3D FLAIR at 7 Tesla highlights peripheral layers of the cortex

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Introduction: Recently, the line of Gennari has been depicted successfully, using T_1-weighted and phase contrast images at high field (3T and 7T) [1]. In further exploring the potential of improving contrast and spatial resolution for observing different cortical layers at 7T, we observed that 3D FLAIR yields high signal in a layer different from the line of Gennari (Fig. 1). This layer produces hyperintense signal at the periphery of the cortex, and also around the ventricles. This finding is consistent with the peripheral demyelinated layers (Approx. layers I – III) of the cortex and with the subependymal layer around the ventricles. The purpose of this work is to describe this contrast in the FLAIR images and to explore its (anatomical) origin.

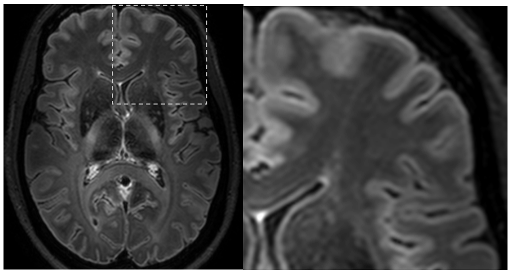


Fig 1. In-vivo 3D FLAIR images at 7T show a hyperintense rim at the periphery of the cortex and around the ventricles.

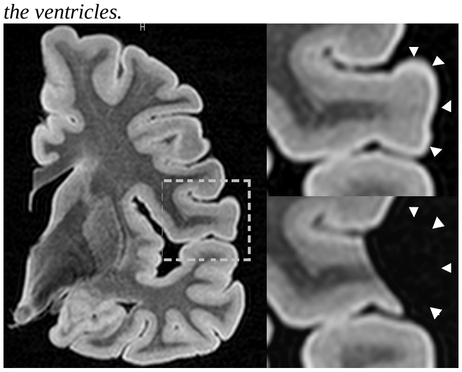


Fig 2. Ex-vivo FLAIR image showing the same contrast. After dissection of a gyrus (arrow heads) a slight ringing artifact remains, but the hyperintense rim is removed.

Methods: All measurements were performed using a 7T scanner (Philips) using a TR head coil with 16 channel receive coil (Nova Medical).

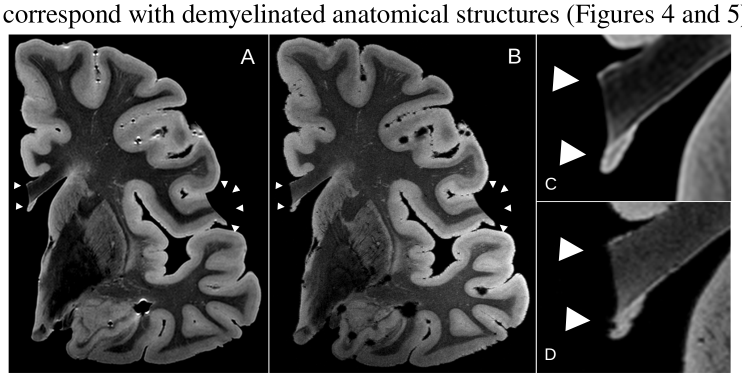
In-vivo. 3D FLAIR images were obtained on five healthy subjects. T_2 preparation was applied before the inversion pulse to minimize contamination with T_1-weighting. Further parameters were: FOV 240 x 240 x 180 mm (FH x AP x RL), 1.0x1.0x1.0 mm acquired resolution, TI/TR/TE 2450/8100/234 ms, echospacing 4.2 ms, SENSE factors 2.4 x 2.5 (AP x RL). The images were evaluated regarding consistent visibility of the hyperintense layer as shown in Fig. 1.

Ex-vivo. To further elucidate the origin of the hyperintense signal, imaging was performed on a human specimen without history of cerebral disease. The arachnoid membrane was removed to exclude this a potential source of the hyperintense signal. 3D FLAIR images were acquired with 0.4 mm isotropic resolution, using a TI of 1750 ms to null the formaline fluid surrounding the specimen. The imaging was repeated after partial dissection of a gyrus. Subsequently, the specimen was placed in fomblin (a lubricant which has no proton MR signal, and facilitates proper susceptibility matching [2]). As grey matter was not surrounded by any proton-containing fluid in this situation, partial volume effects from fluid around the specimen was excluded, as well as potential exchange or diffusion effects. Multiple echo spin echo and gradient echo sequences were acquired. Parameters used for spin echo: FOV 100 x 70 x 12 mm, acquired resolution 0.3x0.3x0.5 mm, TR/first TE/ΔTE 1200/10/10 ms, 10 echoes. Parameters for gradient echo: acquired resolution 180 x 180 x 180 μm, TR/first TE/ΔTE 300/6.0/6.0 ms, 10 echoes, flip angle 35°. T_2 and T_2* weighted images with increased contrast and SNR were constructed from the multiple echo images by summation of multiple echoes.

Results and Discussion: *In-vivo.* All in-vivo images consistently showed hyperintensity of the peripheral layers of the cortex and around the ventricles. In retrospect, this hyperintensity is also visible on both 2D and 3D FLAIR images at a different field strength and at a scanner of a different vendor [3], indicating that it is not likely an artifact of our system. A common ringing artifact and blurring due to limited resolution are the most likely reasons that it has not been recognized on in-vivo FLAIR images before.

Ex-vivo. Fig. 2 shows that the layer is also very distinct on the 3D FLAIR images from the specimen, though a ringing artifact partially masks the rim. Dissection of a gyrus (Fig. 2B) shows the ringing artifact, but not the hyperintense layer. T_2- and T_2* weighted images show the same pattern as the FLAIR images (Fig. 3), while the T_2* weighted images don't show any ringing artifacts. The areas of hyperintensity correspond with demyelinated anatomical structures (Figures 4 and 5).

Fig3. Ex-vivo T_2 (A) and T_2 (B) weighted images show contrast similar to FLAIR. Note the thin line at the top of the ventricle (zoomed details in C and D, respectively) consistent with the subependymal zone. Arrowheads indicate cuts.*



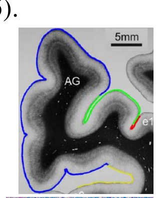


Fig 4. Myelin concentration increases from peripheral (bright, approx. layers I-III) to deep cortical layers (dark, approx. layers III-VI), which corresponds to the FLAIR contrast. (Silver staining, reproduced from Ref. [4])

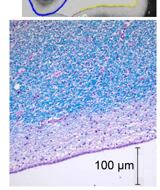


Fig 5. The subependymal zone around the ventricles contains no myelin, which corresponds to the hyperintense signal in the FLAIR contrast. (Luxol fast blue staining at ventricle wall).

Conclusion: FLAIR images at high field show a high intensity structure that is consistent with the peripheral layers of the cortex, and the subependymal zone of the ventricles.

References: [1] Duyn JH, et al, PNAS 104(28):p11796-801, 2006. [2] Benveniste H, et al, Prog.Neurobiol. 67:p393-420, 2002. [3] Bink A, et al, Eur Radiol 16:1104-10, 2006. [4] Annese J. et al, NeuroImage 21:15-26, 2004.