Redefining MRI:
From Image to Insight

ICMRI 2026
THE 14th INTERNATIONAL CONGRESS ON MRI
& 37th ANNUAL SCIENTIFIC MEETING OF KSMRM

AUGUST 27 - 28, 2026
Grand Walkerhill Seoul, Seoul, Korea
https://icmri.ksmrm.org/2026m

Breast 2

SY10-1

Innovations in Diffusion-Weighted Imaging: Clinical Impact on Breast Cancer Diagnosis

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Standard DWI and ADC

Breast MRI is the most sensitive modality for cancer detection, and while dynamic contrast-enhanced (DCE) MRI remains the clinical standard, diffusion-weighted imaging (DWI) has emerged as an essential non-contrast sequence. The latest Breast Imaging Reporting and Data System (BI-RADS) 6th edition formally recognizes DWI as an important complementary component of breast MRI. DWI enables the mapping of water molecule diffusion in biological tissues, providing intrinsic contrast that reflects the cellular microenvironment. The mobility of water is readily quantified via the apparent diffusion coefficient (ADC), derived from images acquired at two or more b-values. Malignant lesions typically exhibit hindered water diffusion and significantly lower ADC values compared to benign or healthy tissues due to their high cellularity. The clinical role of ADC extends from the detection and diagnosis of breast cancer to the assessment of its characteristics and the prediction of prognosis. Quantitatively, ADC improves diagnostic specificity, facilitating the downgrading of BI-RADS 4 lesions and reducing unnecessary biopsies. Furthermore, ADC serves as a non-invasive imaging biomarker for tumor aggressiveness; lower values are significantly associated with higher tumor grades, an increased Ki-67 labeling index, and specific molecular subtypes. In treatment monitoring, a progressive increase in ADC often precedes morphologic changes in responders to neoadjuvant therapy, allowing for early therapeutic optimization. Image quality, including fat suppression, is crucial for utilizing DWI both qualitatively and quantitatively. The European Society of Breast Imaging (EUSOBI) has published minimum requirements to this end. Efforts toward standardization are ongoing to mitigate variability in image quality and quantitative measurements, thereby facilitating the clinical utility of DWI.

Advanced Modeling beyond ADC

Recent innovations have introduced advanced diffusion models that capture information beyond the "apparent" diffusivity of the mono-exponential model. Intravoxel incoherent motion (IVIM) at low b-values distinguishes between pure molecular diffusion (D) and microcapillary perfusion (f). Malignant lesions typically show higher f and lower D values, with the latter potentially outperforming standard ADC in diagnostic accuracy. At high b-values, diffusion kurtosis imaging (DKI) quantifies non-Gaussian water diffusion to reflect tissue microstructural complexity. Metrics such as mean kurtosis (K) and mean diffusivity (MD) differentiate benign from malignant lesions, where higher K values may suggest aggressive features of breast cancer and a greater risk of metastasis.

Technological Advances: Resolution Enhancement and Morphological Evaluation

The clinical utility of DWI is being further transformed by deep learning reconstruction (DLR) and advanced acquisition sequences. DLR facilitates a reduction in scan time while simultaneously suppressing noise and artifacts. High-resolution DLR protocols significantly enhance anatomical delineation and edge sharpness, improving the detection of small malignant lesions. These innovations overcome traditional trade-offs between acquisition speed and image quality, potentially enabling morphological evaluation comparable to DCE-MRI.