# Reduced SAR with Combined Acquisition Technique (CAT) Hybrid Imaging Sequence at 7 Tesla


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**Introduction:**

Fast Spin Echo MRI at high field strengths is challenging due to the increased SAR, which is especially pronounced with single shot TSE sequences such as RARE [1]. Hyperecho-RARE [2] imaging and GRASE [3] have been used to reduce SAR at high field strengths. In this work, the applicability of CAT [4] (Combined Acquisition Technique) is investigated at 7T. In the original CAT implementation a FLASH sequence is used to cover the center part of k-space, and an EPI read-out is applied for the k-space periphery. This FLASH-EPI-hybrid was developed to reduce the total measurement time compared to a conventional FLASH MRI. In our implementation the CAT strategy is used to reduce the total SAR at 7T by combining a TSE with an EPI sequence [5].

The advantage of the sequence is the flexibility of sampling the k-space. On one hand the CAT sequence can be used at low fields (up to 3T) with an extended TSE module, whereas at 7T a smaller TSE module would be applied to minimize SAR. This technique is possible because the energy distribution of the k-space. The main part of k-space energy is cumulated in the center whereas after a few k-space lines outside of the center the energy decline very fast. This effect is more pronounced at high matrix sizes and is thus advantageous for high field applications.

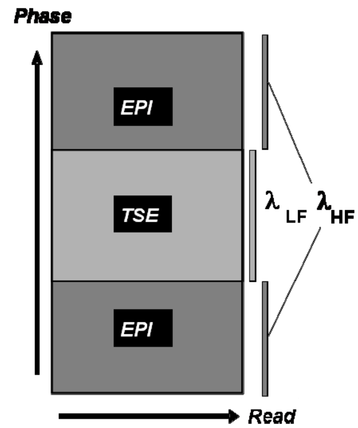


**Fig. 1:** The k-space simplify scheme of TSE-CAT. The TSE module samples the center part and the EPI module the outer part of the k-space with $\lambda_{HF} = 1 - \lambda_{LF}$.

**Materials & Methods:**

The CAT sequence uses a conventional TSE echo train, during which a given number of spin echoes (defined by the so called λ-factor) and gradient echoes (EPI echoes) are acquired. Figure 1 shows a schematic of the sampling scheme of the CAT TSE-EPI-hybrid. The center part of k-space is sampled using a TSE module and the outer part of the k-space is covered by an EPI module. $\lambda_{LF}$ and $\lambda_{HF}$ identify the extend of the TSE portion and the EPI portion ($\lambda_{HF} = 1 - \lambda_{LF}$) in k-space. The Bandwidth can be chosen independently for each module respectively.

Figure 2 shows the pulse program for a single TR of the TSE-CAT sequence. The first three echoes are acquired with a standard TSE read-out after an initial 90° excitation pulse and a series of four 180° refocusing pulses. After the last refocusing pulse the remaining magnetization is used to acquire 3 additional gradient echoes using an EPI readout. Thus, the turbo factor in this example is 6 with $\lambda_{LF} = 0.5$. The SAR reduction compared to a full TSE sequence is about 30% in this example.

In vivo head TSE CAT experiments were performed at a 7T whole body scanner (Siemens, Erlangen, Germany) with various $\lambda_{LF}$ (0.6, 1.0), a turbo factor of 13 and a bandwidth of 130 Hz/px for the TSE module and 930 Hz/px for the EPI module. At $\lambda_{LF} = 0.6$ eight spin echoes and five EPI-echoes are acquired after each excitation and at $\lambda_{LF} = 1.0$ a regular TSE with 13 spin echoes are acquired. The SAR reduction achieved with a $\lambda_{LF}$=0.6 was 27% compared to standard TSE. For all in vivo measurements the echo time TE was 12ms, the matrix size 180×256 with a resolution of 0.9×0.9×5.0 mm.

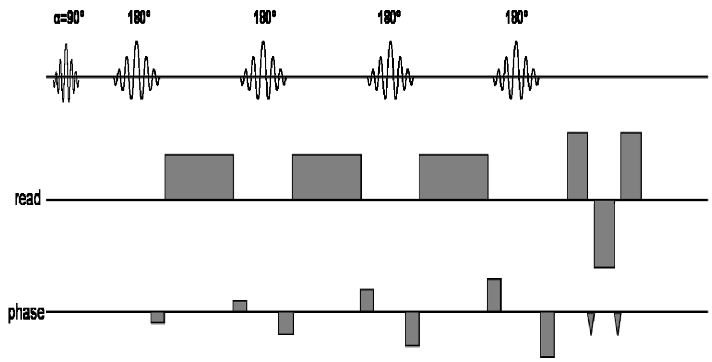


**Fig. 2:** Sequence pulse program for one TR shows a TSE-CAT sequence with a turbo factor of six and a $\lambda_{LF} = 0.5$. The first tree echoes are acquired with the TSE module and the last three echoes with an EPI in which we use phase encoding blips. The SAR reduction is about 30% compared to a regular TSE or RARE sequence.

**Results:**

Figure 3 shows in vivo results of a human head at 7T using the TSE CAT sequence with a turbo factor of 13 and $\lambda_{LF}$=1.0 (TSE only) a), $\lambda_{LF}$=0.6 (8 TSE echoes and 5 EPI echoes) b) within one TR. All images were acquired with TE = 12ms. In this example the conventional TSE image is indistinguishable from the CAT image.

**Discussion:**

In this work we have demonstrated that CAT can be used at 7T to reduce SAR. The high resolution in vivo head images acquired with TSE-CAT with $\lambda_{LF}$=0.6 provide almost similar image quality compared to a standard full TSE acquisition.

In future applications the use of parallel imaging, an improvement of image quality for small $\lambda_{LF}$ (up to $\lambda_{LF}$ = 0.1-0.3) and also a further reduction of SAR is expected. The images obtained clearly show high SNR and high resolution at a significantly reduced SAR deposition by TSE-CAT could be reduced by a factor of around three in comparison to a normal TSE sequence with similar parameters. Thus, CAT imaging at 7T is expected to be a perfect candidate to overcome SAR related problems at high field strength without changing image contrast and at the same time maintaining overall image quality such as SNR and resolution.

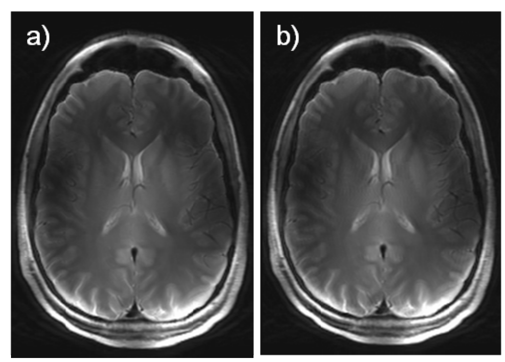


**Fig. 3:** In Vivo measurements with a TSE-CAT sequence of a human head at 7T. Within one TR we acquire 13 Echoes with a bandwidth of 130 Hz/Px for the TSE part and 930 Hz/Px for the EPI part. The image matrix was 256×182 and the echotime TE=12ms. In a) a regular TSE with 13 echoes is acquired. b) shows a TSE-EPI hybrid with a $\lambda_{LF}$=0.6.

**References:**


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