3-D Tracking of the Mammary Ductal Tree Using Diffusion Tensor MR Imaging

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Purpose:

Our goal is to develop and test high spatial resolution magnetic resonance diffusion tensor imaging (MR-DTI) of the breast for tracking the mammary ductal tree and for investigating anomalous patterns of ductal water diffusion.

Introduction:

Mammary malignancies typically develop from the ductal epithelial cells, and spread within the ducts (ductal carcinoma in situ) and outside of the ducts (infiltrating ductal carcinoma). Consequently, the ductal structures are an important area of investigation of both normal breast development and malignant breast transformation. Our current knowledge of the tree of the ductal system is based on several detailed anatomical studies of breast autopsies and mastectomy specimens (1). Non of the available imaging methods employed today has succeeded in tracking the full ductal tree, although this significant challenge has been realized, and initial 3-dimensioal ultrasound detection of sectional ductal structures was recently demonstrated using second-order shape measurements (2). Our aim is to develop an MRI method that will enable us to track the spatial anisotropic diffusion of the water in the breast ducts and thereby map the ductal tree. Although diffusion tensor imaging has been successfully applied in brain and other organs (3 and reference cited therein), to the best of our knowledge MR-DTI has not been applied for tracking the ducts in the breast. Diffusion weighted MRI studies already revealed a significant difference between the mean apparent diffusion coefficient (ADC) of cancers, benign lesions and normal breast tissue.

Methods:

Images were acquired with a 3 Tesla whole body scanner (MAGNETOM Trio, A Tim System; Siemens, Erlangen, Germany) equipped with a transmitting body coil and a receiving, 4 channels breast array coil. Sagital breast images were acquired for a single female volunteer, with no clinical indications of any breast disease. Images included a multi directions, high-resolution, diffusion weighted spic echo (MDDW-EPI) protocol with the following parameters: TE/TR of 106/5300 msec, FOV 24cm, matrix of 128 x 128, yielding a voxel size of 1.9 x 1.9 x 1.9 mm^3 and covering the entire right breast in 30 slices. The diffusion sensitizing gradients were applied along 64 different directions, with an effective b-value of 500 sec/mm^2 and images with zero b-value were also acquired. The signal from the fatty tissue was eliminated by selective fat suppression. In addition, for anatomic characterization, we applied a T2 weighted protocol using a turbo spin-echo sequence with a turbo factor of 21, TE/TR=85/4700 msec, 2 averages and the same geometry and resolution as described for the diffusion protocol. The total acquisition time was 5'37'' and 2'23" for the MDDW-EPI and T2-weighted, respectively.

Data processing: All application necessary for the execution were written in MATLAB programming environment and performed on a standard P4 3GHz PC. A region of interest (ROI) consisting of the entire breast was manually delineated, based on the T2 weighted images. The diffusion tensor was calculated by non linear fitting of the diffusion dataset to the Stejskal-Tanner (4) equations. Principle component analysis (PCA) of the diffusion tensor was applied for each voxel separately, and the average apparent diffusion coefficient (ADC), fractional anisotropy (FA) and a vector field map showing the primary diffusion direction at each location, were derived.

Results:

An example of anatomical structure of the breast, as revealed in the T2-weighted images, is demonstrated in Figure 1a. The T2w (without fat suppression) images show that the central portion of the breast is composed primarily of fibro-glandular tissue (low intensity) while the fatty tissue (high intensity) predominantly populates the peripheral areas of the breast. Figure 1b demonstrates the effect of the fat suppression on the diffusion weighted, b=0 image, the signal from the fatty tissue is almost entirely eliminated compared to the mammary tissue.

A calculation based on the zero b-value and the 64 diffusion weighted images, yielded six parameters (Dxx, Dyy, Dzz, Dxy, Dxz, and Dyz) that describe the diffusion tensor matrix in each individual voxel and for each such matrix the PCA produced three eigen-vectors and three eigen-values that indicate the primary direction and magnitude of the diffusion tensor respectively.

The median ADC value derived from the eigen-values (Fig 2c) for the fibro-glandular tissue was $2*10^{-3}$ mm^2/sec which is similar to previously reported measurements (for example (5)). The FA which measures the magnitude of the anisotropy ranging from 0 (isotropic) to 1 (absolute anisotropy) showed high values for that tissue (Figure 2d) with its values ranging from 0.2 for the 25th percentile to 0.39 for the 75th percentile.

Examining the maps of the primary direction of diffusion and its magnitude revealed that areas related to the fibro-glandular tissue showed high degree of order in the orientation of the main diffusion vector. An example for such area is shown in Fig. 2e.

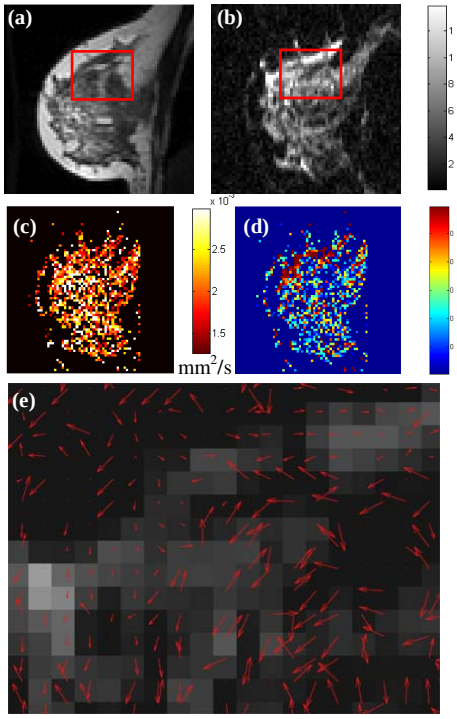

Fig 1: A sagital representative central slice of th right breast acquired with a T2w protocol (a) diffusion weighted protocol with zero b-value (b). Diffusion weighted analysis showing a map of th average ADC (c) and the map of the fractiona anisotropy FA (d). The figure on (e) shows th primary diffusion direction at each pixel based o the PCA transformation. This is a blowup of the are delineated by red in Fig 1,a and b.

Conclusions:

We have shown that diffusion tensor data of the breast can be achieved with relatively high spatial resolution and short acquisition time. The calculated average ADC value for the fibro-glandular tissue was in accordance with previous publications. We found that diffusion in the mammary tissue has an anisotropic nature as reflected from the FA maps and most importantly, the orientation of the main diffusion direction indicates that the tube-like micro structure of the ductal system can be tracked by DT-MRI. Further measurements in normal and pathological breasts are underway in order to evaluate the potential of this approach to provide a non contrast method for the detection of breast lesion.

References: 1. Going, J. J. Breast Cancer Res, 8: 107, 2006. **2.** Gooding, M. J. *et al.* NUMB 3749, Springer-Verlag, 434-441, 2005. **3.** Kingsley PB. Part I Concepts Magn Reson Part A 2006;28:101-22. **4.** Stejskal, E. O. and Tanner, J. E. JCP. Vol 42, Issue 1, pp. 288-292, January, 1965. **5.** Englander, S. A. *et al.* NMR Biomed, 10: 348-352, 1997.