Optimization of Cube-FLAIR 3D FSE imaging at 7T

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Purpose: Refocusing flip angle modulation schemes like SPACE and Cube [1-2] enable use of longer echo-train-lengths in 3D T_2-weighted imaging. For improved lesion conspicuity, an inversion prep is used to null CSF but adds undesirable T_1 weighting at 7T due to incomplete T_1 recovery at the CSF null point, reducing SNR and contrast. The use of a magnetization preparation (MP) scheme [3] can help mitigate this effect but further increases the already high SAR at 7T. We added an MP-FLAIR module to a Cube sequence and optimized the MP-FLAIR-Cube sequence, taking into account image contrast, SAR, and SNR as well as T_1/T_2 values of WM/GM at 7T. Whole brain MP-FLAIR-Cube scans were performed on 20 patients at 7T using these modifications.

Methods: The refocusing flip angle train in Cube [2] is controlled by 3 variables - α_{min}, α_{cent} and α_{last}, which determine signal modulation (and point spread function) as well as influence image contrast, SNR and SAR. An extended phase graph (EPG) simulation was used to study the effect of these variables and to derive optimal values based on desired image characteristics. A rectangular 1-D object was modeled and the mean signal amplitude at the center of the profile was used to represent signal intensity S. Contrast between two species A and B was modeled by two different metrics: relative contrast $(S_A-S_B)/S_B$ and absolute contrast (S_A-S_B). Relative SAR was computed as $\Sigma\alpha_i^2$, where α_i is the refocusing flip angle of echo i. For SNR optimization, α parameters that maximized the signal and minimized SAR were determined. This also optimized the absolute contrast. Relative-contrast optimization was more complex and carried out sequentially: SAR constraints were first applied followed by optimization of image SNR and contrast. Radiologist preference was used to set the minimum tolerable SNR and contrast for diagnostic image quality. Images were evaluated by a neuroradiologist for lesion-WM and GM-WM contrast as well as for overall image quality. To study the effect of B_1 heterogeneity on image contrast and SNR, the effect of replacing the Cube 90º excitation as well as the 90º tipup/tipdown pulses of the MP segment with adiabatic pulses was studied. The hard refocusing pulses of the Cube echo-train were left unmodified to minimize echo-spacing and due to the fact that signal in such a train already exhibits modest immunity to B_1.

All experiments were performed on GE Discovery MR950 7T scanner (GE Healthcare, Waukesha, WI) with a 32-channel head coil. Healthy subjects as well as 20 patients with either mild cognitive impairment or Alzheimer's disease were scanned after informed consent. A 3D coronal slab covering the whole brain was acquired using MP-FLAIR Cube with the following parameters- matrix 224x224x220, FOV 18 cm, 0.8 mm slice thickness, ETL 240, TE/TR/TI 120-150ms/8s/2.1s, 2x2 2D ARC acceleration, scan time 5.5 min. The Cube 90º pulse width was 300µs and refocusing pulses were hard pulses of 500µs duration. The MP segment used hard 90º pulses (300µs width) for tip-up/tip-down and two sech refocusing pulses (16ms) with a TE_{eff} of 100ms. MP-FLAIR Cube volumes were acquired with SNR/absolute-contrast optimized, relative-contrast optimized and default (optimized for 3T) flip angle parameters.

Results: SNR and absolute contrast were maximized with minimal SAR for α_{min}, α_{cent} and α_{last} of [10º,60º,70º]. Figure 1 compares corresponding sections from a coronal whole brain MP-FLAIR Cube volume acquired using the SNR optimized parameters with the vendor-supplied default parameters. SAR was lower by a factor of 3X (4.7 vs. 1.6 W/kg) and the SNR is significantly higher using the optimized flip angles. However, lesion-WM relative contrast was worse due to the high WM signal. Figure 2 shows curves of relative-contrast as a function of α_{cent} for values of α_{min} from 10º-30º. SAR restrictions limited α_{cent} to a maximum of 90º. A lower threshold for relative contrast was set based on radiologist preference while the upper threshold was limited by image SNR as image SNR decreased with increasing relative contrast. The optimal parameters lie in the remaining unshaded region. Figure 3 compares corresponding sections from a coronal whole brain 3D MP Cube volume acquired using one of the relative-contrast optimized flip angles, with the SNR optimized flip angles. Note the significant increase in lesion contrast but a reduction in image SNR for the relative-contrast optimized case. The radiologist preferred the sequence on the left for both WM-GM contrast as well as for lesion-WM contrast. SAR was significantly lower (2.3 W/kg) than when using 3T optimized parameters (4.6 W/kg) for both sets. EPG simulations indicated that significant gains can be achieved by switching to B_1 insensitive excitation pulses in the MP segment as well as for Cube excitation.

Discussion: MP-FLAIR Cube was optimized at 7T to yield either SNR-optimal or relative-contrast-optimal images, both at significantly lower SAR compared to default values. Relative-contrast optimized images were preferred for WM-GM and lesion-WM contrast, as long as the SNR remained above a certain threshold. The use of optimal refocusing flip angles enabled us to achieve a scan time reduction of 3X compared to using a constant flip angle [3], while restricting SAR. This could be used to make 90ºpulses B_1 insensitive and improve SNR and contrast in areas like the temporal lobes and hippocampus.

References: [1] Mugler et al. Radiology 2000;216:891–899 [2] Busse et al. Magn Reson Med 2006;55:1030–1037 [3] Visser et al MRM 2010; 64:194-202.
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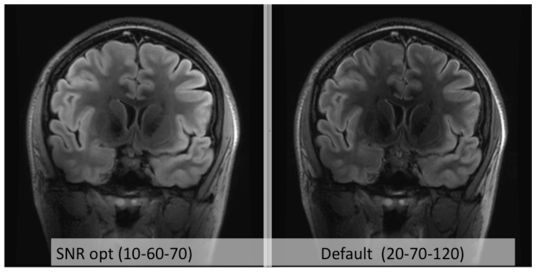

Figure 1. MP-FLAIR-Cube with SNR optimal flip angles (left) vs. 3T default flips (right) on a healthy subject. SAR was less by 3X for the left image (1.6 W/kg vs 4.7 W/kg)

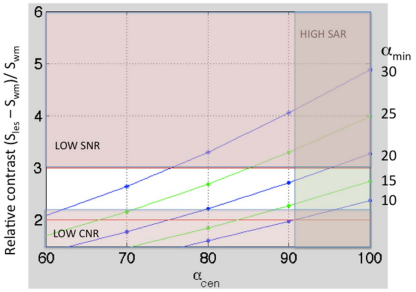

Figure 2. Relative lesion-WM contrast as a function of α_{cen} for various α_{min}. The unshaded region is optimal from SNR, CNR and SAR point of view

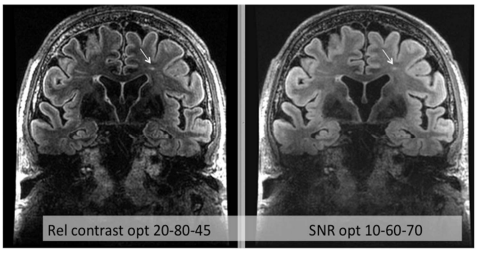

Figure 3. MP-FLAIR-Cube with relative-contrast optimal flip angles (left) vs. SNR optimal flip angles (right) on a 80-year old subject. Note the improved lesion conspicuity in the left image (arrow).