Comparing 1.5T vs. 7T phase contrast MRI for measuring brain tissue pulsation

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Background: The pulsating vasculature in the brain induces pulsatile volumetric strain. These volumetric strain pulsations are small, but of considerable interest as they are related to the inherent material pressure of the brain via the compression modulus, and because they drive metabolite and protein transport in the interstitial space. Recently, feasibility of measuring the pulsatile volume strain with phase contrast (PC) MRI was shown on 1.5T, using a single shot spin-echo echo planar imaging (SE-EPI) acquisition [1]. However, these results showed low signal to noise ratio (SNR) due to long echo times (TE) (116 ms), caused by extremely low encoding velocities (V_{enc} < 1 cm/s) in combination with single shot readouts. Due to the long TE needed to achieve a low V_{enc}, it is unclear whether the intrinsic SNR gain at higher field strength (7T) balances the increase in signal loss due to the shorter T_2* at high field.

Purpose: The aim of this work is to find the optimal TE for PC-MRI with extremely low encoding velocities and to determine both theoretically and experimentally the potential gain in SNR at 7T compared to 1.5T.

Theory: We numerically predicted the SNR in the phase contrast images using $SNR_{\Delta\varphi} \propto \frac{|v|}{Venc} \cdot SNR_{mag} = \sin\theta \frac{(1-E_1)}{(1-E_1\cos\theta)} e^{-\frac{TE}{T_2^*}} \cdot \frac{|v|}{Venc}$, with $E_1 = e^{-TR/T_1}$ and θ the Ernst angle. T_1/T_2^* was taken as 650/66 ms for 1.5T and 1200/27 ms for 7T respectively, approximating white matter [2,3]. The maximum SNR occurs when the V_{enc} is in the order of 10^{-3} cm/s, which is much smaller than the maximum velocity of the brain tissue over the cardiac cycle (~0.2 cm/s [4]). For optimal sensitivity, V_{enc} is to be chosen slightly larger than the maximum expected velocity. Choosing a V_{enc} of 0.3 cm/s and the gradient performance as shown in Table 1, the minimum TR/TE was approximately 37/23 ms, resulting in an expected gain in SNR of ~200 % between 1.5T and 7T. (The gradient performance was less than maximum to allow shorter TR, given the duty cycle limits of the hardware.)

Methods: Six healthy volunteers (age 27 ± 12 years (mean±SD), 3 males) underwent PC-MRI on a 1.5T and a 7T scanner (Philips Healthcare). An 8 channel T/R head coil (Philips, 1.5T) and a volume transmit coil with 32 channel receive coil (Nova Medical, 7T) were used. A single transversal slice was selected approximately 20 mm above the ventricles. Flow data was acquired using a PC turbo field echo (TFE) and a PC multi-shot gradient echo EPI sequence, with a V_{enc} of 0.3 cm/s (in feet-head direction). Sequence parameters are given in Table 1, the flip angle was chosen slightly above the Ernst angle to mitigate B1 inhomogeneity at 7T. Retrospective cardiac gating was achieved using a pulse oximeter on the index or middle finger. Possible phase errors induced by eddy currents were quantified by imaging of a 2.5 l agar phantom (50g agar, 6g NaCl) using identical acquisition parameters. The time integral per voxel was set to 0 cm/s to remove static background phase errors. Noise measurements were obtained by an acquisition without RF and gradient readout to sample the noise. The root-mean-square of the standard deviations of the real and imaginary parts of the noise image was used to compute the SNR of the modulus image of the PC acquisition, SNR_{mag}. SNR_{mag} was determined over the entire brain and over only the inner region of the brain to approximately assess the influence of the receive coils on the results.

Results: The increase in SNR was significant (P<0.001) for all comparisons between 1.5T and 7T acquisitions as shown in Table 2. EPI on 7T has the highest SNR efficiency (SNR per square root acquisition time), with compensation for the readout bandwidth. The SNR efficiency increases on average by a factor 5.2±0.3 when switching to 7T. Velocity profiles on the phantom in time showed a root mean squared error of $(5.1\pm0.2)\cdot 10^{-4}$ cm/s, implying that time varying phase errors induced by eddy currents were negligible on both the 1.5T and 7T system (not shown).

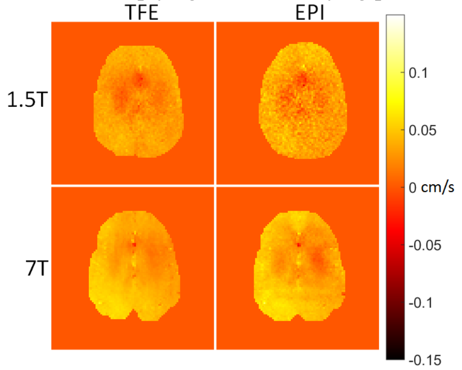

Table 1. Acquisition parameters used in the experiments. Scan time is based on an average heart rate of 60 beats per minute.

	1.5T		7T	
Sequence	TFE	GE-EPI	TFE	GE-EPI
EPI factor	-	5	-	5
Voxel size	2x2x2 mm³	2x2x2 mm³	2x2x2 mm³	2x2x2 mm³
TR/TE	39/23 ms	39/24 ms	37/23 ms	37/23 ms
Bandwidth	383 Hz/pix	2645 Hz/pix	383 Hz/pix	1760 Hz/pix
Flip angle	24°	24°	18°	18°
Averages	2	2	2	2
Gradient strength	20 mT/m	20 mT/m	21 mT/m	21 mT/m
Slew rate	60 T/m/s	60 T/m/s	200 T/m/s	200 T/m/s
Scan time	211 s	44 s	178 s	37 s

***Figure 1.** Example velocity (FH direction) maps of the different acquisitions at peak systole. Maps acquired using EPI on 1.5T show the lowest SNR while TFE acquisitions on 7T show the highest SNR.*

***Table 2.** Comparison for the SNR of the different acquisitions. Note that the SNR strongly decreases when only the center of the brain is taken into account on 7T. *SNReff gain was computed as the gain in SNR efficiency: $SNR^*[\sqrt{(BW)}/\sqrt{(\text{Scan time})}]|_{7T}$ / $SNR^*[\sqrt{(BW)}/\sqrt{(\text{Scan time})}]|_{1.5T}$*

		TFE			GE-EPI		
		1.5T	**7T**	**SNR_{eff} Gain***	**1.5T**	**7T**	**SNR_{eff} Gain***
SNR	Full brain	31.9±2.1	153.7±14.5	5.2±0.5	14.8±0.9	73.0±5.8	5.2±0.3
	Mid-brain	26.2±1.7	120.0±7.1	4.9±0.3	13.2±1.0	57.5±2.8	4.7±0.2

Discussion: We have shown that SNR is higher at 7T compared to 1.5T, despite the decreased T_2* of brain tissue. Both TFE and EPI have proven to be suitable methods for PC-MRI, with GE-EPI being the most time efficient. It is expected that the increase in SNR was larger than predicted due to the difference in head coils used. The influence of the number of channels on the SNR in the center of the brain should be relatively small, so the discrepancy between predicted and measured SNR is probably due to a closer fit of the 7T receive coil to the head.

Conclusion: This research has shown the feasibility of 2D PC MRI at 7T with sufficient SNR, despite the relatively long TEs needed and the shorter T2* at high field. This suggests that whole brain coverage using 3D PC MRI is possible. Future work will focus on 4D PC MRI with whole brain coverage at 7T in order to calculate complete 3D velocity divergence (volumetric strain rate) maps with high resolution.

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