogenic damage at cellular level than traditional MRI measurements such as T1 or T2 relaxation rates [1]. The procedure was first described in 1965 by Stejskal and Tanner [2].

DW images are obtained by adding a series of 2 sequential gradient pulses to a 90° and 180° spin-echo sequence (Figure 1). The first gradient pulse is applied between the 90° and the 180° pulse. The resultant motion causes molecules to acquire phase shifts of their transverse magnetization. Both the 180° and the second gradient pulse rephase stationary spins. Phase shifts acquired in mobile molecules lead to failure of such molecules to rephase completely, resulting in substantial signal loss [2].

This can be represented as

$$\textbf{Degree of signal loss} = \frac{\text{S : signal after application of diffusion gradients}}{\text{So : signal before use of diffusion gradients}}$$

$$\mathbf{S/S0 = exp\,(-b\ factor\ X\ ADC)}$$

where S/S0 is the ratio of signal with diffusion gradients to signal without diffusion gradients and ADC is the apparent diffusion coefficient ($\mu m^2/s$) and is tissue dependent.

Diffusion gradients sensitize the MR image to motion of water molecules. Thus, a loss of motion results in restricted diffusion and appears bright on DWI and greater motion produces a darker image (Figure 2). Lesions with diffusion restriction appear bright on DW images and dark on ADC maps. Structures with increased diffusion such as

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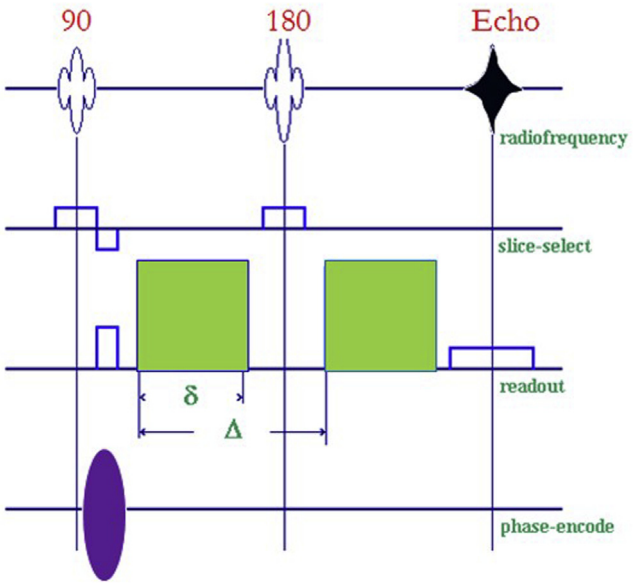

Figure 1. Spin echo sequences at 90° and 180° with 2 sequential gradient pulses.

cerebrospinal fluid (CSF) will appear dark on DW images and bright on ADC maps.

The attenuation factor (s/mm^2) b is a value that includes all gradients effect (imaging gradients + diffusion gradients). The b value can be regarded as analogous to the echo time for T2 weighting. At low diffusion weighting (small b values), there is minimal sensitivity to diffusional motions and images will show predominant T2 contrast. At high b values, the contrast is largely produced by the diffusion properties (Figure 3). However, even at larger b values, there will be some T2-weighted component. This can be confirmed only by looking at the ADC maps. Hyperintensity on both DWI and ADC maps is secondary to the inherent T2 characteristics of these images and is described as T2 shine-through effect (Figure 4).

According to Fick's law, true diffusion is the net movement of molecules due to a concentration gradient. With MRI, molecular motion due to concentration gradients cannot be differentiated from molecular motion due to pressure gradients, thermal gradients, or ionic interactions. Also, traditional MRI is not corrected for the volume fraction available or for increases in distance traveled due to tortuous pathways. Therefore, when measuring molecular motion with DWI, only the ADC can be calculated.

The ADC value does not depend on the field strength of the magnet or on the pulse sequence used (which is different for T1 or T2). The ADC obtained at different times in a given patient or in different patients or in different hospitals can be compared. By comparing differences in the apparent diffusion between tissues, tissue characterisation becomes

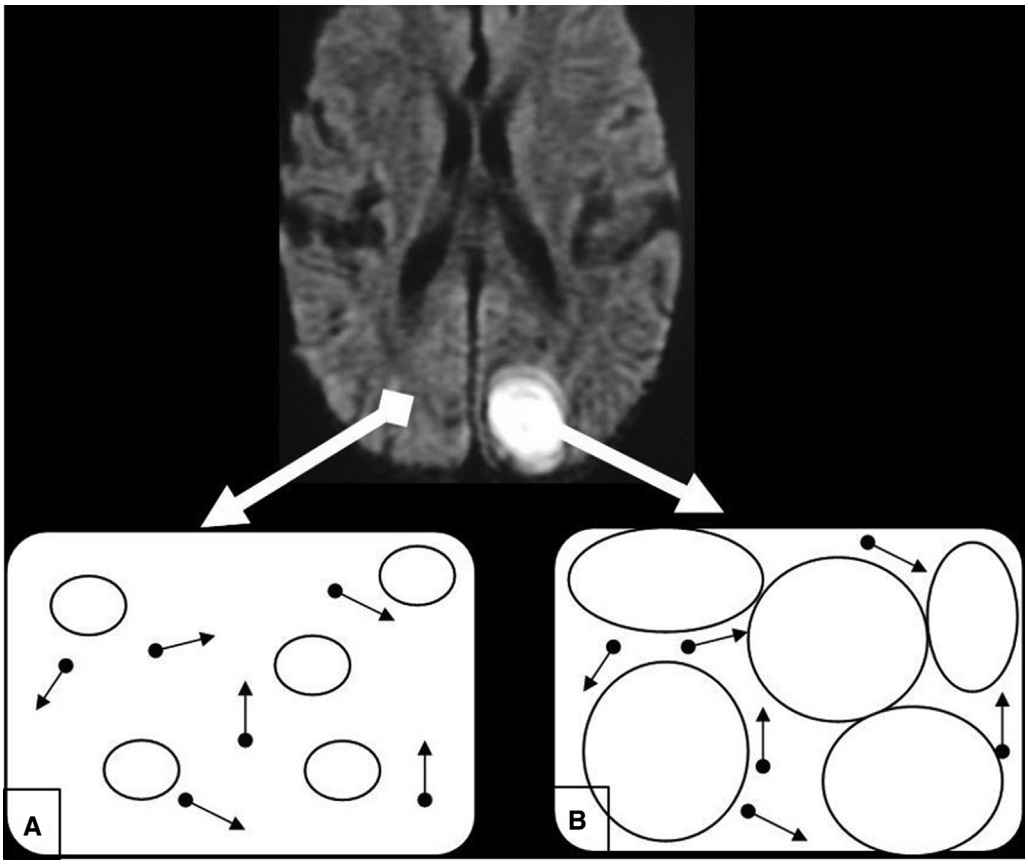

Figure 2. Restricted patterns of diffusion are bright on diffusion-weighted imaging and commonly reflect wide range of pathological processes: (A) normal brain showing relatively free diffusing water (isointense) and (B) pathology showing restricted diffusion (hyperintense).