Verification of the Susceptibility value of de-oxy-hemoglobin in the blood using Susceptibility Weighted Imaging (SWI)

M. E. Haacke, Ph.D. [1,2], K. Prabhakaran[1], I. Elangovan[1], J. Hu, Ph.D. [2], Y. Xuan[2], P. Morton[2]

[1]MRI Institute for Biomedical Research, Detroit, MI, United States, [2]Wayne State University, MR Research Facility, Detroit, MI, United States

Introduction: The widely used value for the magnetic susceptibility difference between fully deoxygenated and fully oxygenated red blood cells in the MR literature is 0.18 ppm as measured by Weiskoff and Kiihne (1). However, Spees et al (2) measured this value to be 0.27 ppm at 37$_0$C, which they validated with an independent MR and superconducting quantum interference device (SQUID) measurement. Our goal is to prove as plausible either of the above reported values for magnetic susceptibility difference using a high resolution 3D gradient echo phase map of the blood vessels in the leg. The phase ϕ in radians is given by:

$$\phi = -\gamma \triangle B\,(TE), \qquad \text{..... (1)}$$

where γ is the gyromagnetic ratio of protons, ΔB is the field difference between blood and the surrounding tissue, and TE is the echo time. Vessels that are at an arbitrary angle θ to the main field develop an intravascular field proportional to $3\cos^2\theta - 1$. The phase inside the vessel is given by:

$$\phi = -\gamma \chi_{do} B_0\, Hct\, (1-Y)\, (3\cos^2\theta - 1)\, (TE) / 6 \qquad \text{.....(2)}$$

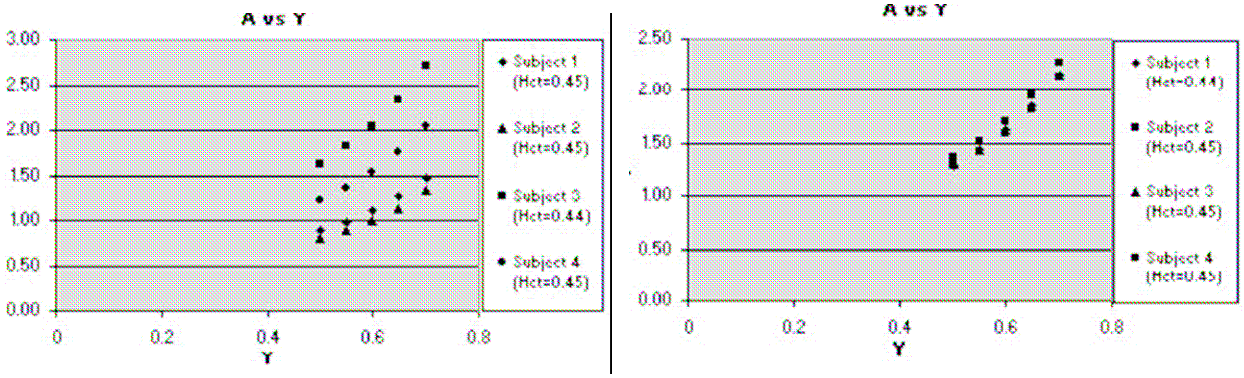
where χ_{do} = 4π x 0.18 ppm/unit of Hct. Through the above equation, a relationship between phase and the magnetic susceptibility difference value is obtained. Hence this method can be quoted as a "phase method" for estimating the magnetic susceptibility difference χ_{do}

Methods: All data were acquired using a Siemens 1.5 T Sonata Scanner with a flexible coil, in the leg, in the thigh region above the knee. Healthy volunteers were recruited for the study with proper procedure and written consents obtained. Shimming was performed before imaging to optimize the static field homogeneity. Transverse images were acquired typically using a flow compensated, strongly T2* weighted, low bandwidth (78.125 Hz per pixel) sequence. The sequence was designed with a symmetric echo. Up to 40 partitions were acquired with a typical voxel volume of 0.5mm x 0.5mm x 2.0mm. The minimum TE was chosen to be as 20.5 msec, TR as 70 msec and the flip angle as 20$_0$ or 30$_0$. The total imaging time varied from 7-8 minutes. The same sequence was run six times continuously, each time with an increase in TE of 2.4 msec, keeping all other parameters the same. Also, 2D TOF vein only gradient-echo images with arterial blood saturation were obtained to identify veins and also to facilitate the measurement of the angle they made to the main magnetic field direction. Images were obtained using a flip angle of 20$_0$, an in-plane resolution of 0.8mm x 0.8mm and a slice thickness of 2mm. Since χ_{do} is uncertain, we replace it by Aχ_{do} and putting all other constants in the expression for phase into the term k = 2π x 42.58 x 4π x 0.18 x 1.5 x (TE) / 6 we get,

$$\phi / (3\cos^2\theta - 1) = A * k * Hct * (1-Y) \qquad \text{..... (3)}$$

Hematocrit (Hct) and venous oxygen saturation (Y) values were measured using an OXICOM 2100 oximeter and IL Synthesis blood gas analyzer. A was determined from Eq.(3) by inputting the phase, the angle θ, k, Hct and Y. A value of A =1 indicates that the value Weisskoff calculated is correct while a value of A = 1.5 would vindicate the work by Spees et al. The femoral vein and numerous small veins in the upper leg were analyzed.

Results: The measurements for Y were very inconsistent. In a number of cases, we repeated the blood draws and found very good reproducibility for the Hct but widely ranging values for Y using the IL Synthesis blood gas analyzer. This rather disconcerting fact led us to try the same experiment on the OXICOM 2100. The results were equally variable. This raises the question as to just how accurately Y can be measured and how consistent results are by extracting blood from the arm either from physiological changes or difficulties in measuring such low oxygen saturation values. We plot the results for A for a range of Y values. As seen in Figure 1, when Y is varied from 0.5 to 0.7, the **A** value is consistent with unity if Y is at the lower end of the scale and is consistent with 1.5 if Y is closer to 0.7. The story is a bit different in Figure 2 where even the lower values for Y tend to lie between 1.25 and 1.5 while from Y = 0.55 upward the value of A = 1.5 would be most consistent with the data.



Discussion: The estimation of Y was done with two different instruments (OXICOM 2100, IL Synthesis) both yielding a range of values for the venous oxygen saturation, a problem widely encountered by other groups as well (3). Hence, based on the fact that it is widely believed that the venous oxygen saturation is close to 0.7, it would not be unreasonable to conclude that χ_{do} is 0.27 ppm although the results are still somewhat equivocal here. This result is critically important for predicting the forward problem, that is measuring Y from the phase of blood vessels once A is known with certainty.

References:

1. R.M.Weisskoff, S.Kiihne, *Magnetic Resonance in Medicine* 24, 375 – 383 (1992).

2. W.M.Spees et al, *Magnetic Resonance in Medicine* 45:533-542 (2001).

3. T.Lee, et al, Blood Relaxation Properties at 3T - Effects of Blood Oxygen Saturation, ISMRM, Toronto, 2003.