Original Investigation

Comparison and Optimization of 3.0 T Breast Images Quality of Diffusion-Weighted Imaging with Multiple B-Values

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Rationale and Objectives: Breast 3.0 T magnetic resonance diffusion-weighted imaging (MR-DWI) of benign and malignant lesions were obtained to measure and calculate the signal-to-noise ratio (SNR), signal intensity ratio (SIR), and contrast-to-noise ratio (CNR) of lesions at different b-values. The variation patterns of SNR and SIR were analyzed with different b-values and the images of DWI were compared at four different b-values with higher image quality. The effect of SIR on the differential diagnostic efficiency of benign and malignant lesions was compared using receiver operating characteristic curves to provide a reference for selecting the optimal b-value.

Materials and Methods: A total of 96 qualified patients with 112 lesions and 14 patients with their contralateral 14 normal breasts were included in this study. The single-shot echo planar imaging sequence was used to perform the DWI and a total of 13 b-values were used: 0, 50, 100, 200, 400, 600, 800, 1000, 1200, 1500, 1800, 2000, and 2500 s/mm^2. On DWI, the suitable regions of interest were selected. The SNRs of normal breasts (SNR_{normal}), $SNR_{lesions}$, SIR, and CNR of benign and malignant lesions were measured on DWI with different b-values and calculated. The variation patterns of SNR, SIR, and CNR values on DWI for normal breasts, benign lesions, and malignant lesions with different b-values were analyzed by using Pearson correlation analysis. The SNR and SIR of benign and malignant lesions with the same b-values were compared using t-tests. The diagnostic efficiencies of SIR with different b-values for benign and malignant lesions were evaluated using receiver operating characteristic curves.

Results: Breast DWI had higher CNR for b-values ranging from 600 to 1200 s/mm^2. It had the best CNR at b = 1000 s/mm^2 for the benign lesions and at b = 1200 s/mm^2 for the malignant lesions. The signal intensity and SNR values of normal breasts decreased with increasing b-values, with a negative correlation ($r = -0.945$, $P < 0.01$). The mean SNR values of benign and malignant lesions were negatively correlated ($r = -0.982$ and -0.947, respectively, and $P < 0.01$), gradually decreasing with increasing b-values. The mean SIR value of benign lesions gradually decreased with increasing b-values, a negative correlation ($r = -0.991$, $P < 0.01$). The mean SIR values of malignant lesions gradually increased with increasing b-values between 0 and 1200 s/mm^2, and gradually decreased with increasing b-values ≥ 1500 s/mm^2. For b-values of 600, 800, 1000, and 1200 s/mm^2, the sensitivity and specificity of SIR in identifying benign and malignant lesions gradually increased with increasing b-values, peaking at 1200 s/mm^2.

Conclusions: Breast DWI had higher image quality for b-values ranging from 600 to 1200 s/mm^2, and was best for b-values ranging from 1000 to 1200 s/mm^2. The SIR had the highest diagnostic efficiency in differentiating benign and malignant lesions for a b-value of 1200 s/mm^2.

Key Words: Breast; breast neoplasm; diffusion-weighted imaging.

INTRODUCTION

Diffusion-weighted imaging (DWI) in magnetic resonance imaging (MRI) plays an important role in the diagnosis and differential diagnosis of breast lesions as well as in the evaluation of therapeutic efficacy in breast cancer (1–4). DWI can provide information at the tissue, cellular, and molecular levels, which is often used for diagnosis and prognosis evaluation in breast cancer (4,5). Therefore, the selection of DWI parameters for application and studies of its association with diagnostic efficacy have gained increasing attention (6,7). B-value is one of the most important parameters of DWI. B-value selection is closely related to the image quality of DWI and its ability to identify lesions. Currently, there are no widely accepted selection criteria for the optimal b-value for breast DWI at 3.0 T MR scanner (8–12). Therefore, the study of b-value optimization is of important clinical interest.

This study used multiple b-values to obtain DWI of normal breasts to measure and calculate the signal-to-noise ratio (SNR) for normal mammary glands. Diffusion-weighted images of

Acad Radiol 2016; ■:■■–■■

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http://dx.doi.org/10.1016/j.acra.2016.11.006

benign and malignant lesions were obtained to measure and calculate the SNR, signal intensity ratio (SIR), and contrast-to-noise ratio (CNR) of lesions at different b-values to analyze the variations of SNR, SIR, and SIR. Furthermore, we compared diffusion-weighted images at four different b-values with higher image quality. The effect of SIR on the differential diagnostic efficiency of benign and malignant lesions was compared using receiver operating characteristic curves to provide a reference for obtaining the best quality of DWI.

MATERIALS AND METHODS

Patient Data

Our institutional review board approved this retrospective study and the requirement for patients' informed consent was waived because of the retrospective design. Authors had access to identifying information during or after data collection because data are available from our medical college's institutional Data Access/Ethics Committee for researchers who meet the criteria for access to confidential data. A retrospective analysis was performed on a total of 126 female patients who underwent breast MRI (Magnetom Skyra, Siemens, Erlangen, Germany) in our hospital from June 2014 to December 2015. The lesion inclusion criteria were: (1) noncystic tumor-like lesions; (2) maximum lesion diameter greater than or equal to 1.5 cm; (3) confirmed by postoperative pathological examination; and (4) an interval of no more than 14 days between surgery and MRI. The patient exclusion criteria were: (1) those undergoing biopsy for breast lesions within 2 weeks prior to the MRI examination; (2) those with history of surgery, radiotherapy, or chemotherapy prior to the MRI examination; (3) absence of pathological results for confirmation; and (4) poor image quality that affected lesion observation and measurement. Seventeen patients were excluded from this study because of movement or susceptibility artifacts; a total of 96 qualified patients with 112 lesions were included in this study. The patients were aged 27 to 71 years, with a median age of 42 years. There were 59 patients with benign breast disease with a total of 72 lesions, including 48 fibroadenomas, 13 papillomas, two inflammatory lesions, four phyllodes tumors, and five adenopathies accompanied with atypical hyperplasia. There were 37 patients with malignant breast disease with a total of 40 lesions, including 33 invasive ductal carcinomas, four invasive lobular carcinomas, and three ductal carcinomas in situ. All patients provided informed consent before MRI. The patients underwent surgery and postoperative pathological examination 1 day to 1 week after MRI. In addition, a total of 14 patients with their contralateral 14 normal breasts were included in the study; the patients aged 34 to 58 years, with a median age of 41 years.

MRI Equipment and Measurement Parameters

A 3.0 T MR scanner (Magnetom Skyra, Siemens) with a dedicated bilateral four-channel breast surface coil (In Vivo, Orlando, FL, USA) was used. Patients were instructed to lie in a prone position so that their breasts were naturally overhanging on the surface coils with minimal movement. DW MR images were acquired before the gadolinium-based contrast material injection after a T1-weighted turbo-fast low-angle shot sequence and a T2-weighted short inversion time inversion-recovery sequence. The single-shot echo planar imaging sequence was used to perform the DWI of cross-sectional scans with repetition time of 6200 ms, echo time of 77 ms, 4.0 mm thickness, field of view of 340 mm × 148 mm, and spatial resolution of 1.8 × 1.8 × 4 mm. Three-direction trace diffusion protocol and inversion-recovery fat suppression were performed with anteroposterior phase encoding. A total of 13 b-values (0, 50, 100, 200, 400, 600, 800, 1000, 1200, 1500, 1800, 2000, and 2500 s/mm^2) were used and two averages were acquired at each value.

Images from all patients were postprocessed and the data measurements were examined by two experienced breast imaging radiologists and a chief physician to reach a consensus. The selection of region of interest (ROI) and the measurement of DWI parameters were as follows: (1) the region of background noise along the phase-encoding direction used to measure the background signal intensity, to obtain the standard deviation, SD_{noise}; (2) the normal breast tissue or surrounding breast tissue at the same layer as the lesions used to measure the signal intensity of normal breast tissue, S_{tissue}; (3) the maximum level of lesions to avoid necrosis and parenchymal cysts used to measure the signal intensity of the lesions, $S_{lesions}$; and (4) the average results of three different regions with consistent size measured three times. The copy feature of the image processing software was used to allow the ROIs obtained with different b-values to be placed on the same level and position. In addition, the consistency in shapes and sizes of ROI obtained from each patient was maintained.

Image Quality Grading and Evaluation Criteria

By referring to grading standards, the image quality of DWI was divided into three grades based on the presence of image displacement and artifacts: Grade A, absence of breast displacement and artifacts, with a clear breast contour; Grade B, the breast contour appeared to have mild deformation or displacement, and mild artifacts, which did not affect the measurement and display of lesions; Grade C, breast contour appeared to have significant deformation or displacement, and artifacts were present that affected lesion display and measurement.

The SNRs of normal breasts (SNR_{normal}), SNR of benign and malignant lesions ($SNR_{lesions}$), and SIR of benign and malignant lesions were measured on DWI with different b-values and calculated according to the following equations: $SNR_{normal} = S_{tissues}/SD_{noise}$, $SNR_{lesions} = S_{lesions}/SD_{noise}$ (13), and $SIR = S_{lesions}/S_{tissues}$, where $S_{lesions}$ is the measured signal intensity of lesions, SD_{noise} is the standard deviation of signal intensity of background noises on the same level, and $S_{tissues}$ is the signal