Radiology

Emerging Techniques Bring Diffusion-weighted Imaging of the Breast into Focus

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The past decade has revealed multiple areas of clinical value for diffusion-weighted imaging (DWI) of the breast. But spatial resolution limitations and image quality issues remain hurdles to clinical use. In this issue of *Radiology*, McKay et al (1) present an emerging breast DWI acquisition and reconstruction strategy that concurrently improves spatial resolution, image quality, and anatomic coverage compared with current techniques. These technological improvements are essential for adapting breast DWI into routine clinical practice.

DWI is an MRI technique that uses motion-sensitizing gradients to measure water diffusivity in tissue, which reflects microstructural characteristics including but not limited to cell density, organization, and membrane integrity. In breast malignancies, alterations in these characteristics often cause reduced diffusion rates compared with normal fibroglandular tissue. This makes DWI a useful tool in both detecting and characterizing breast cancer. Promising data demonstrate the utility of DWI to improve breast MRI performance, characterize breast cancer subtypes, monitor response to neoadjuvant chemotherapy, and even be a stand-alone tool in detecting breast cancer (2). DWI also has practical advantages of short acquisition time (typically 2–3 minutes), wide availability across commercial scanners, and no need for a contrast agent. As a result, there is increasing interest in the mainstream breast imaging community regarding how to incorporate DWI into their breast MRI protocols.

Despite growing interest, clinical implementation of breast DWI remains hampered by lack of protocol standardization and suboptimal image quality. Thus, consensus guidelines were recently proposed for clinical breast DWI by the European Society of Breast Imaging International Breast Diffusion-weighted Imaging working group (3). Basic acquisition recommendations included use of a spin-echo–prepared echo-planar imaging pulse sequence, axial acquisition with in-plane spatial resolution 2×2 mm^2 or less and slice thickness 4 mm or less, parallel imaging acceleration factor of two or greater, shortest possible echo time, repetition time of 3000 msec or longer, and at least two *b* values of 0 and 800 sec/mm^2. These recommendations represent minimum requirements to perform breast DWI with adequate signal-to-noise ratio while minimizing artifacts and distortions. Also, in their DWI profile, the Radiological Society of North America Quantitative Imaging Biomarkers Alliance put forth breast DWI acquisition and analysis specifications to support the use of the apparent diffusion coefficient as a robust quantitative biomarker (with defined confidence intervals) (4). But even with close adherence to these specific protocol recommendations, the inherent technical limitations of DWI often result in inadequate image quality for breast applications.

Conventional DWI uses a single-shot echo-planar imaging sequence, which acquires all k-space lines that form the image during a single excitation. A single-shot echo-planar imaging sequence provides the rapid imaging needed to freeze bulk motion and retain good signal-to-noise levels. But the technique provides limited spatial resolution for breast imaging because of the combined need for large field of view (to obtain full bilateral coverage and avoid phase wrap) and restricted matrix sizes (to keep echo train durations short enough to retain sufficient signal-to-noise levels and minimize spatial blurring). Single-shot echo-planar imaging is also prone to artifacts and susceptibility-based distortions, which further degrade image quality. Versus brain imaging, in which DWI is successfully used routinely, application in the breast involves extra technical challenges because of the greater coverage requirements (approximately double the field of view), off-isocenter imaging and air-tissue interfaces that exacerbate field inhomogeneities and distortions, and significant fat content in the breast that must be suppressed to avoid detrimental chemical shift artifacts.

To improve the image quality of echo-planar imaging–based breast DWI, a variety of techniques have been explored that shorten echo spacing and/or echo train lengths (2), including multishot (eg, readout-segmented and multiplexed sensitivity encoding [5]) and reduced field of view. Such techniques offer improved spatial resolution capabilities and reduced susceptibility artifacts but also result

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See also the article by McKay et al in this issue.

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in longer imaging times and/or reduced coverage and are not yet widely implemented across vendor platforms.

The Eastern Cooperative Oncology Group–American College of Radiology Imaging Network 6702 multicenter trial illustrates the challenges of breast DWI in clinical settings. The trial confirmed that DWI apparent diffusion coefficient measures could reduce false-positive findings at conventional dynamic contrast-enhanced breast MRI across practice sites and also found technical issues limited overall utility (6). The trial used a standardized DWI protocol adhering to criteria of the international breast DWI working group and Quantitative Imaging Biomarkers Alliance recommendations, yet many breast lesions detected at MRI could not be detected or evaluated with confidence on the corresponding images from DWI. Along with variable presence of common DWI technical issues (eg, poor fat suppression, low signal-to-noise, susceptibility-related distortion, and misregistration) the trial showed partial volume averaging to be a primary issue. This was the result of suboptimal spatial resolution of DWI, precluding lesion localization and visibility for 8.0% (nine of 114) of the lesions detected at MRI even in the absence of technical issues.

Spatial resolution is of particular importance for breast imaging, which has long relied on high spatial resolution for detection of subtle disease characteristics. Digital radiographic mammography, the most common breast screening modality, entails high spatial resolution with pixel sizes of 50–100 μm, and American College of Radiology breast MRI accreditation mandates minimum spatial resolution of at least 1 × 1 × 3 mm for conventional dynamic contrast agent–enhanced MRI scans (7). However, for DWI, spatial resolution has historically been a necessary trade-off to achieve the high technical demands of the technique. Thus, the capability of DWI in detecting breast lesions that are small and not masses and in assessing important diagnostic features relating to lesion shape and intratumoral heterogeneity remains limited. Not surprisingly, in situ cancers (often manifesting as nonmasses) and small (≤1 cm) invasive cancers are often reported as false-negative findings across studies testing the sensitivity of DWI as a stand-alone unenhanced breast screening tool (8,9). However, emerging developments in image acceleration and multishot techniques are enabling DWI acquisitions with spatial resolution approaching conventional anatomic MRI sequences. This may be a much-needed game changer for expanding the clinical role of DWI in breast imaging.

In their study, McKay et al (1) evaluated an axially reformatted simultaneous multislice imaging (SMS) technique well-suited to breast imaging to achieve high spatial resolution with full coverage and minimal spatial distortions. SMS approaches, which accelerate acquisitions in the slice dimension, show promise to reduce breast DWI acquisition times and have been used in conjunction with readout-segmented echo-planar imaging in the breast to leverage benefits of both techniques (10). The authors compared the resulting image quality of their axially reformatted SMS method with standard single-shot spin-echo echo-planar imaging and advanced readout-segmented echo-planar imaging techniques within the same participants. Each technique was independently optimized to achieve maximal spatial resolution while providing bilateral coverage in a clinically acceptable (<5 minutes) imaging time. The authors performed quantitative and qualitative assessments in phantom and in vivo examinations. The proposed axially reformatted SMS imaging protocol provided higher spatial resolution and image quality than both the single-shot echo-planar imaging and readout-segmented echo-planar imaging breast DWI approaches (with spatial resolutions of 1.25 × 2.5 × 1.25 mm, 1.7 × 1.7 × 4 mm, and 1.8 × 1.8 × 2.4 mm, respectively). The authors acknowledged that both axially reformatted SMS and readout-segmented echo-planar imaging have promise for improving breast DWI, but the axially reformatted SMS technique achieved greater anatomic coverage and better image quality than readout-segmented echo-planar imaging in head-to-head comparison.

Several limitations should be considered for interpreting the relevance of the study findings. This was a proof-of-concept study and the axially reformatted SMS approach required considerable offline processing time (authors reported >6 hours average reconstruction time per case). Thus, further work is necessary to improve efficiency for feasible clinical use. In particular, axially reformatted SMS required robust distortion correction. The authors accomplished this by using a reversed polarity gradient method, which substantially increased postprocessing time. The authors could likely have further optimized spatial resolution of the standard single-shot echo-planar imaging technique used as reference by using increased averages and distortion correction to maintain image quality, rather than spending imaging time to acquire extra *b* values. Also, the authors did not compare in vivo quantitative apparent diffusion coefficient measures across techniques, therefore accuracy and reliability of the proposed method as a quantitative marker requires further confirmation.

Compared with previous SMS breast DWI studies that used axial acquisitions, McKay et al (1) developed a unique sagittal acquisition strategy. This technique took advantage of greater slice acceleration potential in the right-left direction on the basis of breast coil geometry and then reformatted to the axial plane for standard of care bilateral interpretation. This allowed the authors to reap greater time savings and achieve higher spatial resolution with less in-plane blurring and artifacts. These and other emerging advanced DWI implementations rely on strong field strength for adequate signal, high performance gradients, and dedicated breast radiofrequency coils with many coil elements. At this time, other than the proposed axially reformatted SMS method, the aforementioned advanced diffusion-weighted echo-planar imaging techniques are commercially available through one or more vendors but not all directed specifically toward breast imaging applications.

In summary, DWI offers value in various breast applications, but its implementation remains limited by technical issues. Widespread clinical use of breast DWI requires tailored approaches for breast application, such as that proposed by McKay et al, to raise image quality and reliability closer to the levels of conventional contrast-enhanced MRI. Such technical advancements, across all vendor platforms, will be critical to maximize breast DWI performance and support its expanded role for breast imaging.

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References

1. McKay JA, Church AL, Rubin N, et al. A comparison of methods for high-spatial-resolution diffusion-weighted imaging in breast MRI. Radiology 2020;297:304–312.
2. Partridge SC, Nissan N, Rahbar H, Kitsch AE, Sigmund EE. Diffusion-weighted breast MRI: Clinical applications and emerging techniques. J Magn Reson Imaging 2017;45(2):337–355.
3. Baltzer P, Mann RM, Iima M, et al. Diffusion-weighted imaging of the breast-a consensus and mission statement from the EUSOBI International Breast Diffusion-Weighted Imaging working group. Eur Radiol 2020;30(3):1436–1450.
4. RSNA Quantitative Imaging Biomarkers Alliance. QIBA Profile: Diffusion-Weighted Magnetic Resonance Imaging (DWI). https://qibawiki.rsna.org/index.php/Profiles. Accessed August 3, 2020.
5. Naranjo ID, Gullo RL, Morris EA, et al. High-Spatial-Resolution Multishot Multiplexed Sensitivity-encoding Diffusion-weighted Imaging for Improved Quality of Breast Images and Differentiation of Breast Lesions: A Feasibility Study. Radiol Imaging Cancer 2020;2(3):e190076.
6. Rahbar H, Zhang Z, Chenevert TL, et al. Utility of Diffusion-weighted Imaging to Decrease Unnecessary Biopsies Prompted by Breast MRI: A Trial of the ECOG-ACRIN Cancer Research Group (A6702). Clin Cancer Res 2019;25(6):1756–1765https://doi.org/10.1158/1078-0432.CCR-18-2967.
7. DeMartini WB, Rahbar H. Breast magnetic resonance imaging technique at 1.5 T and 3 T: requirements for quality imaging and American College of Radiology accreditation. Magn Reson Imaging Clin N Am 2013;21(3):475–482.
8. Amornsiripanitch N, Bickelhaupt S, Shin HJ, et al. Diffusion-weighted MRI for Unenhanced Breast Cancer Screening. Radiology 2019;293(3):504–520.
9. Rotili A, Trimboli RM, Penco S, et al. Double reading of diffusion-weighted magnetic resonance imaging for breast cancer detection. Breast Cancer Res Treat 2020;180(1):111–120.
10. Filli L, Ghafoor S, Kenkel D, et al. Simultaneous multi-slice readout-segmented echo planar imaging for accelerated diffusion-weighted imaging of the breast. Eur J Radiol 2016;85(1):274–278.