Improved Dual White Matter and CSF Suppression using MP-nRAGE

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TARGET AUDIENCE: Researchers and clinicians that study gray matter or use double inversion recovery sequences.

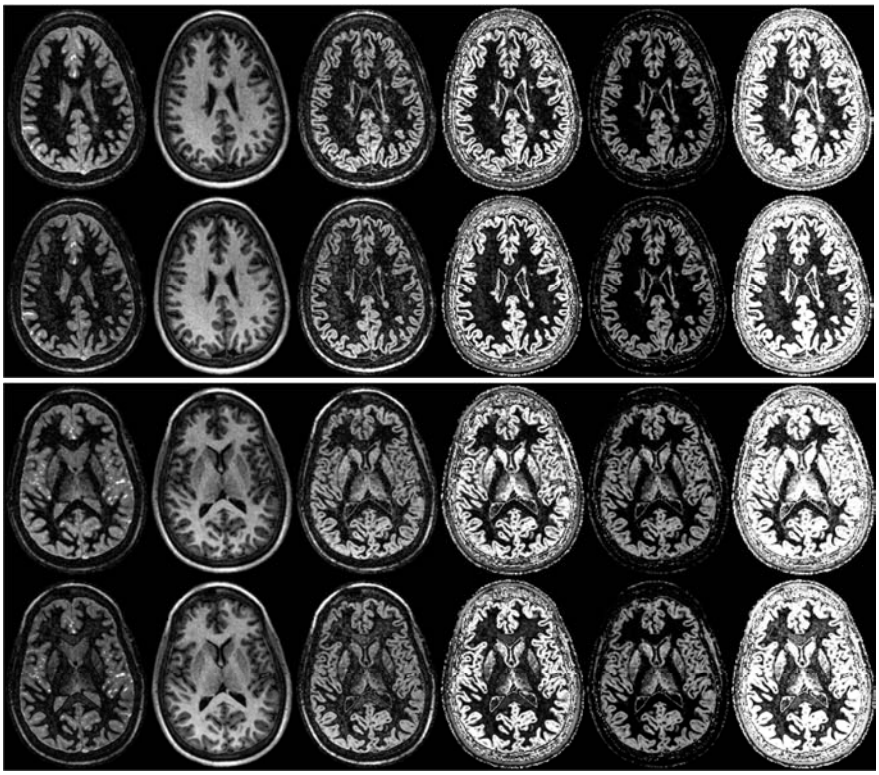
PURPOSE: Double inversion recovery (DIR) pulse sequences are commonly used to obtain images of gray matter (GM) by simultaneously suppressing the signal from white matter (WM) and CSF.[1-3] Unfortunately, these DIR methods are typically slow with low SNR in the GM regions of interest. Recently, a promising single inversion recovery method (FLAWS) based upon MP2RAGE was developed to simultaneously suppress the signal from CSF fluid and white matter to generate GM images similar to DIR. *The purpose of this work is to demonstrate improved methods for double tissue nulling using an MP-nRAGE sequence[6], which acquires n>100, whole-brain single inversion recovery image volumes with isotropic 1 mm resolution in under 8 minutes.*

BACKGROUND: The MP2RAGE sequence obtains two images with different inversion times following a single inversion pulse.[4] Recently, this method was adapted to collect the inversion null frames for CSF and WM.[5] The FLAWS (Fluid and White Matter Suppression) method generates a GM map by taking the minimum intensity projection (MinIP) of the two frames.[5] The result is an image that is similar in appearance to a DIR study. Limitations of the FLAWS method include slow acquisition (roughly twice as long as MPRAGE T1w), decreased performance for frames incorrectly selected for CSF and WM nulling (e.g., from T1 and B1 changes), and intensity variations from coil sensitivity. Recently, an MPRAGE sequence was developed with 3D radial k-space sampling, which repeated samples the center of k-space over the entire inversion recovery curve.[6] By a clever view sharing strategy, (n=) 100s of image volumes with different inversion recovery contrasts may be reconstructed, corresponding to an MP-nRAGE sequence. The acquisition of MP-nRAGE for whole-brain coverage with 1 mm isotropic resolution is roughly 7.5 minutes, which is similar to a fully-sampled MPRAGE sequence on our scanner. Different inversion recovery volumes from this MP-nRAGE include null frames for WM, GM, and CSF, as well as intermediate frames, proton-density-weighted and more conventional T1w images.[6] Since all of the images are acquired simultaneously, they are inherently co-registered. Advantages of the MP-nRAGE method over MP2RAGE include the acquisition speed (~7.5 minutes), the ability to select the best null frames for each subject, and the ability to perform different dual nulling (e.g., CSF+WM, CSF+GM, GM+WM) for tissue-specific imaging. Dual nulled frames may be processed using the FLAWS MinIP method. In this study, we improved the FLAWS method by normalizing the MinIP by the maximum intensity projection (MIP) of the two frames – i.e., MinIP/MIP. This was further improved by using the MIP of all frames at inversion times equal to the CSF null point and longer (MinIP/MIP+ method).

METHODS: Whole-brain MP-nRAGE exams with 1mm isotropic spatial resolution were collected at 3T in both healthy adult subjects and patients with multiple sclerosis. The inversion time frames were computed across the entire recovery curve and combinations of MP2RAGE and MinIP/MIP images were used to generate a range of contrasts.

RESULTS: Results for GM maps generated using MP2RAGE, FLAWS, MinIP/MIP and MinIP/MIP+ processing are shown in the Figure for two slices in a study of a patient with multiple sclerosis (MS). Note that the FLAWS method shows signal variations from coil sensitivity that are normalized out in the MP2RAGE and MinIP/MIP(+) processing. The results are also shown for the case where the null frames are incorrectly selected, indicating that the MinIP/MIP(+) processing is less sensitive to this problem. One advantage of MP-nRAGE over MP2RAGE is that the CSF and WM null frames may be selected retrospectively from the data to achieve the best performance for a specific exam and subject.

DISCUSSION AND CONCLUSION: We demonstrated the power and flexibility of a single 7.5 minute, whole-brain, 1-mm isotropic MP-nRAGE with new processing methods to general multiple images with different T1w contrast as well as dual nulling for tissue specific mapping. We believe that these GM maps will be valuable for gray matter morphometry studies as well as clinically for detection of cortical lesions. Note that for MP-nRAGE, it is possible to generate $(n^2-n)/2$ image pairs that may be used to provide other contrasts (e.g., WM specific maps).



Results Figure. MP-nRAGE images (two slices) for a 7.5min study in an MS patient using an 8-channel receiver coil at 3T. left to right columns: WM null frame, GM null frame, FLAWS (MinIP), MinIP/MIP, MinIP/MIP+ using a concatenation of the first 50 frames and the final 180 (basically, out of 296, everything but frames 51 to 99), and finally, MP2RAGE image using the WM and CSF null frames.
For each slice, top row: images processed using optimized null frames for WM and CSF (inversion time frames 44 and 105, respectively); bottom row: unoptimized null frames for WM and CSF (shifted by 30 ms -- frames 50 and 111 respectively). The scalp signal is best removed in the MinIP/MIP+ images. Note the deterioration in contrast nulling for FLAWS and MP2RAGE when the frames are not selected optimally.

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