Caipirinha acceleration for intracranial 3D DCE MRI: Determination of the optimal sampling pattern

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Target audience

Perfusion sequence optimizers

Introduction

Acceleration of the image acquisition is an ever important technique in dynamic contrast-enhanced MRI – and when no gain in temporal resolution is necessary, acceleration is useful to increase spatial resolution and coverage. GRAPPA acceleration is limited by the SNR loss at higher acceleration factors and by potential reconstruction artefacts. A recently introduced method, CAIPIRINHA, promises a more robust image reconstruction by modifying the k-space sampling schema (1). At higher acceleration factors, a large number of CAIPIRINHA sampling schemes is possible. The aim of the present study is to identify the optimal sampling pattern for a 3D DCE MRI perfusion measurement with coverage of the entire neurocranium and high temporal resolution.

Methods

Phantom and patient measurements were performed on a 3T system (Magnetom Skyra, Siemens Healthcare) with a standard 20ch head coil. For all measurements, a 3D gradient echo sequence with TE/TR=0.97/2.87ms, flip angle 18°, matrix size 128x104x40 and spatial resolution 1.875x1.875x3mm^3 was used.

Phantom measurements were carried out with a spherical water phantom doped with $NiSO_4$; all filters were turned off. 50 consecutive volumes were acquired with all possible sampling patterns for acceleration factors R=1,2,3,4 (see Table 1 and Fig. 1). The patterns are encoded as R R_y R_z Δ, where R is the total acceleration factor, R_y and R_z the acceleration factors in y- and z-direction and Δ the shift of successive lines (1). Additionally, 50 volumes were acquired with the 4221–sequence using 7/8 partial Fourier imaging, distortion correction and an elliptical filter. For each sampling pattern, maps of the g-factor g=SNR_{ref}/SNR/sqrt(R) were calculated (2), where SNR_{ref} is the SNR of the acquisition with R=1. SNR was calculated as mean/standard deviation over the 50 frames.

Patient measurements In two patients, cerebral perfusion was measured with IRB approval with i) a previously (3) used sequence, using GRAPPA with R=2, 24 reference lines and view sharing acceleration (TWIST, pA=0.24, pB=0.20) and ii) an optimized 4221-CAIPIRINHA sequence with 7/8 partial Fourier imaging and an elliptical filter. Both sequences had a temporal resolution of 2.1 sec/volume and acquired 80 consecutive during and after administration of a standard dose of contrast agent (gadobutrol, 1ml/10kg bodyweight). Regions of interest were defined in the middle cerebral artery and in the thalamus. A compartment uptake model (4) was fitted to the thalamus curve to assess the influence of the sequence on the sum of squared residuals.

Results

Phantom measurements Table 1 and Figure 1 show the results from the phantom measurements. Patterns with Δ>0 generally have lower g-factors than standard-GRAPPA patterns with Δ=0. The highest g-factors for each R occur when undersampling is performed in z-direction only with Δ=0. The 4221-sequence with elliptical k-space filter and partial Fourier imaging has the lowest g-factor of all R=4 sequences, but with a higher standard deviation.

Patient measurements yielded a maximal relative signal enhancement in the thalamus of 0.44 and 0.51, respectively (see Fig. 2). After model fitting, the sum of squared residuals was 0.071 for the TWIST acquisition and 0.068 for the CAIPIRINHA acquisition.

Discussion and conclusion

For the coil and acquisition geometry investigated in this study, which is appropriate for fast cerebral DCE MRI in the brain, the 4221 sampling scheme with R=4, combined with an elliptical k-space filter and 7/8 partial Fourier imaging, was found to be optimal. For other receiver coils or body parts, other sampling patterns might be preferable. CAIPIRINHA allows for applying higher acceleration factors than standard GRAPPA acceleration, so that additional view sharing acceleration is not required. Compared to view-sharing techniques, CAIPIRINHA has the advantage that it measures in a truly time-resolved manner and does not perform any kind of temporal interpolation with the risk of temporal blurring.

We identified an optimal CAIPIRINHA sampling pattern and conclude that CAIPIRINHA acceleration appears to be a promising technique for the dynamic acquisition in cerebral DCE-MRI.

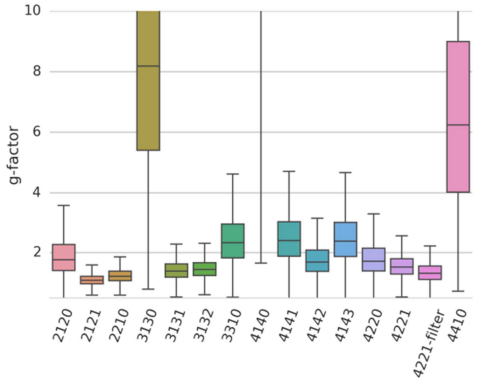

Figure 1: g-factor distributions of the CAIPIRINHA sampling patterns in the phantom measurements. Sampling patterns are encoded as RR$_y$R$_z$Δ

Table 1: Investigated sampling patterns, along with mean values and standard deviations of the g-factor

R	Ry	Rz	Δ	mean(g)	sd(g)	Sampling
2	2	1	0	1.93	0.71	GRAPPA
	1	2	0	1.10	0.19	CAIPIRINHA
			1	1.24	0.25	CAIPIRINHA
3	1	3	0	8.57	4.15	GRAPPA
			1	1.42	0.33	CAIPIRINHA
			2	1.48	0.34	CAIPIRINHA
	3	1	0	2.45	0.84	GRAPPA
4	1	4	0	25.77	15.34	GRAPPA
			1	2.50	0.85	CAIPIRINHA
			2	1.80	0.62	CAIPIRINHA
			3	2.51	0.87	CAIPIRINHA
	2	2	0	1.85	0.69	GRAPPA
			1	1.56	0.38	CAIPIRINHA
	4	1	0	6.88	3.62	GRAPPA
4	2	2	1	1.39	3.12	CAIPI+ filter

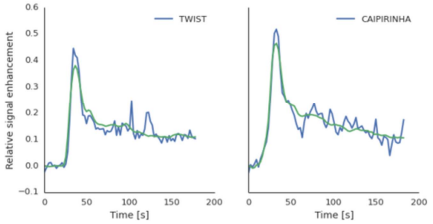

Figure 2: Relative signal enhancement in the thalamus (blue) along with model fits (green); measured with TWIST (left) and CAIPIRINHA (right)

References

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