Advanced Calibration for Echo Planar 2D selective RF Pulses

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Introduction

Current applications of Echo Planar RF Pulses (EPP) include brain diffusion imaging [1], coronary angiography [2-4] and real-time flow measurement [5, 6]. In all these techniques RF excitation is restricted to a region of interest and a Reduced Field Of View (RFOV) is acquired. The advantages are manifold: Especially when used in conjunction with EPI, echo time is significantly reduced and data acquisition is speeded up. Motion tracking is no longer hampered by different motion patterns inside the FOV, but can be optimized for a homogeneously moving region of interest. Nevertheless, the time gain on the acquisition side gets partly absorbed by the extended pulse duration. Moreover, long RF pulses may exhibit profile distortions, which are caused by in-pulse T_2* effects and by in-pulse motion. The frequently used fly-back EPP, in which RF power is emitted only during positive (or only during negative) gradient lobes, is particularly prone to these effects. The forward-backward EPP (Figure 1A) is twice as time-efficient and, therefore, more robust face to in-pulse effects. It is however subject to N/2 ghosting in the presence of eddy currents which alter gradient fields and B_0. Correction of these system imperfections is reported to be particularly difficult in oblique image planes due to gradient anisotropy [4, 5].

In this context we propose a novel calibration method, which is capable to suppress N/2-ghosting in EPP with angulated and non-angulated image planes.

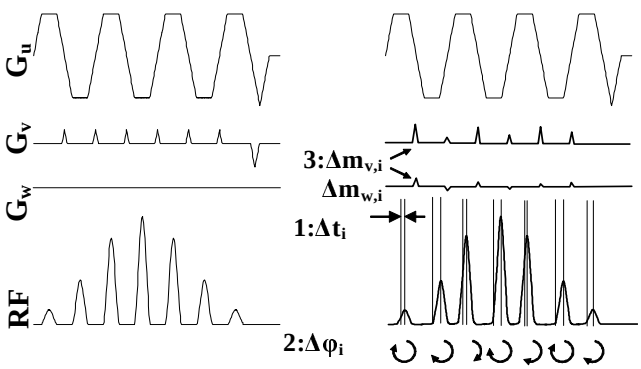


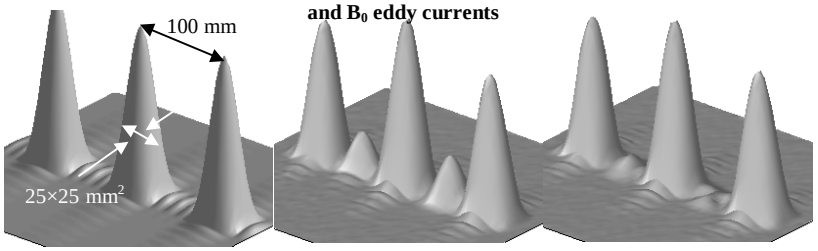
Figure 1 A **B**

Methods

The original EPP (Figure 1A) is modified in three steps to obtain the calibrated EPP sequence (Figure 1B). Step 1: Delays of the continuous selection gradients G_u are compensated by shifting sub-pulse i by Δt_i. Step 2: Each sub-pulse is given a phase offset $\Delta\varphi_i$ to correct for phase errors due to B_0 eddy currents. Step 3: gradient anisotropy is corrected by changing the 0-order moment of the gradient blips G_v by $\Delta m_{v,i}$ in the discrete selection direction and by adding correction blips G_w with $\Delta m_{w,i}$ in the direction with no selectivity. In order to determine Δt_i, $\Delta\varphi_i$, $\Delta m_{v,i}$ and $\Delta m_{w,i}$, the spatial phase modulation is measured in the transverse magnetization generated by each sub-pulse separately. To this end, the EPP is played out 3 times with the first sub-pulse active and all the others scaled to zero amplitude: 3 gradient echoes are acquired with the measurement gradient pointing into the directions of G_u, G_v and G_w in turn. This procedure is repeated for each sub-pulse. The resulting signals are transformed into Fourier domain and their phase is computed. The phase difference between sub-pulses is approximated by linear regression. The values for Δt_i, $\Delta m_{v,j}$ and $\Delta m_{w,i}$ are computed from the slope using the Fourier shift theorem, $\Delta\varphi_i$ is given by the offset. All experiments were performed on a Philips Intera 1.5T scanner with a maximum gradient strength of 30mT/m and a slew rate of 150mT/m/ms. Gradient and RF functions of the EPP are plotted in Figure 1. The nominal dimensions and the excited volume are labelled in Figure 2A. The spatial phase measurement in the preparation experiment was performed with a 1D spatial resolution of 1.5 mm. and with T_E varying between 2.9 and 6.2ms between the first and the last sub-pulse. The calibration method was validated in-vitro and in-vivo by examination of transverse magnetization maps (Figure 2 and Figure 3). These were generated with a gradient echo imaging sequence, in which the EPP was used as excitation pulse and the measurement gradient was pointing into the direction of G_u.

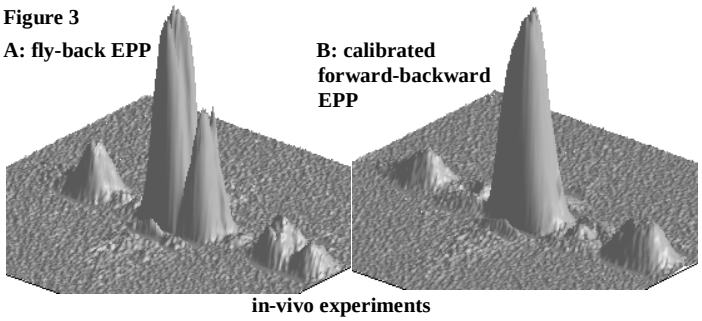
Results

Figure 2 illustrates the transverse magnetization profiles generated by an EPP. The profile in A is obtained by simulation of the ideal pulse sequence and represents the nominal profile. B shows an in-vitro profile after correcting timing and phase for each sub-pulse (calibration steps 1 and 2). C shows the situation after additional correction for anisotropic gradient delay (step 3). Figure 3 illustrates the excitation profiles of a fly-back pulse (A) and of a calibrated forward-backward pulse (B) in the femoral artery of a volunteer. Under these conditions of fast and pulsatile flow, the fly-back pulse with a duration of 8ms is subject to severe profile aberrations. The profile of the corresponding calibrated forward-backward pulse (with a duration of only of 4.4 ms) remains largely unaffected. In both profile plots the Nyquist ghosts are attenuated since they lie at the periphery of the surface coil sensitivity area.



Discussion

The proposed method for EPP pulse calibration suppresses N/2 ghosting caused by gradient delay, gradient anisotropy and B_0 eddy currents in angulated and in non-angulated planes in-vitro and in-vivo. Therefore, it makes forward-backward EPP available for practical use. The resulting savings in pulse duration make EPP more attractive for many applications: Motion sensitive applications will benefit from a shorter T_E and from the improvement of the excitation profile. The reduction of T_R may be significant and lead to a reduction of scan time in many sequences. If neither motion sensitivity nor scan time needs to be reduced the time savings can be traded for a more sophisticated excitation profile with more sub-pulses. The residual N/2 ghosting may be due to the difference in the concomitant fields during positive and negative gradient slopes. The preparation experiments take only a few seconds, and the procedure to determine the calibration parameters is not inherently interactive. Therefore, the method could be implemented as automatic pre-scan and become available for clinical applications.



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