ORIGINAL ARTICLE

Image Quality Analysis for Optimization of b-value in Diffusion Weighted MRI of Breast

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ABSTRACT

Introduction: Diffusion-weighted (DW) is an evolving technique that provides both qualitative and quantitative data about the diffusion of water molecules and b-value plays a significant role in DW images. The aim of this study is to find the optimal b-value in diffusion-weighted MRI for the detection of breast lesions. **Methods:** The study included 124 subjects. T2-FS sequences were acquired for lesion measurement. DW was acquired with b-values 300, 600 and 1000 s/mm^2. DW images were evaluated by two radiologists under the criteria's - signal-to-noise ratio (SNR), contrast differentiation of lesion from the glandular tissue, and contrast differentiation of glandular tissue from fatty tissues. Relative Signal intensity ratio (SIR), SNR and contrast-to-noise ratio (CNR) were calculated. **Results:** Kappa value is highest for a b-value of 600 for all the three criteria, for subjective SNR the kappa value was 0.906 which indicates that the inter-rater reliability rate is an almost perfect agreement. Differentiation of lesion from the fibro-glandular tissues, the kappa coefficient is 0.904 which interprets that the agreement between the readers is almost perfect and the kappa coefficient to differentiate the fibro-glandular from fatty tissues is 0.875 which shows that there is substantial agreement. Relative SIR, SNR, and CNR is highest for a b-value of 600 with a mean value of 4.6, 14.7, and 44 respectively. **Conclusion:** Optimal b-value for good image quality is 0, 600 s/mm^2. Standardizing an optimal b-value is highly significant since it improves the overall image quality and enhances multi- center diagnosing with an accurate report.

Keywords: b-value, Diffusion-weighted, MRI, Breast

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INTRODUCTION

Worldwide statistics shows breast cancer as the most commonly occurring cancer for women with attributed lifetime risk. Over the past years mammography and ultrasonography were being used as common medical diagnostic tools for diagnosing of breast abnormalities. In recent time, the demand of new imaging modalities surfaced due to lower sensitivity and specificity of mammography and ultrasonography techniques. This limitation has overcome with the advancement in Magnetic Resonance (MR) techniques. Previous studies (1-11) shows that Diffusion-Weighted technique has higher sensitivity and specificity in breast lesions detection and provides differential diagnosis as compared to mammography and ultrasonography, therefore standardizing the b-value in DW sequence for breast lesion detection is warranted (12).

Diffusion-weighted technique is a magnetic resonance sequence which measures the in vivo mobility of water molecules and provides information of the tissue at the cellular level (13). In diffusion weighted technique the image contrast is derived from the water molecules motion within the tissue, which is referred to as Brownian motion. This technique is highly sensitive to biophysical characteristics of tissues, such as membrane integrity, density of the cells including its microstructure. The DWI sequence provides excellent quantitative and qualitative information due to its sensitivity to self-diffusion of water protons, which shows changes at the cellular level and illustrate distinctive recognition of the cellularity and integrity of cell membranes of the tumor (14). Presently the diagnosis of breast abnormalities depends basically on the conventional techniques using mammography and ultrasound. Due to its lower sensitivity and specificity, the research interest in recent time have moved towards MR imaging because of its excellent lesion detection, characterization and staging of breast cancer (15, 16).

In diffusion weighted sequence the sensitivity towards the lesion detection can be adjusted easily by manipulating the extrinsic parameters known as b-value where the higher b-value illustrate strong DW signal but shows lower SNR but for lower b-values the sensitivity of the diffusion sequences is affected by perfusion (17). Therefore, in order to establish a meaningful interpretation, diffusion weighted sequences are always performed using a combination of at least two b values. However, currently there is lack of accepted standardized approach to perform breast MRI with DW sequences, hence the data quality varies widely. Though, DWI technique has shown promising improvement in terms of positive predictive value for detection of breast cancer, but till date no standardized optimal b-value in DW sequences of MRI breast has been recognized, knowing the fact that the b-value plays a significant role in apparent diffusion coefficient (ADC) values. Hence, the use of diffusion technique in MR breast imaging still remains sporadic. Therefore, the main objective of this study is to find the optimal b-value in MR Diffusion Weighted technique for detection of breast lesions.

MATERIALS AND METHODS

The study approval for this prospective study was acquired from the Institutional Ethics Committee, Kasturba Hospital, Manipal (Ref No: IEC 261/2017). After screening of the patient, informed consent was obtained from all the subjects. The study subjects were females with age group of 25 - 60 years (49 ± 2 mean ± SD). 124 subjects with breast lesions of various BIRADS grading (BIRADS 1–5) as detected in ultrasonography and mammography were recruited for Breast MRI, with total number of lesions count of 141. Patients with cystic lesions were considered as exclusion criteria of the study. For all the detected lesions, histo-pathological confirmation were obtained, out of which 83 lesions were malignant and 58 lesions were benign and the MRI scan was scheduled between 7^{th} to 15^{th} days of the menstrual cycle for premenopausal subjects.

MRI Techniques

MRI scan was performed using Philips Achieve 1.5 Tesla MRI (16-channels). Bilateral MRI breast scan was conducted, where the normal side was taken for evaluation of the normal breast tissue. The diseased side was evaluated for detection of breast lesions. The examination protocol consists of conventional pulse sequences -Axial T2W (18) (TE/TR: 120/3500 ms, slice thickness: 1mm, matrix: 340x512, NSA: 2) for lesion localization and lesion size measurement and DW sequence (TE/TR: 95/8200msec, flip angle: 90°, slice thickness: 3mm, matrix: 192x192, signal averages: 4) with three combination of b-values (b=0, 300, 600, and 1000 s/mm^2). The acquired diffusion series was registered prior to creating the corresponding ADC maps for each b values.

Image Analysis

Two independent radiologists with six or more years' of experience in the field of breast imaging reviewed the diffusion weighted examination findings and assessed the DW images of all the three b-values. The radiologists were blinded from each other. T2 FS sequence were used for lesion localization, measurement and to analyze any identified suspicious. Image evaluation for diffusion weighted sequence were analyzed on the bases of certain criteria's such as subjective SNR, contrast differentiation between lesion and fibro glandular tissues and contrast differentiation between fibro glandular tissues and fatty tissues. A 5-point Likert grading scale, were used to score image quality where 1 represents unacceptable image quality, 2- Suboptimal, 3- Average, 4- Acceptable and 5- Excellent.

Image post processing and calculation

Signal intensity (SI) for lesion, normal fibro glandular tissue, and background noise was obtained by placing the 3 region of interest (ROI) on the acquired images and averaged. For lesion, the 3 ROIs were placed in hyper intense area of the lesion, for normal fibro glandular tissue the 3 ROIs were placed on the normal tissue, and for background noise 3 ROIs were placed in the air between the breasts. The SI values was used to calculate signal intensity ratio by using the formula SIR = signal intensity of lesion/ signal intensity of normal tissue, SNR by using the formula signal intensity of lesion/ signal intensity of background noise, and contrast to noise ratio (CNR) by using the formula signal intensity of lesion – signal intensity of tissue / standard deviation of background (6, 9, 19, 20).

Statistical analysis

The data analysis was performed using SPSS, version 16.0. Descriptive statistics was used to calculate mean for quantitative variables and Cohen's kappa coefficient statistics was used for qualitative assessment of DW image quality assessed by two independent radiologist to determine inter-rate reliability.

RESULTS

Subjective SNR assessment is measured by the differences in signal intensity between region of interest and the background. From table I, it is clearly noted that the kappa value is highest for b-value of 600 for all the three criteria, wherein for subjective SNR the kappa value is 0.906 which indicate that the inter-rater reliability rate between the two readers is an almost perfect agreement. In order to differentiate the lesion from the fibro- glandular tissues, the kappa coefficient is 0.904 which interprets that the agreement between the readers is almost perfect and the kappa coefficient to differentiate the fibro-glandular from fatty tissues is 0.875 which shows that there is substantial agreement between the two readers. For b-value of 300 and 1000, the inter rater reliability rate ranges from moderate agreement to substantial agreement which is comparatively lower as compared to b-value 600. Dichotomized overall agreement between the inter-readers were very good with a kappa value of > 0.8 for all three abbreviated

Table I: Subjective assessment of breast lesions on DW images with respect to the following criteria of SNR, Lesion versus Fibro-glandular Tissue (FGT), and FGT versus Fatty Tissue

b-value	Kappa Coefficients		
	Criteria I **Subjective SNR**	***Criteria II*** **Lesion vs Fibro-glandular differentiation**	***Criteria III*** **Fibro-glandular vs fatty tissues differentiation**
300	0.561	0.581	0.671
600	0.906	0.904	0.875
1000	0.700	0.639	0.691

Table II: Quantitative assessment of Signal Intensity ratio (SIR), Signal to Noise Ratio (SNR) and Contrast to noise Ratio (CNR) of the breast lesion on diffusion weighted images with respect to multiple b-values

b-value	300	600	1000
Signal Intensity Ratio (SIR)	4.3	4.6	3.9
Signal to Noise Ratio (SNR)	13.5	14.7	12.8
Contrast to noise Ratio (CNR)	41	44	37

criteria of MR image quality of breast in diffusion weighted series.

As note in table II, according to quantitative calculation for SIR, SNR and also for CNR, is highest for b-value of 600 with a mean value of 4.6, 14.7, and 44 respectively which indicate that b-value 600 has high signal intensity and low noise, therefore SNR is high with a better contrast for differentiating the lesion from the glandular tissues.

DISCUSSION

Magnetic resonance DW technique with quantitative measurement of ADC values is an increasingly applied technique for differential diagnosis of the tumor, but prior to differential diagnosing, detection of the lesion is necessary, whereby the b-value plays a significant role in lesion conspicuity (1,19). In our present study, the qualitative assessment of b-value shows the optimal b-value for detection of breast lesion is 600 s/mm^2, with a kappa value of 0.906 and 0.904 for SNR and contrast differentiation of breast lesion from FGT respectively.

The sensitivity of the DW technique is highly influenced by b-value therefore the selection of small b-values shows high signal attenuation since the water molecules have large degree of motion (e.g. in the intravascular space) (21). In the present study, the breast lesions in DW sequence appears to be confined and exhibit strong signals with well-defined margins of the lesion. We observed that the lesion size with less than 1 cm does not

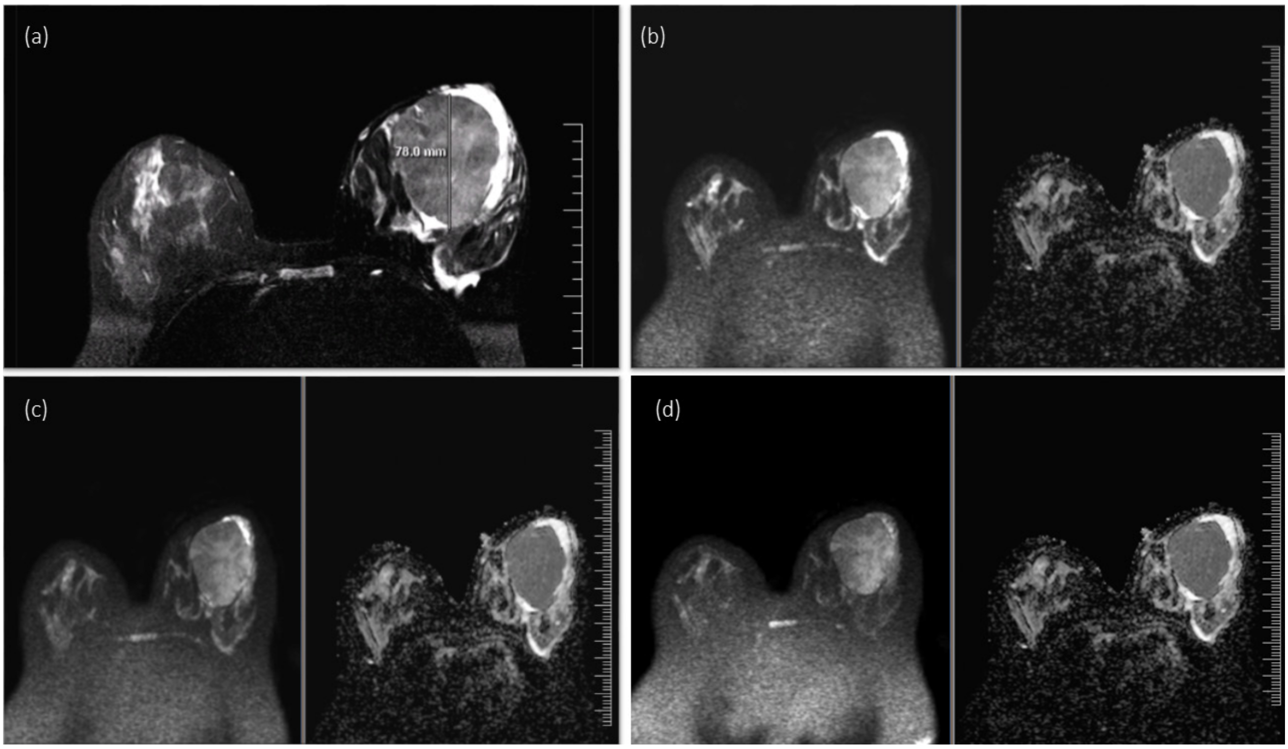

Figure 1: A female of 49 years old was diagnosed with a lesion on the left breast with change in color of the skin (red, swollen and warm) but no enlargement of the axillary lymph nodes. (a) Axial T2 fat suppression sequence of the bilateral breasts show an oval shaped tumor measuring 7.8 cm in the left breast. (b, c and d) The diffusion weighted images with multiple b value of 300,600 and 1000 s/mm^2 demonstrated SIR of 4.1, 4.6, and 3.9, SNR of 13.5, 14.7, 12.8 and CNR of 41, 44, and 37 respectively. Similarly in Qualitative analysis, b-value of 1000 s/mm^2 shows lower SNR since higher b value manifest rapid echo decay. Good contrast differentiation between lesion and fibro glandular tissues was noted on b-values of 300 and 600 s/mm^2.

show the characteristics of the tumor margins, such as the appearance of being speculated, due to lower spatial resolution and partial-volume artifacts. Therefore, cases with lesion size less than 1 cm were excluded from the study. In DW imaging, b- value is highly sensitive and hence variation in b-value will affect both the qualitative and quantitative analysis. On the contrary, it is well understood that the SNR tends to decrease with higher b-values (4, 19, 22, 23).

In the present study the significance of DWI sequence in diagnosing the breast lesions using b-value of 0, 300, 600, and 1000 s/mm^2 showed a good diagnosis of breast lesions within normal breast tissue for all the b-values, but the b-value of 0, 600 s/mm^2 showed optimal image quality in comparison with other b-values when the DW images were analyzed qualitatively. We also noted that diffusion coefficient decreases as the b-value increases and the b-value of 0, 1000 s/mm^2 was not very optimal for lesion detection since small lesions tend to loose signal intensity, but higher b-value of 1000 s/mm^2 was favorable for diagnosing dense breast of BIRAD category C and D. Xin Chen et al, (22) in their study found no significant difference in lesion conspicuity in b-values of 600, 800, and 1000 s/mm^2. Savannah et al (24) express that higher b value may be desired to optimized better contrast differences between lesion to the adjacent fibro glandular tissue for better lesion detection and conspicuity. Woodham et al (15) in his visual assessment of DW images of breast lesion stated that CNR was good for both b value of 1000 s/mm^2 and 1500 s/mm^2, but lesion conspicuity was excellent in 1500 s/mm^2 than 1000 s/mm^2. Fernanda Philadelpho et al (25) in their study recommended the use of b value 0, 750 s/mm^2 for the diagnosis of breast lesions with the 92% sensitivity and 96% specificity. In a study conducted by P. Belli et al (26) the DW sequence of b-value 0,1000 s/mm^2 showed the ability to diagnose breast lesions, and noted high correlation between the hyper intense areas in breast lesions with very good contrast difference between the lesions and fibro glandular tissue. Though they make use of only one b-value due to which the result showed that the b value of 1000 s/mm^2 being excellent in lesion detection. Whereas our study showed b value of 600 s/mm^2 has better image quality, which does not mean that the b-value of 0, 1000 s/mm^2 does not provide any lesion detection clarity for diagnosis. The quantitative assessment in this present study showed the lower value of SNR and CNR with increase in b-values but the signal intensity ratio showed increasing trend with increase in the b-value. Xiaowei Han et al (20) in their study noted the decrease in SNR values with the use of higher b-value of 2500 s/mm^2. They performed the study with 12 different b-values ranging from 0 to 2500 s/mm^2 and observed higher CNR with the b-values from 600 - 1200 s/mm^2, but the CNR decreased with the b-values above 1200 s/mm^2, which means the CNR values is decreasing with the increase in the b-value. Also they noted the gradually increase of SNR with increasing b-values up to the b-value of 1200 s/mm^2, above which the SNR values started to decrease. However, for normal fibro glandular tissue the signal intensity and SNR values tend to decrease with an increase the b-values. Their study findings in terms of lower values of SNR and CNR with increase in the b-values is similar to the present study. Since their study make use of b-values above 1000 s/mm^2 up to 2500 s/mm^2, the finding we reported was up to the b-value of 1000 s/mm^2, therefore when comparing it with our study their study showed better SNR and CNR values for the b-value of 1200 s/mm^2, whereas in our study the SNR and CNR values for 1000 s/mm^2 showed lower values compared to 300 and 600 s/mm^2 b-values. This is because they are comparing the SNR and CNR values for 12 different b-values with maximum b-value of 2500 s/mm^2, that is why there is the difference in the report noted but the fact that the SNR and CNR values decreases with the increase in b-value remains intact. Similarly Bogner et al (12) in his study reported that the CNR between normal tissue and tumor increases with higher b-values, but with b-values above 850mm^2/sec showed significant decrease of CNR for tumors. Their study reported that with the use of 850 mm^2/sec b-value, the CNR for malignant lesions was 22% higher than benign lesions. According to Hubert Bickel et al (9), with increasing b-value the SNR and CNR decreases but signal-intensity ratio between tumor and fatty tissue increases, b-value between 1200–1800 s/mm^2 had better image quality. Similarly, in this study, we noted that with increasing b value the Signal intensity increases but SNR decreases. In Xin Chen et al (22) study SNR of both malignant and benign lesion decreases with higher b-value, However they noted the CNR of malignant lesion decreases with higher b value but CNR for benign lesion shows no differences with higher b-value. In the present study according to the inter reader agreement rate concerning lesion visibility and image quality, the optimal b-value for breast lesion detection was noted to be 600 s/mm^2 though higher b-value of 1000 s/mm^2 has better Signal intensity ratio of breast lesion. We also noted that chemical shift artefacts and partial volume artefacts were more pronounced in higher b-values. We believe that breast density can play a significant role in calculating the CNR, in further study the factor such as age and breast density should be taken into consideration. Further study should be done for optimal b value for differential diagnosis since the selection of b values significantly affects the ADC value of breast lesions.

However to obtain good image quality in diffusion weighted MR of the breast tissues, a number of technical aspect should be considered, firstly being the positioning of the patient where the MRI operator has to be very precise and cautious since patient positioning is very significant factor to obtain good quality image. The breast tissue should fit in the center of the coil without any skin folds. Another important aspect is fats suppression whereby to attain uniform fat suppression shimming should be done including the entire both breast preferably in block system. Inherent susceptibility artifact was more pronounced due to the environment surrounding the breast and also the thorax cavity filled with air, but this particular artefacts was noted in higher b value. While MR diffusion-weighted technique is also sensitive to various confounding factors, affecting the quantification of diffusion values (ADC) including blood flow, perfusion, hormonal fluctuation, composition, still various studies has shown that MR diffusion weighting technique has various advantages, especially when screening patients with high risk of breast cancer. This technique also aid in evaluating treatment response in patient undergoing neo-adjuvant chemotherapy, metastatic axillary adenocarcinoma and unknown primary site. Unfortunately, till date there is no standardized b-value for evaluating the breast lesions either for qualitatively diagnosing or quantitative differential diagnosis.

CONCLUSION

Diffusion weighting technique is a valuable and effective technique that provides information on tumor cellularity and the integrity of cellular membrane of the tissue. Good quality MR diffusion weighted images exhibit adequate SNR and contrast with the absence of artifacts, hence compromises are often necessarily made with various parameters in order to achieve this. Diffusion weighted imaging represents a new useful tool in the detection and diagnosis of breast lesions. Standardizing and selecting an optimal b-value is highly significant since it improves the contrast differentiation between tissues and lesion, lesion visibility, and improve the overall image quality. Therefore the optimal b-value for obtaining a good image quality with respect to various characteristics of MR images such as signal intensity, signal to noise ratio and also contrast to noise ratio is 0, 600 s/mm^2.

DWI has a very promising liability in breast imaging and helps in improving the positive predictive value for detection and characterization of breast lesions. However further study should be done in order to ascertain whether the same b-value for obtaining good image quality will also provide accurate apparent diffusion coefficient (ADC) value for differential diagnosis.

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