A Comparative Study of Oxygen-Sensitive Contrast Between Femoral Artery and Vein in Spin-Echo and Balanced Steady-State Free Precession Imaging

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Introduction Blood is a magnetically inhomogeneous medium with the magnetic susceptibility of red blood cells strongly dependent on the oxygen saturation of the blood (%O_2) [1,2]. Previously, this idea has been exploited to quantify oxygen state *in vivo* with spin-echo sequences [1,2]. However, the scan times associated with these techniques are on the order of tens of seconds to minutes, which limit the diagnostic usefulness of this technique for some cardiac applications. Over the past decade, steady-state free precession (SSFP) imaging has gained recognition for its ability to provide fast scans with high signal-to-noise ratio [3]. Recently, we reported that the dominant source of contrast observed between arteries and veins in SSFP-based images [4] could be attributed to the motion of spins through local field inhomogeneities in and around deoxygenated red blood cells [5]. In this work, we extend the analysis to an *in vivo* situation and consider the contrast between arteries and veins with spin-echo and SSFP sequences. The rationale for this work is (1) to show that the optimized parameter set for balanced-SSFP sequences determined from *in vitro* work is capable of providing robust oxygen-based contrast between arteries and veins and (2) to directly compare the magnitude of the SSFP contrast with the classic spin-echo based sequences such as CPMG.

Methods Both spin-echo and SSFP based measurements were performed on a 1.5T GE Signa CV/i system. The spin-echo and SSFP signals were collected from the femoral artery and vein in the thigh of 2 healthy human volunteers using a receive-only flex coil (GPFlex). On each volunteer the measurements were performed 5 times. The arterial and venous blood T2 values were obtained at three different refocusing intervals (τ_{180} = 6 ms, 12 ms, and 24 ms) with a T2-weighted magnetization-prepared spiral sequence with the following parameters: 10 mm thick axial slices, 2 s TR, 4096 points in the spiral trajectory with 6 interleaves, 24 cm FOV (1.48 mm resolution), 2 averages, and 4 TEs ranging from 12-200 ms [6]. The T2 of arterial and venous blood were computed by fitting the measured signals at the different TEs to a mono-exponential curve. The SSFP signals were collected from the same vessels with a 2D balanced-SSFP sequence (10 mm thick oblique slices, 256 x 256 matrix, 24 cm FOV) at TR = 6, 8, 10, 12 ms with flip angle = 60°, TE = TR/2, and number of phase-cycled RF-pulses to reach steady-state = 1000. To minimize flow effects, the SSFP signals were measured from the oblique slices with vessels in-plane. The contrast between arteries and veins with both sequences was computed as follows: for T2-based measurements, contrast = $|T_2^{Artery} - T_2^{Vein}| / T_2^{Vein}$ and for SSFP-based measurements, contrast = $|Signal^{Artery} - Signal^{Vein}| / Signal^{Vein}$. These values were calculated for each τ_{180}, TR, and volunteer. The results were averaged, and mean and standard deviations were computed for each τ_{180} and TR. Then using population data for T2-%O_2 calibration [7], and the measured mean T2 values, mean and standard deviation of %O_2 in the femoral vein was computed for each τ_{180}. In addition, the expected contrast behaviour in the SSFP method was simulated as in [5] assuming the %O_2 of the femoral artery = 97 and varying the %O_2 of femoral vein from 77 to 47 in intervals of 10.

Results The spin-echo and SSFP based contrast between arteries and veins are shown in Fig.1A and Fig.2A, respectively. The solid lines in Fig.2A show the theoretically expected contrast for a given change in %O_2 between the arteries and veins. Fig. 1B and Fig. 2B show the typical contrast we observed between the arteries and veins with spin-echo and SSFP-based measurements. The T2-based %O_2 values for veins are shown in Table 1.

Table 1 T2-based values of %O_2

τ_{180} (ms)	%O_2 ± std in Vein
6	71 ± 5
12	69 ± 2
24	68 ± 3

Fig. 1A

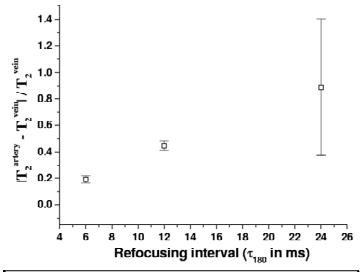

Fig. 1B

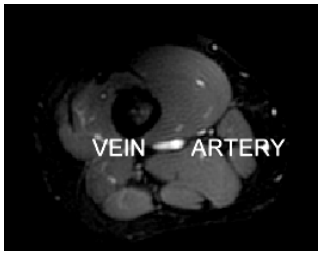

Fig. 2A

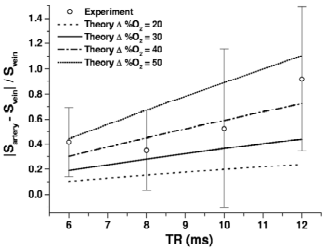

Fig. 2B

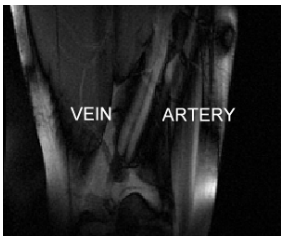

Fig. 1A T2-based contrast between the femoral artery and vein as a function of τ_{180}. **Fig. 1B** shows typical T2-based contrast in the veins and arteries (TE = 58ms).

Fig. 2A Experimentally observed and theoretically expected SSFP-based contrast between the femoral artery and vein as a function TR.
Fig. 2B shows typical SSFP-based contrast in the veins and arteries

Discussion The results show reasonable %O_2 levels in the vein, and the expected contrast enhancements based on differences in oxygen saturation levels in the arteries and veins with spin-echo sequences. With the optimized parameter set proposed [5], oxygen-based contrast is observable *in vivo* with SSFP methods, as well. Variability in SSFP contrast is large. This may be related to partial volume effects and/or flow artefacts that do not allow the spins to reach steady-state and/or mixing of spins with different phase histories within an imaging voxel. However, the student t-test statistic shows that mean contrast changes observed in T_2-based and SSFP-based measurements with refocusing interval or TR, respectively are significant. Comparison of the %O_2 values in the femoral vein estimated with T_2-based oximetry to the expected oxygen-sensitive SSFP contrast related to change in %O_2 show reasonable agreement within measurement errors seen. Scheffler et al. [8] have shown SSFP sequences can behave as spin-echoes when TE = TR/2. We see contrast behaviour from SSFP similar to that seen in spin-echoes; that is, increasing TR in SSFP yields similar effects to increasing τ_{180} in spin-echo studies. Hence, this study demonstrates that oxygen-based contrast between arteries and veins may be established with SSFP. We envision that with catalyzed or magnetization prepared starter sequences [9], it may be possible to reach steady-state quicker and thus reduce flow effects which otherwise may disrupt oxygen based contrast in SSFP imaging.

References

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