Spatiotemporal Encoding Diffusion Weighted Imaging of the Breast: Comparison with SE-EPI-based methodology

Eddy Solomon[1], Noam Nissan[1,2], Amir Seginer[1], Edna Furman-Haran[3], Myra Shapiro-Feinberg[4], Hadassa Degani[2], and Lucio Frydman[1]

[1]*Chemical Physics, Weizmann Institute of Science, Rehovot, Israel,* [2]*Biological Regulation, Weizmann Institute of Science, Rehovot, Israel,* [3]*Biological Services, Weizmann Institute of Science, Rehovot, Israel,* [4]*Radiology, Meir Hospital, Kfar Saba, Israel*

Introduction: Currently, the clinical protocol used for breast MRI examinations is based on dynamic contrast enhancement (DCE) [1]. In recent years, diffusion weighted imaging (DWI) of the breast was shown to provide an additional diagnostic value [2]. Cancers exhibit lower apparent diffusion coefficients (ADCs) than normal fibroglandular tissues or benign lesions, due to the higher cellularity of the neoplastic tissue [3]. Quantifying this feature requires reliable ADC measurements involving single-shot MR methods, to ensure minimum spatial registration errors. Mainstream single-shot methods like spin-echo echo-planar imaging (SE-EPI), however, are prone to display image artifacts when applied to human breast. This is particularly evident in medium-field (≥3 T) MRI studies, which are complicated by the relatively high environmental heterogeneities that characterize the breast anatomy, the off-center position of the targeted organ, and motion-derived complications. All these factors combined can result in geometric distortions, image blurring, ghosting artifacts and problems with fat suppression; all this in turn leads to unreliable ADC maps, impairing the diagnostic ability of EPI-based DWI. In this work we explore a new methodology based on ***SP***atio-temporal ***EN***coding (SPEN), a single-shot technique that has proven as a highly robust alternative in terms of overcoming B_0-inhomogeneities and heterogeneous chemical environments [4]. The purpose of our study was to qualitatively and quantitatively compare the performance of DW imaging based on single-shot SE-EPI and on new SPEN sequences, among healthy female volunteers and cancer patients.

Methods: This study was approved by the Internal Review Board of the Meir Medical Center (Kfar-Saba, Israel) and included 11 healthy volunteers and 5 patients with 8 biopsy confirmed breast cancer lesions (2x IDC+DCIS, 4x ILC, 2x DCIS). Axial images of both breasts were acquired at 3T on a Siemens Trio scanner using a 4-channels breast coil. The MRI protocol included an experimental protocol described earlier [5] using T2 weighted turbo spin-echo (TSE), Diffusion Tensor Imaging and DCE sequences. 2D DW twice refocused SE-EPI and SPEN (single and multi-slice, n=5) were scanned with fat suppression using $\boldsymbol{\delta}$= 17-26ms, Δ = 35-40 ms, and n=7 b-values in the range: 0-750 (s/mm^2). The spatial resolution of SE-EPI was (1.9-2.0)×(1.9-2.0)×2.5 mm with a R>>L phase encode direction, and of 2D SPEN (1.7-2.0)×(1.7-2.0)×2.5 mm and a A>>P SPEN-encode direction. The total scan durations (per slice) were 138ms/200ms/277ms for the 2D single-slice SPEN, 2D multi-slice SPEN and SE-EPI, respectively. All SPEN data were post-processed with Matlab image-reconstruction algorithms based on super-resolution (SR) principles [6]. SPEN ADC maps were obtained after suitably correcting the b's to account for all the non-PGSE imaging gradients [7].

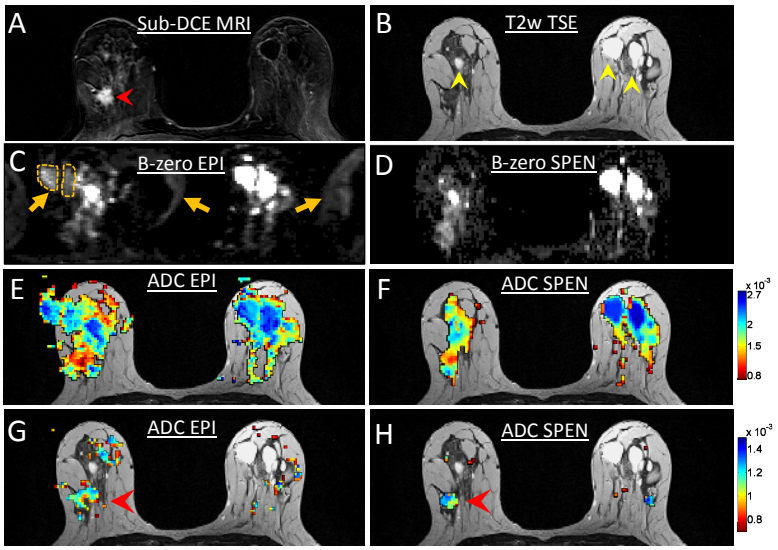

Figure 1. Representative comparison between images derived from SE-EPI and SPEN of a patient with IDC: (A, B) DCE GE subtracted image and TSE anatomical image. (C, D) SE-EPI and SPEN b-zero images and their ADC maps superimposed on TSE image ranging between 0.7-2.8 x 10^{-3} mm^2/sec (E, F) and between 0.7-1.5 x 10^{-3} mm^2/sec (G, H). Head arrows in red highlight the cancer and in yellow the cysts. Arrows in orange highlight folding of cysts and fat in C.

Results and Discussion: Comparisons between the diffusion weighted images of the healthy volunteers and of the cancer patients confirmed that many of the artifacts arising in SE-EPI were absent in the SPEN images. An example of this is given in Figure 1, with a representative slice of a patient exhibiting an Invasive Ductal Carcinoma (IDC). The scanned images include a DCE subtracted image that revealed the cancer location (A) as well as anatomical TSE image (B). Comparisons of the b-zero diffusion weighted images (C and D respectively) clearly demonstrate that unlike what happens in SE-EPI, the SPEN images are free from axial artifacts and from ghosting problems surrounding and overlapping with the breast's regions of interest. Notice as well SPEN's ability to separate fat resonances from fibroglandular tissue resonances, exhibiting a more reliable representation of the anatomical features. For both SE-EPI and 2D SPEN, ADC maps were obtained after subtracting pixels with poor exponential fit (<0.7), as described by a R^2-parametric map derived from fitting the diffusion data and by that neglecting non-fibro-glandular tissue. The resulting maps for all values measured for the ADCs, ranging between 0.7-2.8 x 10^{-3} mm^2/sec in panels (E) and (F), demonstrates the overall distribution of diffusion values in all parts of the breast, whereas panels (G) and (H), ranging between 0.7-1.5 x 10^{-3} mm^2/sec, clearly illustrate the lesion boundaries. Analyses of values measured in breast ROIs for all volunteers (Figure 2), revealed no significant differences between the ADCs derived from SE-EPI and from SPEN, neither in healthy fibroglandular nor in cancerous tissues. These results validate DW SPEN's ability to measure reliably ADC values and detect a reduction in ADCs due to the presence of malignancy.

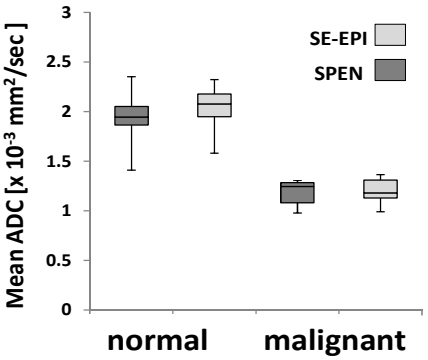

Figure 2. Box and whiskers plots of ADCs of breast malignant (n=7) and normal fibroglandular tissues (n = 11). ADCs of the two groups were not significantly different (p=0.38 and p=0.13, respectively) when measured by SE-EPI and by SPEN.

Conclusions: This study explored the use of 2D SPEN–based strategies incorporating ADC measurements, as a potential new tool for clinical studies of healthy and malignant tissues in breast imaging. Based on comparisons between SPEN and standard single-shot SE-EPI, we demonstrated SPEN's capability to obtain reliable ADC maps while showing significant advantages in terms of higher image quality, robust reduction of artifacts, and a more reliable acquisition of undistorted ADC maps.

Financial support: A Helen Kimmel Award for Innovative Investigation (Weizmann Institute), Kamin-Yeda Grant #711237 (Ministry of Industry and Trade, Israel). H.D. holds the Fred and Andrea Fallek Chair for Breast Cancer Research.

References: [1] Sardanelli F et al. *Eur J Cancer*. 2010 May;46(8). [2] Ei Khouli RH. et al., *Radiology*. 2010 Jul;256(1):64-73. [3] Guo, Y., et al., J *Magn Reson Imaging*. 2002 Aug;16(2):172-8 [4] Rita Schmidt and Lucio Frydman, *Magn Reson Med*. 2013 Aug;70(2):382-9. [5] Eyal et al, *Invest Radiol*. 2012 May;47(5):284-91 [6] Seginer et al, *Magn Reson Med. (in-press)* [7] E. Solomon, N. Shemesh and L. Frydman, *J. Magn. Reson*., 2013, 232, 72–82.