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The feasibility of b-value maps based on threshold DWI for detection of breast cancer
A case–control STROBE compliant study

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Abstract

Diffusion-weighted imaging (DWI) plays an important role in the diagnosis of breast cancer as well as the evaluation of treatment effects. A novel technique named b-value map based on thresholded DWI images has been proposed and can achieve good contrast for demonstrating prostate lesions only by manipulating the window width and center of the images. Its application on the breast has not yet explored, so the aim of the study was to investigate the feasibility of b-value maps based on threshold DWI for detection of breast cancer. A total of 25 patients with pathologically proven invasive ductal breast carcinoma were included and underwent preoperative magnetic resonance imaging (MRI) examinations including DWI at 3T. The capabilities to display lesions of $DWI_{b=800}$, b-value maps and optimal computed DWI (cDWI) images were evaluated by using a 4-point method of scoring. Apparent diffusion coefficient (ADC) values of lesions were measured for the breast carcinoma. Mean scores indicating the display capability were compared among $DWI_{b=800}$, optimal cDWI and b-value maps by using Kruskal–Wallis test followed by Nemenyi test. The scores of both b-value maps (3.92 ± 0.28) and optimal cDWI images (3.80 ± 0.41) were higher than that of $DWI_{b=800}$ (3.48 ± 0.51), with statistical differences ($P = .001$ and $P = .033$, respectively). The optimal b values for manifesting breast carcinoma based on cDWI were 1000 to 1200 s/mm². The b-value map enables fast identification for breast lesions and shows similar performance to the optimal cDWI images.

Abbreviations: ADC = apparent diffusion coefficient, cDWI = computed DWI, DWI = diffusion-weighted imaging, MRI = magnetic resonance imaging, SNR = signal-to-noise ratio.

Keywords: ADC, b-value map, breast carcinoma, computed DWI, diffusion-weighted imaging

1. Introduction

As one of the most comdmonly used magnetic resonance imaging (MRI) technique, diffusion-weighted imaging (DWI) could provide the information of diffusion of water molecules and evaluate the

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tissue microstructure and pathological changes in cellular level.[1] DWI and the derived apparent diffusion coefficient (ADC) value based on monoexponential model have been widely applied in the diagnosis and evaluation of various diseases.[2–7] The pretherapy DWI has shown prognostic value, and the follow-up scan during therapy could determine the treatment response.[8–11] For the breast application, DWI plays a very important role in the diagnosis as well as in the evaluation of treatment effects.[12] With the increasing of b values, DWI images can be more sensitive to tumors due to the restricted diffusion movement of water molecules and the better contrast between lesions and background mammary tissues. However, the acquired DWI images with higher b values normally have lower signal-to-noise ratio (SNR) and more distortion artifacts. Some researchers have tried to use computer-aided postprocessing techniques, such as computed DWI (cDWI) to obtain high b-value DWI images (1000–2000 s/mm²) to get desired contrast and sufficient SNR for lesions detection. Radiologists could obtain specific high-b-value DWI images with high ability for tumor detection and sufficient image quality by using cDWI.[13–15] Recently, Gall et al[16] proposed a novel technique named b-value map, which was calculated based on thresholded DWI images and could achieve similar performance as cDWI on improving lesion visualization. The pixel-wise b-value map is calculated with the DWI signal under a given threshold for each voxel ($b\_thr = -1/ADC * \ln(S_{thr}/S_0)$, where S_{thr} is the signal intensity of a given threshold value). We could easily achieve good contrast for demonstrating lesions on the b-value map only by manipulating the window width and center of the visualization of the image with the computer mouse. The applications of b-value

map in breast have not been reported. Therefore, the aim of the current study is to preliminarily investigate the feasibility of b-value maps in the detection of breast cancer and to compare it with cDWI.

2. Patients and methods

2.1. Patients

Research ethics committee approval was obtained, and patient informed consents were waived for this retrospective study. Twenty-five women (mean age 38 years, range 24–80 years) with single invasive ductal breast carcinoma confirmed by postoperative pathology underwent preoperative breast MRI examinations between March 2017 and August 2017. And all the patients did not receive any preoperative treatment before MRI examination. The mean body mass index of the patients was 23.02 ± 3.31.[17] Two patients had the family history of breast cancer.

2.2. MRI image acquisition

MRI images were acquired at a 3T MR scanner (GE, Signa Hdxt, Milwaukee, WI) using an 8-channel breast coil. Patients were in the prone position with the head in first. The MR protocols included: axial, T2-weighted fat suppression sequence (short time inversion recovery) with TR/TE of 8200 ms/36.9 ms, TI of 170 ms, FOV of 380×380 mm, matrix of 320×192, slice thickness of 4 mm, and slice gap of 1 mm; Axial DWI (b=0 and 800 s/mm²) with TR/TE of 6000 ms/64.8 ms, FOV of 380×380 mm, matrix of 128×128, slice thickness of 4 mm, and slice gap of 1 mm; and Pre- and postcontrast, axial T1-weighted 3D Vibrant sequence (TR/TE of 4.3 ms/2.1 ms; TI 14 ms; FOV 380×380 mm; matrix 416×320; slice thickness 1.4 mm) were obtained before and 7, 67, 127, 187, and 247 seconds after gadopentetate dimeglumine injection (contrast media,0.2–0.3 mL/kg; physiological saline, 10–15 mL). The total scan time for the whole breast examination was about 22 minutes.

2.3. Data analysis

The postprocessing of DWI data was performed with the prototype Body Diffusion Toolbox (Siemens Healthcare, Erlangen, Germany). Before imported to the Body Diffusion Toolbox, some specific DICOM tags related to b values of DWI data were adapted by a DICOM editor software (DicomEdit, Version 7.0, Siemens AG), so that the DICOM data could be processed in the Body Diffusion Toolbox. The ADC map, b-value map with a threshold defined as 50, and cDWI images with a series of b values of 1000, 1200, 1400, 1600, 1800, and 2000 s/mm² were calculated. Two radiologists evaluated the features of tumors on the enhanced images, including the location, size, and the contour of lesions. And they independently assessed the cDWI images with various b values and determined the optimal b value for breast lesion displayed on cDWI. The capability of the lesion visualization were evaluated for DWI$_{b=800}$, b-value maps and optimal cDWI images by using a scoring method (lesions can be displayed=1 point; clear display of the contours of lesions=1 point; the contrast between lesion and surrounding fibroglandular tissue is obvious=1 point; and the contrast of internal components of the lesion is obvious=1 point). The regions of interest for ADC measurement of each lesion were drawn on the slice with the maximum lesion profile on the ADC map.

2.4. Statistical analysis

To evaluate the agreements of the scores between the 2 readers, an unweighted Kappa value (κ) was obtained for each of the 3 image groups (κ < 0.40 weak, $0.40 \le κ < 0.75$ moderate, and $κ \ge 0.75$ good). Mean scores for image quality of DWI$_{b=800}$, optimal cDWI, and b-value map were calculated and compared using Kruskal–Wallis test followed by Nemenyi test to indicate the display capability of the three image groups ($P < .05$ was considered significant).

3. Results

A total of 25 lesions were detected in all 25 patients with the mean diameter of 2.98 ± 1.01 cm (range 1.46–5.09 cm). The out upper quadrant of breast was the major position of lesions (10/25). The average ADC values of breast lesions were 1.049×10^{-3} mm²/s (range, 0.622×10^{-3}–1.373×10^{-3} mm²/s). The optimal b values for better visualization of breast lesions was 1200 s/mm² for 14 lesions, 1000 s/mm² for 9 lesions, and 1400 and 1600 s/mm² for the other 2 lesions, respectively.

The interobserver agreements for the scores of image quality of DWI$_{b=800}$, optimal cDWI, and b-value map between the 2 readers were good (all κ > 0.81). The mean scores of b-value map (3.92 ± 0.28) and optimal cDWI (3.80 ± 0.41) were higher than that of DWI$_{b=800}$ (3.48 ± 0.51), with statistical differences ($P = .001$ and $P = .033$) (Fig. 1). There was no significant difference for the scores between b-value map and optimal cDWI image ($P = 1.000$). Figures 2 and 3 showed the representative images of patients with invasive ductal breast cancer.

4. Discussion

Monoexponential model is the most commonly used in DWI, and it assumes that water molecules diffuse without any restriction and follow a Gaussian behavior. Thus, the signal intensity of DWI images monoexponentially decreases with the increasing of b values. A few studies suggested the optimal b values for the detection of breast lesions were between 1000 and 2000 s/mm².[18–20] However, high b values might reduce SNR and cause distortion of geometric structure on DWI images. So, DWI
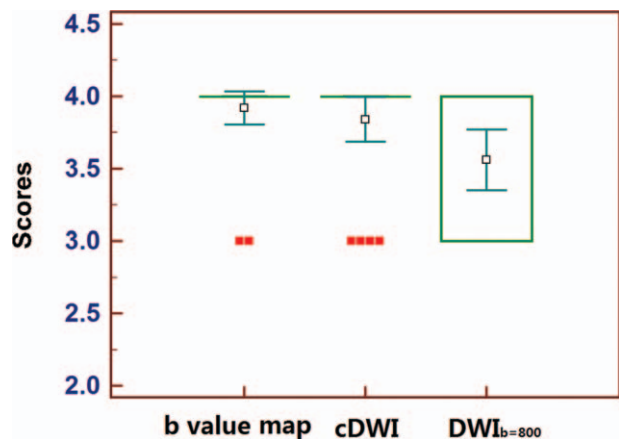

Figure 1. Boxplots of the scores of b-value map, optimal cDWI, and DWI$_{b=800}$. cDWI=computed DWI, DWI=diffusion-weighted imaging.
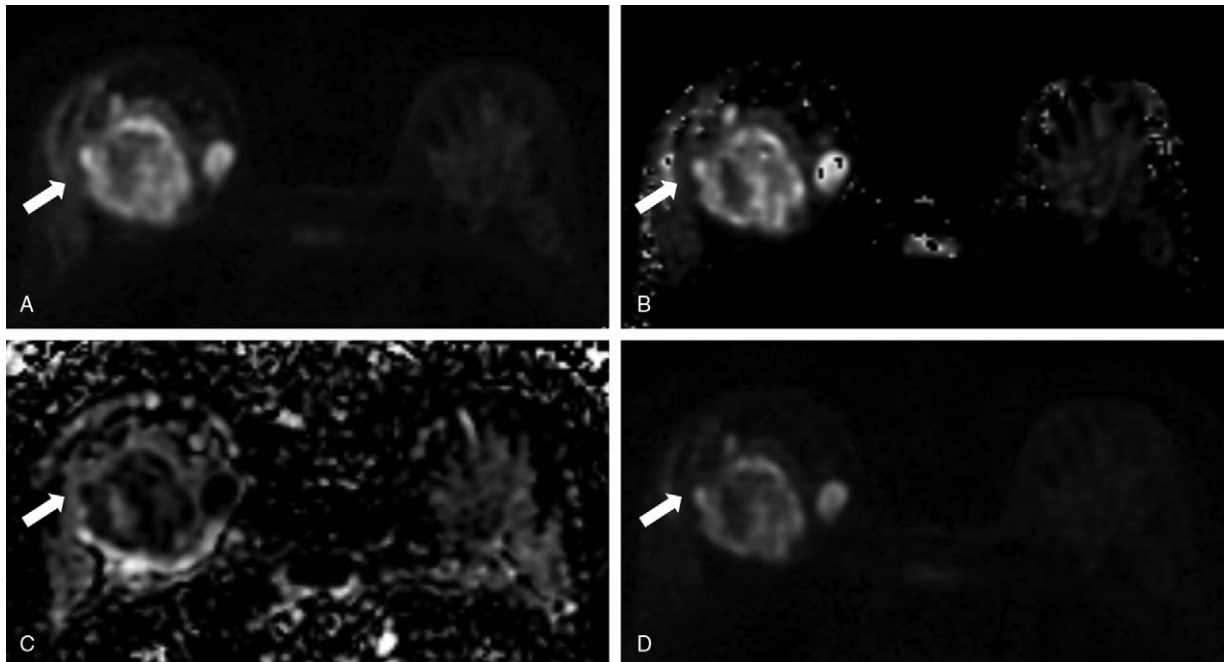
Figure 2. Images of a 24-year-old woman with invasive ductal breast carcinoma in right breast. (A) DWI with b = 800 s/mm^2; (B) b-value map; (C) ADC map; and (D) optimal cDWI (b = 1200 s/mm^2). Both the b-value map and optimal cDWI show the striking contrast between the lesion and the surrounding fibroglandular tissue. ADC = apparent diffusion coefficient, cDWI = computed DWI, DWI = diffusion-weighted imaging.

images are usually acquired with a high b value of 800 s/mm^2 for breast imaging, although some studies showed that the signal of background fibroglandular could be well suppressed and lesions be clearly manifested at b > 1000 s/mm^2.[19,21] The cDWI and b-value map could overcome the shortcomings of the high-b DWI scanning. The cDWI could obtain DWI images with arbitrary b values and it does not suffer from obvious geometric distortion while the acquired high-b-value DWI does. In our study, the cDWI images with optimal b value had better performance for the detection of breast cancer when compared to the acquired
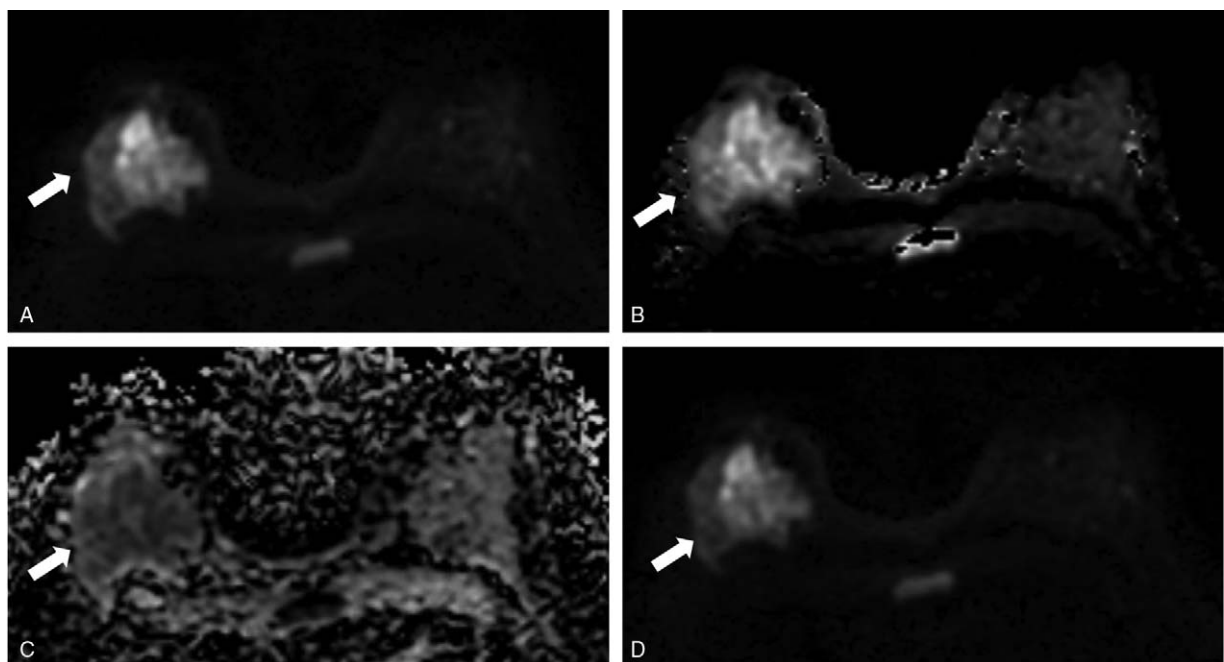

Figure 3. Images of a 37-year-old woman with an invasive ductal breast carcinoma in the right breast (arrow). (A) DWI with b = 800 s/mm^2; (B) b-value map; (C) ADC map; and (D) cDWI with b value of 1000 s/mm^2. The b-value map manifested best signal difference within the lesion than DWI$_{b=800}$ and optimal cDWI$_{1000}$. ADC = apparent diffusion coefficient, cDWI = computed DWI, DWI = diffusion-weighted imaging.

DWI$_{b=800}$. The findings of current study were consistent with some previous studies.[19,22]

Our study found that b-value map and optimal cDWI image have similar performance in the delineation of the breast cancer. The b-value map is the collection of individual voxel of b-value threshold information.[16] And the visualization of lesions can be easily achieved through human–machine interaction. In addition, the b-value map has some advantages on the depiction of the contour and the heterogeneity of the lesion. According to the findings of our study, when b value is $\leq 2000 \, s/mm^2$, the signal contrast between background gland tissue and lesions would increase in cDWI images with the increasing of b values, which is beneficial for the detection of breast lesions. But, due to the decline of overall signal intensity on cDWI images with high b values, the display efficacy of signal differences within lesions was not improved. However, the b-value map would not obviously affect the signal intensity on the premise of ensuring the signal contrast between focus and background gland tissue. Therefore, the difference of signal within lesions was obvious so that the heterogeneity of tumors could be observed easily in b-value map.

The b-value map is based on conventional DWI images so that it retains the similar characteristics of conventional DWI, which shows the diffusion restriction of water molecules and reflects the cellularity. And it can also be easily operated without a new scanning sequence or additional scan time. In addition, b-value map could help to display the contour of lesions assisting the conventional MRI sequences in the detection of breast tumors and also expand the signal difference within lesions. Therefore, b-value maps might be used for further studies for the histological grades and molecular subtypes of breast tumors.

There are several limitations in this study. Firstly, this study includes its retrospective nature, and we cannot control all aspects. Secondly, the study was carried out in a single center with a relatively small sample size and only invasive ductal breast cancer was included. Future studies with a lager sample size and various breast diseases should be conducted for a more reliable conclusions, and a more comprehensive and objective method should be used to evaluate the capability of the images to manifest lesions.

5. Conclusion

This preliminary study shows that the b-value map enables the fast identification for the invasive ductal breast carcinoma through simple human–machine interactive manipulation. And the b-value map has similar performance to the optimal b-value cDWI images.

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Author contributions

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