In Vivo 3D Imaging of Human Lateral Geniculate Nucleus using Optimized Inversion Recovery Sequence at 3T and 7T

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[Introduction] Lateral geniculate nucleus (LGN) functions as a thalamic relay station in the projection of visual pathway from retinal ganglion cells to the primary visual cortex. A recent MR imaging study of human LGN in vivo demonstrated that the height of LGN is smaller in glaucoma patients than normal (those without glaucoma) subjects [1]. This study implies that morphometry of LGN is an important potential biomarker for the neurodegenerative glaucoma disease. However, precise delineation of LGN anatomy in 3D using MR image is technically challenging because of the LGN's location deep in the brain, small size (diameter 4 – 6 mm), and tissue signal similar to the surrounding white matters, such as optic radiation (OR). In this study, we demonstrated a significant improvement in the tissue contrast of LGN by a using magnetization-preparation-rapid-acquisition-gradient-echo (MPRAGE) sequence with optimized inversion time (TI) at 3T and 7T.

[Methods and materials] All scans were performed on a 3T and 7T scanner (Siemens Medical Solutions, Erlangen, Germany) with single-loop surface coils for imaging ex vivo brain specimen, and 32-/9-channel RF head coils for imaging LGN in vivo. MR imaging of the brain specimen was performed at 3T to assess the degree of LGN tissue contrast improvement with inversion-recovery (IR) vs. proton-density (PD) imaging in 2D, which is known to produce the best LGN tissue contrast among conventional MR sequences. The specimen was also scanned at 7T to image the LGN using 3D MPRAGE. MR imaging of LGN in vivo was performed at 3T and 7T with two normal, healthy volunteers (28, 40 yrs). A series of IR gradient-echo (GRE) images were obtained by varying TI's. Tissue signal intensity and contrast was measured by placing ROIs over the OR, LGN, thalamus, and internal capsule and was then plotted against TI. The image intensity (y) vs. inversion time (t) was fitted using $y = a\cdot\{1-2\cdot\exp(-b\cdot t)\}$. We determined the TI that maximized the relative contrast of LGN (L) to other tissues (C) which was defined by $|C-L|/|C+L|$. Then, the relative contrast of LGN was compared between PD turbo-spin-echo (TSE) and IR-GRE image with the optimal TI at 3T. In addition, the proposed LGN imaging method was compared with conventional GRE and MPRAGE imaging with CSF suppression at 7T. Finally, LGN was segmented from the proposed MPRAGE images and the volume of LGN was measured.

[Results and conclusions] Substantial changes in tissue signal intensity with varying TI's were detected on IR-GRE images of ex vivo specimen (Figs. 1A and B). The relative contrast of LGN was maximized at TI = ~120 ms at 3T because the greatest suppression of signal intensity in OR was at this value. The relative contrast of LGN was higher on the IR-GRE images than PD-TSE image: 64.5% vs. 30.5%, and 50.0% vs. 22.3% at two different slices (Figs. 1C – F). The IR imaging of LGN in vivo vs. PD-TSE imaging revealed the same trend (data not shown). High-resolution images of the ex vivo mid-brain obtained using 3D MPRAGE sequence with TI = ~200 ms at 7T are shown in Fig. 2. Sub-nuclei of thalamus, lateral and medial geniculate nuclei, and hippocampus were clearly discernible. In comparison, in vivo LGN was not easily distinguishable from the surrounding structures on conventional GRE or MPRAGE with CSF suppression images (white-arrowheads in Figs. 3A & B), even at high-resolution (~130 μm^2 to ~500 μm^2/pixel). The TI for the highest contrast in MPRAGE imaging of LGN in vivo was ~450 ms (3T) and ~550 ms (7T). At these TI's, LGN was sharply demarcated from OR (Figs. 3C & D). The SNR of LGN in the MPRAGE images at 7T was superior to that at 3T: ~30 vs. ~18. The segmented and measured volumes of LGN were 120.5 - 143 mm^3 from the 7T MPRAGE images which were within the reported 91.1 – 157 mm^3 measured from ex vivo specimens [4]. Volumes of LGN were not measured from the 3T images because the boundary of LGN was not clearly defined (noisy pixels).

In conclusion, excellent tissue contrast of LGN and suppression of the surrounding OR tissue signal were achieved using a 3D MPRAGE sequence with appropriate TI. This sequence was superior to other sequences commonly used for LGN imaging including PD, GRE, and typical MPRAGE. MR imaging of LGN at 7T was superior to 3T with doubling of SNR at 7T. An imaging method that allows accurate and reliable volume measurement of LGN is crucial for the investigation of the association between LGN atrophy in vivo and neurodegenerative glaucoma.

[Reference] **1**. Gupta et al., *Br J Ophthal,* 93:56-60 (2009). **2**. Wright et al., *Magn Res Mater Phy,* 21:121-130 (2008). **3**. Deichmann et al., *Neuroimage,* 12:112-127 (2000). **4**. Andrews et al., *JNS,* 17:2859-2868 (2000).

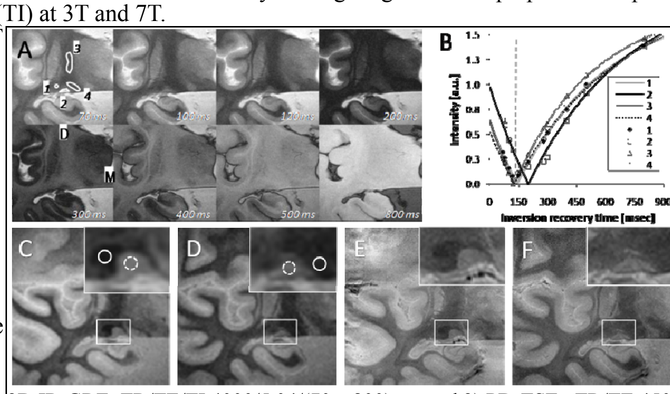

Fig. 1 Ex vivo specimen LGN imaging at 3T. (A) IR-GRE w/ different TIs, (B) Time-plot, (C & D) IR-GRE with TI 150 ms, and (E & F) PD-TSE images; 1) 2D IR-GRE; TR/TE/TI 4000/5.04/(70 – 800) ms and 2) PD-TSE; TR/TE 4500/15 ms.

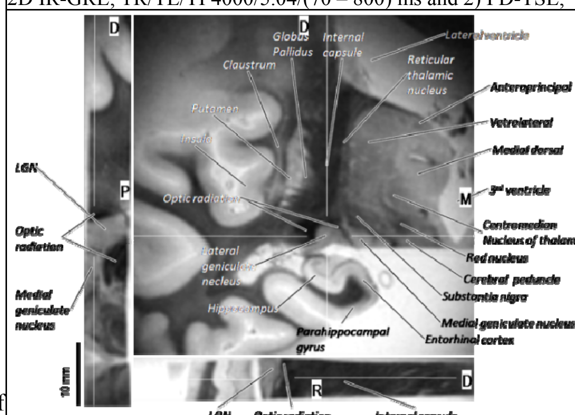

Fig. 2 Ex vivo high-resolution LGN MPRAGE image at 7T. The imaging parameters are TR/TE/TI 2000/3.59/200 ms, and isotropic resolution 0.3 mm^3. Sagittal, coronal, and axial view in clock-wise rotation. Abbreviations; A – anterior, D – dorsal, and R – right.

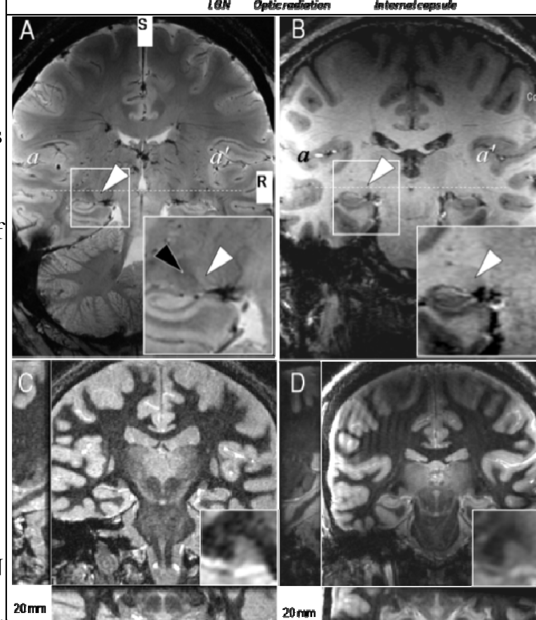

Fig. 3 Comparison of LGN images in vivo by GRE (A, 7T), MPRAGE w/ CSF suppression (B, 7T), and the proposed MPRAGE (C, 3T & D, 7T). (Inset) Magnified LGN image in the white-box. Imaging parameters; 1) GRE – TR/TE 1700/22 ms, 2) MPRAGE w/ CSF suppression – TR/TE/TI 3000/3.6/1200 ms, and 3) Proposed MPRAGE - TR/TE/TI 2500/4.52/(450, 3T and 550, 7T) ms, and isotropic resolution ~1 mm^3. On the coronal view is LGN located above the hippocampus and ambient cistern, beneath and lateral to the thalamus, and bordered by OR (see Inset). On axial view, the shape looks like a wedge and laterally bordered by OR and anteromedially by the posterior limb of IC. Posterior margin of LGN is contiguous to the pulvinar in sagittal view.