# Tractography from regularized high resolution rs-EPI diffusion weighted imaging

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**Target audience:** Neuroradiology, Neurosurgery, Neuroscience

**Purpose**: Readout-segmented echo planar imaging (rs-EPI) with 2D navigator-based reacquisition is a new promising technique that enables the sampling of high-resolution DWI with reduced susceptibility artifacts[1,2]. Despite the undisputed merits of this method, long scan times are required for sufficient SNR, limiting the clinical applicability. It has been shown previously[3] that for low-SNR DWI locally dependent regularization of the diffusion tensor by means of total variation (TV) significantly improves tensor-derived quantities, such as the fractional anisotropy (FA). With this technique, the use of rs-EPI becomes feasible in a clinically acceptable time. In this work, we set out to regularize the diffusion tensor from rs-EPI measurements acquired in 16 minutes and compare tractography results with measurements from three averages obtained with a scan time of 48 minutes. Our proposed method has two convincing features. Firstly, the regularization parameter is evaluated automatically by being updated at every iteration step of the optimization algorithm, making the method user independent. Secondly, the regularization parameter varies locally, accounting for variations in SNR due to the spatial dependence of the coil sensitivity. The necessary information about the noise was extracted from the high-resolution DWI data by means of independent component analysis (ICA).

**Methods:** Data from a healthy volunteer were measured using an rs-EPI sequence with the following parameters: TR = 5600 ms, TE = 70 ms, FOV = 240 mm, resolution = 1x1x2.5 mm$^3$, slices = 38, b = 1000 s/mm$^2$, diffusion directions = 12, number of readout segments = 11, averages = 3. Measurements were carried out on a clinical 3T system using a 32 channel head coil. Data were processed further for three averages, for two averages, for one average and for one average with regularization. In order to obtain the noise information for the locally dependent TV regularization, ICA[4] was performed for all 12 directions with an active diffusion gradient (b = 1000 s/mm$^2$) to separate diffusion-related components from noise components. By inverting the ICA transformation for the diffusion components and the noise components separately, a denoised DWI dataset and a DWI noise dataset were evaluated. Using the Stejskal–Tanner relation for both DWI datasets, the diffusion tensor ($\widetilde{\mathbf{D}}_{\mathbf{ICA}}$) and a corresponding noise tensor ($\widehat{\mathbf{D}}_{noise}$) were calculated. The noise tensor was converted into a noise variance tensor $\mathbf{\Sigma}$ by measuring the local noise variance for each tensor element. $\widetilde{\mathbf{D}}_{\mathbf{ICA}}$ served as input for the TV-based optimization function:

$$\min_{\mathbf{D}}\left\{\int_{\Omega}\left|\nabla\widetilde{\mathbf{D}}\right|d\Omega+\frac{1}{2}\int_{\Omega}\mathbf{\Lambda}\left(\widetilde{\mathbf{D}}-\widetilde{\mathbf{D}}_{\mathbf{ICA}}\right)^2 d\Omega\right\}$$

where $\widetilde{\mathbf{D}}$ is the target regularized diffusion tensor and $\mathbf{\Lambda}$ is the regularization tensor with $\Omega$ being the image domain. This noise variance tensor $\mathbf{\Sigma}$ enabled an automatic update of the regularization tensor according to:

$$\mathbf{\Lambda}^{n+1}=\frac{\mathbf{\Lambda}^n\mathbf{\Sigma}}{\left\|\widetilde{\mathbf{D}}_{\mathbf{ICA}}-\widetilde{\mathbf{D}}\right\|}$$

Fiber tracts for visualization and tractography related parameters have been evaluated using TrackVis software (Ruopeng Wang, Van J. Wedeen, Athinoula A., Martinos Center for Biomedical Imaging, Massachusetts General Hospital, Boston, MA).

**Results:** The evaluation of tractography parameters Mean Length (ML), Track Count (TC), Volume (V), and Voxel Count (VC) obtained from fibers through a central transverse plane revealed an increase as a function of the number of averages (rs-EPI$_1$ < rs-EPI$_2$ < rs-EPI$_3$). Overall the regularized data (rs-EPI$_{1,reg}$) showed the highest values for all parameters (Table 1). Visually an increase of fiber length and fiber density can be observed for the regularized data compared to fiber tracts from one average (Figure 1).

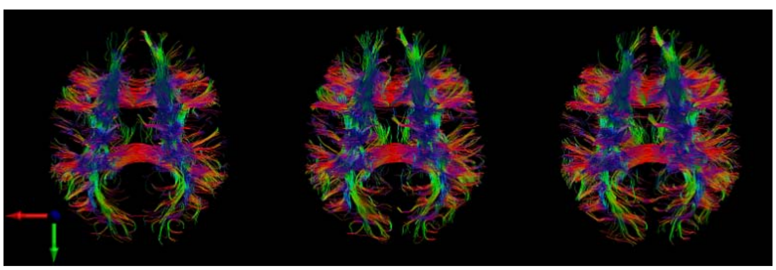

Figure 1: Tractography for rs-EPI data from one average (left), three averages (middle) and one average with regularization (right). Central regions of the regularized data show a higher fiber density more similar to data obtained from three averages.

Table 1: Evaluation of tractography parameter Mean Length (ML), Track Count (TC), Volume (V) and Voxel Count (VC) for rs-EPI data obtained from one average (rs-EPI$_1$), two averages (rs-EPI$_2$), three averages (rs-EPI$_3$) and one average with regularization (rs-EPI$_{1,reg}$).

| | **rs-EPI$_1$** | **rs-EPI$_2$** | **rs-EPI$_3$** | **rs-EPI$_{1,reg}$** |
|---|---|---|---|---|
| **ML (mm)** | 37,51 | 43,31 | 44,6 | 45,91 |
| **TC (1)** | 46935 | 55638 | 57269 | 59234 |
| **V (ml)** | 260,294 | 300,216 | 311,041 | 321,863 |
| **VC (1)** | 83294 | 96069 | 99533 | 102996 |

**Discussion & Conclusion:** It has been shown that automatic, locally dependent regularization of rs-EPI DWI significantly improves tractrography with respect to the parameters Mean Fiber Length, Track Count, Voxel Count and Volume. Specifically in central regions the regularization algorithm reveals structures that can be observed in data from three averages but not in data from one average (see Figure 1). Our data confirm that regularizing rs-EPI DWI data obtained from one measurement acquired within 16 minutes produce results comparable with DWI measurements from three averages obtained in 48 minutes. This significant reduction in scan time may advance the applicability of rs-EPI DWI in a clinical workflow.

**References:** 1. Porter DA, Heidemann RM. High Resolution Diffusion-Weighted Imaging Using Readout-Segmented Echo-Planar Imaging, Parallel Imaging and a Two-Dimensional Navigator-Based Reacquisition. Magn Reson Med. 2009;62:468–475, 2. Holdsworth SJ, Skare S, Rexford DN, Bammer R. Robust GRAPPA-Accelerated Diffusion-Weighted Readout-Segmented (RS)-EPI. Magn Reson Med. 2009;62:1629-1640., 3. Reishofer G, Koschutnig K, Langkammer C. Local regularization of the diffusion tensor by means of independent component ananlysis and total variation - application to high resolution DTI. Melbourne, Australia: ISMRM 20th Annual Meeting & Exhibition, 4. Li XL, Adali T. Complex Independent Component Analysis by Entropy Bound Minimization. Ieee Transactions on Circuits and Systems I-Regular Papers. 2010;57:1417-1430.