Comparison of locus coeruleus volume between gradient echo and turbo spin echo sequences using a landmark-based segmentation scheme

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INTRODUCTION:

Neuromelanin pigment in the locus coeruleus (LC) generates contrast which decreases as Parkinson's disease (PD) and Alzheimer's disease (AD) progress. The locus coeruleus (LC) is a small cylindrically-shaped structure (approximately 2-mm wide and 15-mm long) located in the dorsolateral pontine tegmentum (PT) along the fourth ventricle. Visualization and volumetric quantification of this structure would be beneficial to the study and early detection of PD and AD. Initial work on visualization focused on generating neuromelanin (NM)-sensitive contrast in the LC using a high-resolution multi-slice 2D turbo spin echo (TSE) magnetic resonance (MR) imaging technique which was sensitive to T1-shortening effects and incidental magnetization transfer contrast (MTC) effects [1]. Although that work successfully generated images exhibiting good contrast for LC and substantia nigra, the primary source of NM-sensitive contrasts still remains unclear [1,2]. More recent work examined the use of a T1-weighted gradient echo (GRE) sequence with an MTC pulse to visualize the LC [3]. In this work, a method for segmenting the LC is developed using landmarks adopted from [4]. The performance of the method is then assessed by applying it to segmenting LC in TSE and GRE images to estimate neuromelanin.

METHODS

All experiments were performed on a 3 T scanner (TRIO, Siemens Medical Solutions, Malvern, PA) using a body coil transmitter and a 12-channel head receiver coil. Seven normal volunteers participated in this study after obtaining informed consent in accordance with our institutional review board regulations. Two-dimensional gradient echo imaging was performed with the following parameters: TE/TR=2.68/260 ms, 11 contiguous slices, 416×512 imaging matrix, 162×200 mm (0.39×0.39×3 mm), 7 measurements, flip angle (FA)= 40^0, MTC pulses (300^0, 1.2 kHz off-resonance, 10 ms duration), and 470 Hz/pixel receiver bandwidth with a scan time of 12 min 37 s. Two-dimensioanl TSE imaging was performed with the following parameters: TE/TR= 12/600 ms, 11 contiguous slices, 416×512 imaging matrix, 162×200 mm (0.39×0.39×3 mm), 6 measurements, echo train length (ETL)= 2, and 142 Hz/pixel receiver bandwidth (12 min 32 sec scan time). The number of measurements was selected differently for both sequences to match the imaging time for comparison.

The individual measurements, with each sequence, were spatially registered to the corresponding first measurement using FLIRT in the FSL software package (Oxford University, United Kingdom). The registered images were averaged to generate the images used in the segmentation.

A region of the pons was selected and applied to image volumes from the both sequences. Then, the following procedure was used to detect the LC:

1) The apex of the fourth ventricle was identified.
2) To define a target region of interest (ROI) for LC after following a known landmark [4], two circular ROIs with radius 3 mm, centered 3 mm left / right and 2 mm posterior to the apex of the fourth ventricle, were drawn,
3) Pixels within the ROI whose intensity is equal to or higher than 4 times the standard deviation above the average signal intensity of pons were considered to be part of LC. Contrast-to-noise ratio (CNR) was then calculated by taking the difference of average signals of LC and pons, divided by the background standard deviation.

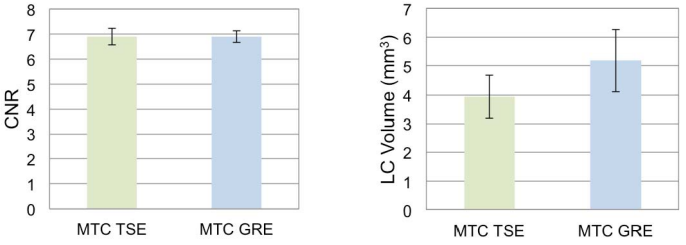

Figure 1. (Left) The mean CNR for the LC in eight control subjects using TSE and GRE sequences. (Right) The estimated volume for the LC in eight control subjects using both TSE and GRE sequences.

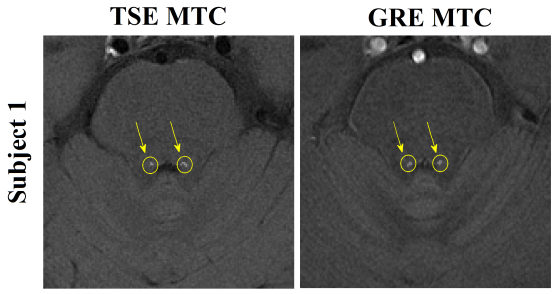

Figure 2. The estimated LC volume for slice 7 of Subject 1 using the images acquired from the TSE sequence (Left) and the GRE sequence (Right).

RESULTS AND DISCUSSION

Fig. 1 shows that the images acquired with the GRE-based sequence generates similar CNR as the images acquired with the TSE-based sequence with a mean CNR across all subjects of $\mu = 6.9 \pm 0.3$ for the TSE based approach and a mean CNR across all subjects of $\mu = 6.9 \pm 0.2$ for the gradient echo-based approach. The mean of the estimated LC volume across all subjects was $\mu = 3.9 \pm 0.8$ mm^3 and $\mu = 5.4 \pm 1.2$ mm^3 for the TSE datasets and the GRE datasets, respectively. The mean CNR and estimated LC volume for all eight subjects are given in Table 1. Fig. 2 displays the estimated LC volume with the ROIs overlaid for Subject 1.

Given the small stature of the LC, head motion could be detrimental and complicate LC segmentation. Other artifacts may be generated by the pulsation of the fourth ventricle. These artifacts can be mitigated by applying a motion correction algorithm. In summary, the mean CNR for both sequences was similar; however, the estimated LC volume from the GRE-based approach was significantly larger than that of data acquired using the TSE sequence.

	Subject 1 (TSE, GRE)	Subject 2 (TSE, GRE)	Subject 3 (TSE, GRE)	Subject 4 (TSE, GRE)	Subject 5 (TSE, GRE)	Subject 6 (TSE, GRE)	Subject 7 (TSE, GRE)	Subject 8 (TSE, GRE)
Mean CNR	(7.24, 6.23)	(7.61, 7.10)	(6.01, 6.66)	(5.69, 6.01)	(6.26, 7.97)	(7.17, 7.47)	(8.56, 7.27)	(6.62, 7.27)
LC Volume (mm^3)	(6.84, 6.84)	(5.93, 11.40)	(5.02, 2.28)	(1.37, 4.10)	(4.10, 3.19)	(1.82, 2.73)	(1.36, 3.19)	(5.01, 10.03)

Table 1. The mean CNR and estimated LC volume for the eight control subjects considered in this study. The mean CNR and estimated LC volume are shown in the second and third rows, respectively. For each cell in the table, the first number in the ordered pair represents the value from the TSE sequence and the second number represents the value from the GRE sequence.

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