Visualization of human brainstem substructures using gray matter nulling 3D-MPRAGE at 7Tesla

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INTRODUCTION

The human brainstem and its substructures are known to be involved in a multitude of functions and can thus be interpreted as the neuronal gate to the cortex[1]. Incorporated substructures vary according to their cytoarchitecture, are small and densely packed, rendering their in-vivo MR visualization highly challenging in terms of resolution and contrast. Combining ultra-high field MRI (7T) with state-of-the-art image acquisition strategies may provide the requirements to elucidate this issue[2]. This work describes the application of a modified 3D-MPRAGE sequence in the gray matter nulling regime[3] at 7T in the human brainstem. Substantial improvements in visualization of specific brainstem substructures are observed, promising to aid the exploration of both anatomical and functional features towards better understanding of the normal status as well as pathology of the brainstem.

MATERIAL & METHODS

All measurements were acquired on a 7T MR system (Philips Healthcare, Cleveland, USA) using a quadrature transmit head coil together with a 32-channel receive array (NOVA Medical, Wilmington, USA). A modified 3D-MPRAGE sequence in the sagittal and transverse planes with the following parameters was applied. FOV: 200 x 200 mm^2, TR for Inversion: 3 s, TR: 11 ms, TE: 5.2 ms, readout flip angle α: 7°, acquired voxel size: 0.6 x 0.6 x 1.6 mm^3, reconstructed voxel size: 0.5 x 0.5 x 0.8 mm^3, 75 slices, 3 signal averages, acquisition time: 12:10 minutes. To compensate for B_1 inhomogeneity, a highly adiabatic inversion prepulse (hypersecant, duration 22 ms, amplitude 15 µT) was implemented. The acquisition delay (TI) after the inversion prepulse was experimentally optimized and set to 875 ms for gray matter nulling (Fig 1). Five healthy volunteers (median age 28 years, range 24-28 years, 2 female, 3 male) were examined following informed consent in line with the local ethics regulations. The resulting images were visually compared to histological plates and post-mortem MRI images from Duvernoy's Atlas of the Human Brainstem and Cerebellum[4].

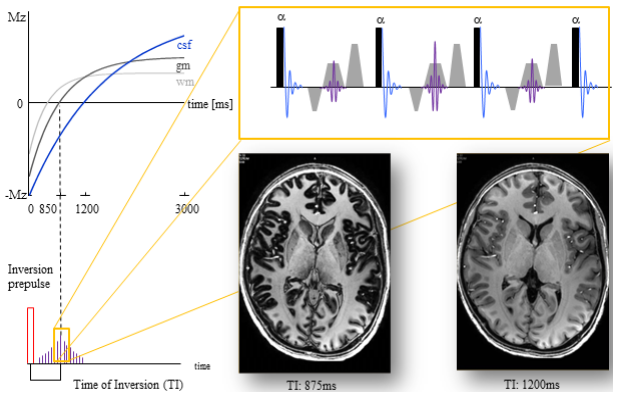

Figure 1: Scheme of the modified MPRAGE sequence with short inversion time. Gray matter nulling is achieved with an inversion time of 875 ms. For illustrating reasons a low TI image (TI 875 ms) is compared with an image of an inversion time of 1200 ms, normally used for regular T1 weighted imaging.

RESULTS

Figures 2 and 4 display typical results in three sagittal slices (subject #2) and four transverse slices (subject #4), respectively, showing excellent differential contrast. Within the sagittal images, we identified 22 structures, clearly assignable to the Duvernoy's Atlas histology data (Fig. 3). In the brainstem, specifically, 12 substructures were manually outlined for all five subjects, based on correspondence with the histology section. Using the nomenclature of the latter, the readily identifiable structures were the following: (19) spinal trigeminal nucleus, (20) lateral cuneate nucleus, (21) inferior olivary nucleus, (26) pons (corticospinal tract), (28) medial lemniscus, (29) superior cerebellar peduncle, (31) substantia nigra, (32) red nucleus, (33) inferior colliculus, (34) superior colliculus, (43) centromedial thalamic nucleus, (44) pulvinar.

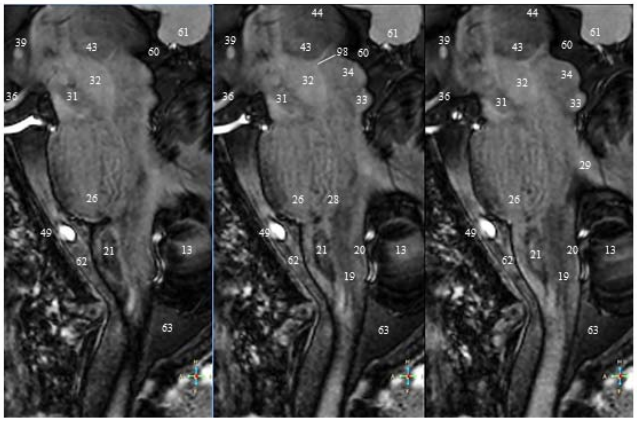

Figure 2: 7T invivo gray matter nulled MPRAGE images. Three sagittal slices of subject # 2.

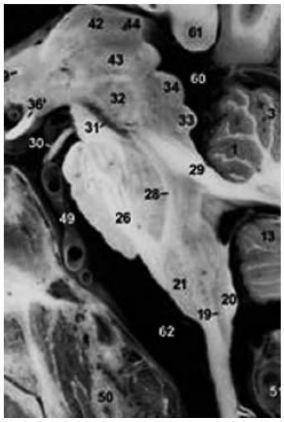

Figure 3: Histology section, sagittal plane from the Duvernoy Atlas 11.67D, page 822.

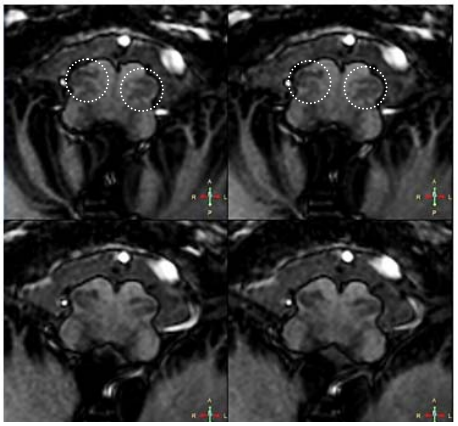

Figure 4: Four 7T invivo axial slices throug the Brainstem showing the olivary nucleus (dotted circles) in great detail.

19 Spinal trigeminal nucleus (CN V)
20 Lateral cuneate nucleus
21 Inferior olivary nucleus
26 Pons (corticospinal tract)
28 Medial lemniscus
29 Superior cerebellar peduncle
30 Oculomotor nerve (CN III)
31 Substantia nigra
32 Red nucleus
33 Inferior colliculus
34 Superior colliculus
36 Prechiasmal optical nerve
39 Anterior commissure
42 Dorsomedial thalamic nucleus
43 Centromedian thalamic nucleus
44 Pulvinar
49 Basilar artery
60 Quadrigeminal cistern
61 Splenium
62 Premedullary cistern
63 Cerebellomedullary cistern
98 Zona incerta

DISCUSSION

To visualize the brainstem, MPRAGE sequences have been used in the past, aiming for regular T1-weighted imaging with nulled CSF. Alternatively, nulling of white matter has been explored in other brain regions [2, 5]. The present work indicates that the intermediate option of gray matter attenuation offers particularly specific contrast for brain stem studies. It permits superior delineation of numerous, closely neighboring brainstem substructures. The known limitations (SNR, long acquisition times) of this sequence strategy at lower field strength (1.5T, 3.0T) speak for the favor of ultra-high-field imaging for this specific question[2]. 7T MRI provides higher SNR and due to increased T1 dispersion, higher contrast between tissue types. Shorter T2* relaxation times and possibly magnetization transfer effects of the long adiabatic inversion prepulse may further influence the resulting contrast and form a target of further investigation.

CONCLUSION

The use of an optimized high resolution 3D-MPRAGE sequence in the gray matter nulling regime at 7Tesla provides a clearly enhanced image contrast between different substructures in the human brainstem, which are nearly invisible with normal MR imaging.

REFERENCES

1. Sessle J., J Dent Educ 66 (1), pp. 108–112 (2002)
2. Tourdias et al., NeuroImage 84, 534-545 (2014)
3. Bender et al., Am J Neuroradiol, 32:2110-15 (2011)
4. Duvernoy's Atlas of the Human Brain Stem and Cerebellum, Springer 2009
5. Sudhyadhom et al., NeuroImage 47, T44-T52 (2009)