Viable b-value Range for Diffusion Weighted Imaging of the Breast at 1.5T

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Introduction: Diffusion weighted imaging (DWI) has been proposed as a potential technique for breast cancer imaging [1]. The goals of the extant research were threefold: (1) to find the optimal b-value for breast DWI that yields minimum error in apparent diffusion coefficient (ADC), (2) to solve for a maximum b-value before becoming biased by non-Gaussian noise, and (3) to note the confounding effects of fat on breast ADCs and the consequential variation in determining the optimal b-value.

Methods: DWI echo-planar imaging (EPI) scans with varying b-values were performed on 4 healthy volunteers (ages 24, 25, 37, 47) at 1.5T. Fat suppressed spin-echo DWI EPI parameters included the following: TR/TE = 3s/70ms, matrix = 128 x 128, FOV = 26 cm, slice/gap = 8mm/0mm, NEX = 3, sagittal slice. B-values ranged from 0 to 1200 (s/mm^2) and data were collected in b-value increments of 100. Diffusion encoding gradients played in 12 non-collinear directions. Non-linear least square fits of the image data from all 12 directions provided isotropic ADCs (trace) that could be assessed with respect to different b-ranges. A weighted multipoint nonlinear fit over the whole b-range served as data for ADC computations.

Results: The signal course showed a multi-exponential decay (Figure 1) without evidence of perfusion/inflow-related overshoot in the low b-range as would be expected in vascular tissue. A mono-exponential model was expected. Since our signal is multi-exponential, it does not obviate limiting b-values due noise floor constraints. We have to rely on other factors to determine b-value limits. These include measuring a b-max determined by an SNR analysis of diffusion images at higher b-values, a theoretical calculation of b-optimum, and lastly the fall off of the fast decay of the water component as the fat component becomes more influential. From an SNR analysis, it can be determined that the noise floor in fatty breasts at the higher b-values inhibit diffusion image quality. From the b=0 images (Figure 2. (A) dense breast, (B) fatty breast), we noted that the two younger volunteers' breasts consisted of mostly dense glandular tissue, while the two older volunteers' breasts consisted of mostly fatty tissue. At b = 1200, the SNR in the DW images of the fatty breasts approached the threshold SNR limit of SNR > 2.5 [2]. The dense breasts had higher SNR (7+) values and data could potentially be collected at b>1200. However, for the b-value to be viable for all breast types, b-maximum needs to meet the minimal SNR standards for both glandular and fatty breast tissue. From the data collected in this study, b-max is therefore 1200 s/mm^2.

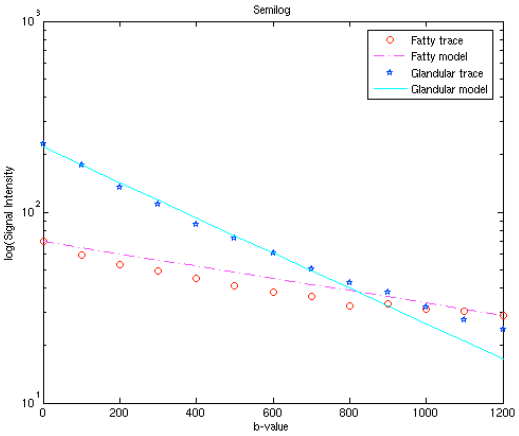

Figure1 (above).Diffusion weighted semilog decay correlated to increased b-value for 24 year-old volunteer (Glandular breast) and 37 year-old volunteer (fatty breast). Notice the linearity of the fits, as the noise floor does not appear to affect their decay.

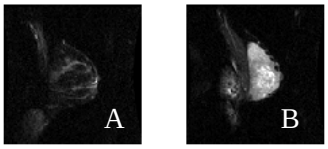

Figure 2. (A) 37 year-old volunteer's b = 0 breast image. (B) 24 year-old volunteer's b =0 breast image. Both A,B are windowed the same. Notice the greater signal coming from B than A. A is thus more susceptible to SNR limits.

ADC/b-range b-opt/b-range	Volunteer			
	(age 24)	(age 25)	(age 37)	(age 47)
ADC 0-600 (mm^2/s)	2.29	2.17	1.08	1.54
b-opt 0-600 (s/mm^2)	2520	2390	1190	1690
ADC 0-1200 (mm^2/s)	2.01	2.01	0.86	1.29
b-opt 0-1200 (s/mm^2)	2210	2210	9460	1420

Table 1(right). ADC measurements of breast tissue for the four volunteers and the corresponding optimal b-value calculations. ADC 0-600 represents where b-values decay more linearly. ADC 0-1200 covers the range collected in this study.

B-optimum can be solved with the following equation: b-opt = 1.1 * ADC [3]. Table 1 lists the ADCs measured at the varying b ranges for each volunteer and the corresponding calculated b-opt. B-values 0-600 generally produce a more linear fit as they are not as affected by the noise floor, and primarily represent decay due to the water component. The b-values and corresponding ADCs measured with b-values 0-1200 include the total range of collected data. B-opt should not be larger than b-max. However, in breast tissue our results show that b-opt is larger than b-max. This is most likely due to bi-exponential diffusion. Bi-exponential diffusion becomes an issue at higher b-values where the fast diffusing water component has decayed away. Thus, diffusion imaging in the breast must be guided by the b-value limited by SNR and the water weighted range of diffusion, rather than the b-value theoretically obtained by the ADC calculation.

Discussion: Due to the admixture of fat and glandular tissue in breasts, and the variation of this admixture between individuals, calculating a global ADC and a b-opt for breast tissue requires careful consideration. Even with suppression of lipid-bound protons (very low ADCs), it has been noted that the barrier produced by the physical presence of fat hinders the diffusion of water protons [3]. In essence, this leads to a bi-exponential diffusion decay that becomes increasingly apparent with higher b-values. A mono-exponential fit will therefore be biased towards lower ADCs, if the chosen b-value is too high. Recent findings of DWI in the breast [1] suggest that this method has clinical potential in better characterizing abnormalities. However, a careful consideration of noise and the percent content of breast fat is crucial when incorporating DWI into large-scale clinical studies. Both optimal b-value and ADC biases due to fat are determined by the patient, whereas the threshold b-value above which the measurements become biased by the noise is determined by the desired imaging protocol.

Our current recommendation for clinical breast diffusion imaging is to abide by the b-value determined by limits set by the SNR and tapering off of the water signal due to fat. These standards will provide more reliable b-values compared to the theoretical b-opt solved from knowledge of a tissue type's ADC. This is because b-opt lies in a range where other effects have fully already fully developed. For our protocol, the guiding b-value obtained in fatty breast tissue, was b-max = 1200 s/mm^2, with a limit of b~600 for the water weighted decay. The guiding b-max, is protocol dependent and can be determined by the SNR at the highest b-value of interest.

References: [1] Guo et. al. JMRI. 16: 172-178 (2002). [2] Henkelman. Med Phys. 12(2): 232-233 (1985). [3] Bammer et. al. AJNR. 24: 5-12 (2003).
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