Diffusion Weighted Magnetic Resonance Imaging of the Breast

Protocol Optimization, Interpretation, and Clinical Applications

Savannah C. Partridge, PhD*,
Elizabeth S. McDonald, MD, PhD

KEYWORDS

• Diffusion-weighted imaging • Breast MR imaging • Oncologic imaging • Breast cancer • b-value • Apparent diffusion coefficient • Neoadjuvant chemotherapy

KEY POINTS

- Diffusion-weighted (DW) imaging has shown potential to improve accuracy for lesion characterization on dynamic contrast-enhanced (DCE) magnetic resonance (MR) imaging in multiple studies.
- DW imaging may be a noncontrast method of breast MR screening that could be used as an adjunct to mammography.
- Increases in tumor apparent diffusion coefficient (ADC) in response to chemotherapy may provide a valuable early indication of treatment efficacy.
- Malignant lesions demonstrate restricted diffusion manifested by high signal intensity on DW imaging and low ADC values.
- Reproducible uniform fat suppression and techniques to reduce artifacts are essential for high-quality DW imaging of the breast.
- To reproduce reported ADC thresholds for lesion characterization, similar b-values must be used.
- ADC normalization may reduce variation from individual breast characteristics and technical factors.

INTRODUCTION

Diffusion-weighted (DW) imaging is a magnetic resonance (MR) imaging technique that characterizes the three-dimensional mobility of water in vivo and enables indirect assessment of tissue microstructure.

DW imaging is an established diagnostic tool in neuroimaging. Initially used for detecting acute stroke, its application to other areas of the body has been challenging because of technical limitations. More recent advances in MR technology including echo-planar imaging (EPI), high-amplitude gradients, multichannel coils, and parallel imaging have been instrumental in extending the use of DW imaging outside of the brain.[1–5] DW imaging was first applied for breast imaging in 1997 by Englander and colleagues,[6] and there have been numerous studies exploring the clinical utility of the technique since then.

DW imaging has shown promise for the detection and characterization of breast cancer. As a result, a

The support for NIH grant R01CA151326 are gratefully acknowledged.
Department of Radiology, Seattle Cancer Care Alliance, University of Washington School of Medicine, 825 Eastlake Avenue East, G3-200, Seattle, WA 98109-1023, USA
* Corresponding author.
E-mail address: scp3@u.washington.edu

Magn Reson Imaging Clin N Am 21 (2013) 601–624
http://dx.doi.org/10.1016/j.mric.2013.04.007
1064-9689/13/$ – see front matter

growing number of imaging centers are incorporating DW imaging into the clinical breast MR examination. However, DW imaging techniques are not standardized and there is no uniform method of interpretation, which limits widespread use. Apparent diffusion coefficient (ADC) values allow quantification of diffusion signal, and can facilitate in differentiating benign and malignant breast tumors[7–19] as well as identifying early response in tumors undergoing preoperative treatment.[20–27]

The purpose of this review is to cover the basic principles of diffusion, discuss protocol optimization, review malignant versus benign diffusion imaging features, and discuss potential clinical applications of this promising technology.

BASIC PRINCIPLES OF DW IMAGING

Above the temperature of 0 K, gas and liquid molecules move through thermal agitation, a process known as molecular diffusion. In pure water this movement, called Brownian motion, is random, as first formally described by Einstein in 1905.[28] In vivo, the motion of water molecules is restricted by intracellular and extracellular compartments as well as tissue cellularity.[29] The degree of water diffusion in biological tissue is inversely correlated to the tissue cellularity and the integrity of cell membranes. In the case of breast tumors, which typically have high cellular density and intact cell membranes, the motion of water molecules is more restricted than in the normal parenchyma. By contrast, in areas of low cellularity or where the cellular membrane has been breached, the motion of water molecules is less restricted (**Fig. 1**).

DW imaging is a type of MR imaging scan performed using motion-sensitizing gradients to measure the Brownian motion of water. Whereas contrast-enhanced MR imaging demonstrates tissue vascularity, DW imaging reflects the microscopic cellular environment and is sensitive to characteristics such as cell density, membrane integrity, viscosity, and microstructure.

MR Acquisition

DW imaging involves short acquisition times, approximately 2 to 5 minutes, and can easily be incorporated into standard clinical breast MR imaging examinations. It is typically performed using a T2-weighted spin-echo prepared EPI sequence with an additional pair of motion-sensitizing gradient pulses (**Fig. 2**), based on methods originally proposed by Stejskal and Tanner.[30] Diffusion gradients should be applied in at least three orthogonal directions to obtain rotationally invariant measures. EPI is used because image acquisition is very fast, which minimizes effects of subject motion. Multiple factors

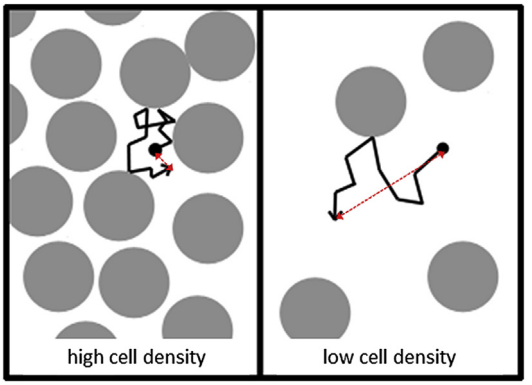

Fig. 1. Comparison of water diffusion in tissues with differing cellularity. The net distance (*red dashed arrows*) traveled by protons in the extracellular fluid during a specific time is much greater in regions of low cellularity (*right*) where random motion is not impeded by the presence of cellular membranes. In this way, the degree of water diffusion in biological tissue is inversely correlated with the tissue cellularity and the integrity of cell membranes.

determine the sensitivity of the diffusion sequence to water motion, the primary of which is the degree of diffusion weighting, described by the b-value (unit s/mm^2), given by:

$$b = \gamma^2 G^2 \delta^2 (\Delta - \delta/3) \quad \textbf{(1)}$$

where γ is the proton gyromagnetic ratio, G is the gradient strength, δ is the gradient duration, and Δ is the time delay between the leading edges of the two diffusion-sensitizing gradients,[31] as indicated in **Fig. 2**. Water protons moving between the timing of the gradients will not be properly phased at the time of readout. As a result, the resulting MR

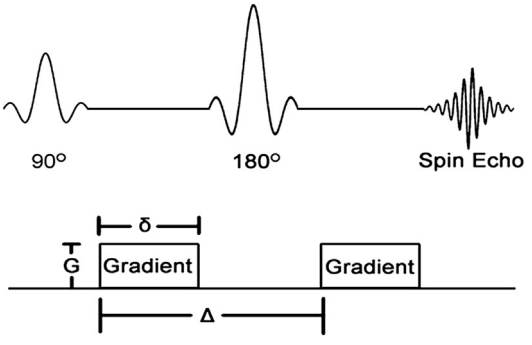

Fig. 2. Pulse-sequence diagram of a diffusion-weighted spin-echo sequence based on a Stejskal-Tanner encoding scheme. Two precisely matched diffusion-sensitizing gradients are inserted before and after a 180° radiofrequency refocusing pulse. Important factors defining the degree of diffusion sensitization are the gradient amplitude (G), duration (δ), and the time between the two sensitizing gradients (Δ).