Visualization of human brainstem structures at 3T using 3D inversion recovery sequences

Zhe Zhang[1], Changcun Pan[2,3], Xiaodong Ma[1], Jie Tang[3], Lihong Wang[1], Liwei Zhang[2,3], and Hua Guo[1]

[1]*Center for Biomedical Imaging Research, Department of Biomedical Engineering, School of Medicine, Tsinghua University, Beijing, China,* [2]*Department of Neurosurgery, Medical Center, Tsinghua University, Beijing, China,* [3]*Department of Neurosurgery, Beijing Tiantan Hospital, Capital Medical University, Beijing, China*

TARGET AUDIENCE: neurosurgeons and neuroscientists interested in human brainstem structures

PURPOSE: Brainstem has nuclei and fiber bundles which are vital to our life. Brainstem lesions, such as gliomas, cavernous malformations and hemangioblastomas can be lethal. Advanced MR imaging techniques, along with microsurgical and electrophysiological monitoring techniques, have been proven indispensable for surgical planning and resection of brainstem lesions. The multi-contrast and multi-planar capabilities of MR imaging reserve the potentials to accurately localize lesions and clarify their relationships with surrounding structures (e.g. nuclei, neural fibers), which would provide valuable information for selecting the surgical route with the minimum risk of injury to the surrounding neurovascular structures [1]. However, due to the small size of the brainstem and the poor contrasts between nuclei and white matter, the precise identification of nuclei using MR imaging remains challenging, especially on clinical scanners using conventional T1w (3D MP-RAGE, etc.) and T2w (FSE, etc.) images. Previous work has reported the clear visualization of specific brainstem substructures in vivo using gray matter nulled 3D MP-RAGE at 7T with about 12 minutes scan [2], which may not be feasible for clinical applications. In this work, gray matter nulling and white matter nulling are respectively introduced in the sequence design to enhance contrasts between nuclei and white matter. The corresponding two 3D sequences for visualizing brainstem substructures in vivo at 3T with about 5 and 6 minutes scan time each are described and compared, which are potentially significant for preoperative brainstem MR scans.

METHODS:

All scans were performed on a Philips 3.0T MRI scanner (Philips Healthcare, Best, The Netherlands) using a 32-channel head coil. In order to enhance the contrast and visualize brainstem structures, 3D T1w MP-RAGE and FGATIR [3] sequences were modified by optimizing the inversion time (TI) and repetition time (TR) to null the gray matter and white matter respectively. The scan parameters are shown in Table 1. Data were acquired from 4 healthy volunteers (median age 24 years, range 23-26 years, 1 female, 3 male, protocols IRB approved) in the axial view. DTI scan with 2.2 mm isotropic resolution and SENSE = 3 was also implemented for fiber tracking. The 3D images were reformatted in the sagittal view during the post-processing. The images were visually compared to sectional anatomy and post-mortem high-field MRI images from *Duvernoy's Atlas of the Human Brainstem and Cerebellum* [4].

Table.1 Scan parameters of modified 3D T1w MP-RAGE and FGATIR for brainstem imaging

Sequence	Modified 3D MP-RAGE	Modified 3D FGATIR
Field of view (mm, AP/RL/FH)	230×192×180	230×192×180
Acquisition voxel Size (mm, AP/RL/FH)	0.8×0.8×2	0.8×0.8×2
Repetition time (TR) / Inversion time (TI)	2375 ms / 780 ms	3000 ms / 384 ms
Slice orientation	Axial	Axial
Flip angle	8°	8°
TFE factor	78	78
SENSE acceleration (P /S direction)	2×1.5	2×1.5
Acquisition time	4:53	6:06

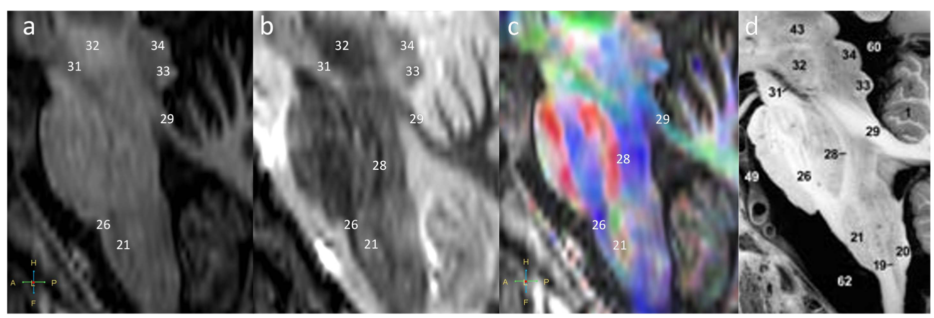

Fig. 1. The reformatted sagittal view of brainstem images using modified MP-RAGE (a), modified FGATIR (b) and DTI FA map overlaid on modified MP-RAGE (c) at 3T, along with an anatomy image from *Duvernoy's Atlas* (d). The brainstem structures can be visualized.

RESULTS AND DISCUSSION:

Fig. 1 shows a representative slice (from subject #3) in the sagittal view using the proposed sequences (Fig. 1a for MP-RAGE, Fig. 1b for FGATIR and Fig. 1c for DTI color FA map overlaid on MP-RAGE), along with *Duvernoy's Atlas* histology image (Fig.1d, from book P.882). The brainstem structures including inferior olivary nucleus (21), corticospinal tract (26), superior cerebellar peduncle (29), substantia nigra (31), inferior colliculus (33) and superior colliculus (34) can be visualized by both sequences. FGATIR imaging has better contrast for medial lemniscus (28), corticospinal tract (26) and red nucleus (32). The fiber orientations on FA maps confirm the fiber structures of 26, 28 and 29. Fig. 2 shows the axial view of the inferior olivary nucleus (from subject #1) at the slice location 21, along with the with *Duvernoy's Atlas* high-field MR image (Fig. 2c, from book P.262). Both sequences (Fig. 2a for MP-RAGE and Fig. 2b for FGATIR) provide good contrast of olivary nucleus (white arrow heads).

The visualization of inferior olivary nucleus can help to localize the fiber tracts nearby. In Fig. 2d, the pyramid (corticospinal tract, green), medial lemniscus (blue), spinothalamic tract (yellow) and intramedullary part of the hypoglossal nerve (violet) can also be located due to their relative positions to the inferior olivary nucleus (red). This information can be useful in guiding preoperative brainstem surgical route selections. As the brainstem imaging can be affected by CSF pulsation, the structures were inevitably affected. Thus future optimization should also include motion artifact suppression to increase the image sharpness.

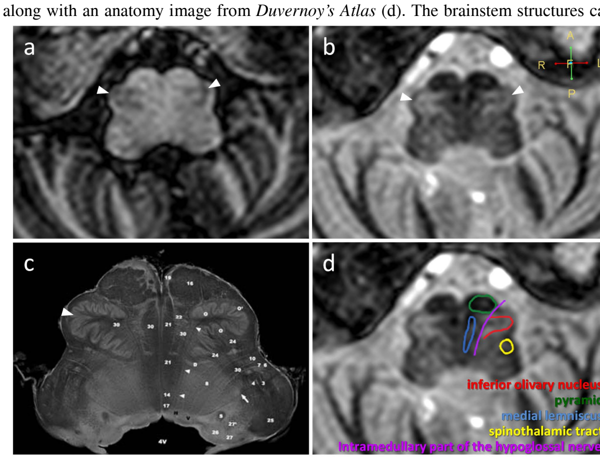

Fig. 2. Olivary nucleus can be visualized using the modified MP-RAGE (a) and modified FGATIR (b) at 3T in the axial view, along with the olivary nucleus anatomy from *Duvernoy's Atlas* (c). The visualization of inferior olivary nucleus can help to locate the nearby fiber tracts and guide surgical planning (colors in d).

CONCLUSION:

The two proposed optimized 3D sequences can provide good visualization of brainstem structures in vivo using gray matter or white matter nulling on a 3T scanner within 6.5 minutes scan time each. The visualization of structures like the inferior olivary nucleus can be potentially significant for preoperative brainstem MR scans.

REFERENCES: [1] Bricolo A. Oper Tech Neurosurg 2000;3:137-154. [2] Michael W., et al. ISMRM 2014:4632. [3] Sudhyadhom A., et al. Neuroimage 2009;47 T44-52. [4] Duvernoy's Atlas of the Human Brain Stem and Cerebellum, Springer 2009