

# A Study of the Effect of CSF Suppression on White Matter Diffusion Anisotropy of Human Brain

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**Abstract**—Healthy human brain anisotropy maps derived from standard spin-echo diffusion tensor imaging (DTI) were compared with those using fluid-attenuated inversion recovery (FLAIR) preparation prior to DTI to null the signal from cerebrospinal fluid (CSF). Qualitative comparisons and objective quantitative analyses over white matter structures demonstrated that FLAIR DTI achieved extended delineation of major white matter tracts (genu, splenium and body of the corpus callosum) close to large CSF-filled spaces (lateral ventricles), but did not affect tracts remote from CSF (internal/external capsule and coronal radiation).

**Introduction**—Although diffusion tensor imaging (DTI) [1] of human brain is concerned mainly with gray and white matter (GM, WM), cerebrospinal fluid (CSF) may compromise these measurements because of: (i) CSF properties (high proton density,  $T_2$  and diffusivity), and (ii) imaging parameters (coarse EPI in-plane resolution, long echo times). Since stationary CSF is largely isotropic, it may affect major WM structures (eg, corpus callosum) proximal to large CSF spaces (eg, lateral ventricles). While CSF-suppressed DTI using fluid-attenuated inversion recovery (FLAIR) preparation [2], has been applied in several studies [3,4], it is not known how CSF suppression influences WM anisotropy. This study investigates the effect of CSF on DT anisotropy of healthy human brains by comparing standard (non-FLAIR) and FLAIR DTI.

**Methods**—**Experiments** Standard and FLAIR-prepared DTI was performed on 11 healthy subjects at 1.5T (Eclipse, Marconi Medical Systems), using single-shot, diffusion-weighted spin-echo EPI with: TE/TI/TR (standard)/TR (FLAIR)=125ms/1.7s/3.5s/7s, 128<sup>2</sup> matrix, 24cm FOV, and 6 5mm-thick contiguous transverse slices. DTI parameters were:  $\delta=24$ ms,  $\Delta=63$ ms, 6 directions with  $b=100$ s/mm<sup>2</sup>, 72 directions with  $b=1600$ s/mm<sup>2</sup> [5]. **Data processing** Relative anisotropy (RA) maps were calculated. Pixels with unreliable DT information, due to poor signal and/or fitting (such as those in the FLAIR dataset within/close to CSF spaces) were assigned zero DT and RA values, following masking based on a normalized  $\chi^2$  measure for each pixel (a separate abstract describes this measure). 5 WM structures were considered for region of interest (ROI) analysis: splenium, genu and body of the corpus callosum (scc, gcc, bcc), internal and external capsule (iec) and coronal radiation (cr). Each was defined by drawing multislice ROIs separately on the standard and FLAIR RA maps, and the ROIs fully encompassed the WM structure in-plane, and it also included neighbouring, low-anisotropy pixels (CSF, GM).

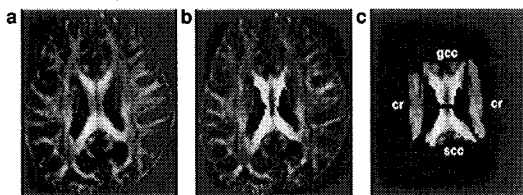


Figure 1

**Results & Discussion**—Figure 1 shows standard (Fig. 1a) and FLAIR (Fig. 1b) RA maps of a slice from one subject (scaled 0-1) together with the WM ROIs drawn on the FLAIR map (Fig. 1c). While standard and FLAIR RA maps appear very similar in areas remote from the lateral ventricles (cortical WM and cr), the corpus callosum (gcc, scc) appear extended in the FLAIR RA maps.

Figure 2 plots group histograms of the standard and FLAIR RA

distributions for: (a) total brain volume covered (b)-(f) the 5 WM structures. The histogram groups (bins) for which the difference between standard and FLAIR was statistically significant (paired  $t$  test,  $P<0.05$ ) are labelled as "Significance".

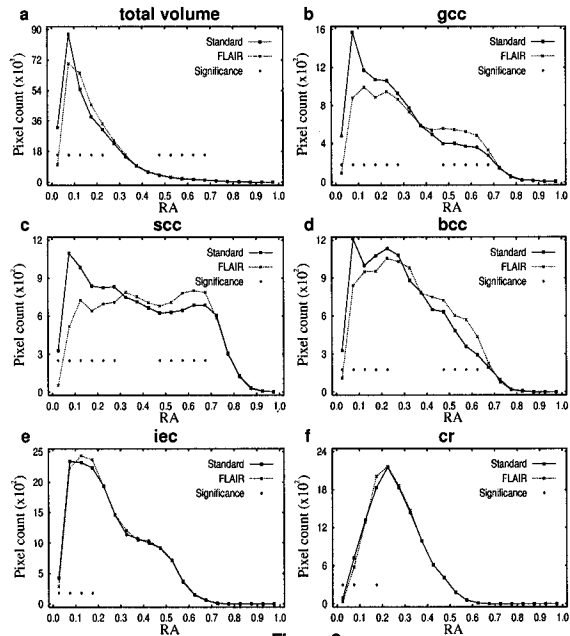


Figure 2

The difference in the histograms of Fig. 2a for  $RA<0.3$  is because: (i) CSF pixels were masked out and excluded from the FLAIR histogram, while they were kept in the standard histogram (increased pixel count for standard DTI at  $RA<0.1$ ) and (ii) the lower SNR in FLAIR slightly increased low anisotropy (increased count for FLAIR at  $0.1<RA<0.3$ ). Despite the apparent agreement between the histograms of Fig. 2a for  $RA>0.3$ , their statistically significant difference for  $0.45<RA<0.7$  (in this RA interval, FLAIR has 10% more pixels than standard DTI) is explained by Figs. 2b-d. For WM in direct proximity to large CSF spaces (gcc, scc, bcc), FLAIR gives larger pixel counts than standard DTI for  $0.45<RA<0.7$  (Figs. 2b-d); in this RA interval FLAIR has 30% (gcc, bc) and 15% (scc) more pixels than standard DTI, and these differences are statistically significant. For WM remote from CSF (iec, cr) FLAIR and standard DTI give similar RA distributions for  $0.45<RA<0.7$  (Figs. 2e-f), differing in pixel count by about 2%.

**Conclusions**—The qualitative observation that CSF-suppressed DTI extended anisotropic WM proximal to CSF, but did not affect WM remote from CSF, was supported by RA pixel distributions over WM ROIs for  $0.45<RA<0.7$ . This effect is related with partial voluming (PVM) between CSF and underlying parenchyma. Since PVM is not just volumetric but is affected by CSF properties (high proton density,  $T_2$  and diffusivity), further studies may investigate how these results are affected by voxel size.

**References**—[1] Basser, P.J. et al., *J. Magn. Reson. B*, 103, 247, 1994. [2] Hajnal, J.V. et al., *J. Comput. Assist. Tomogr.*, 16, 506, 1992. [3] Hirsch, J.G. et al., *Magn. Reson. Imaging*, 17, 705, 1999. [4] Eriksson, S.H. et al. *Brain*, 124, 617, 2001. [5] Papadakis, N.G. et al., *J. Magn. Reson.*, 137, 67, 1999.