The Viscoelastic Properties of the Venous Compartment are Dependent on Baseline CBF

Y. Behzadi[1], T. T. Liu[2]

[1]Bioengineering, UCSD, La Jolla, CA, United States, [2]Center for Functional Magnetic Resonance Imaging, UCSD, San Diego, CA, United States

Introduction

Recent studies have shown that the temporal dynamics of the cerebral blood flow (CBF) and the blood oxygenation level dependent (BOLD) responses to stimulus are modulated by changes in baseline CBF induced by various vasoactive agents [1,2]. A recently proposed nonlinear dynamic CBF-Balloon model has been shown to predict to first order the observed changes in the temporal dynamics of the CBF and BOLD responses as a function of baseline CBF [3,4]. However, the model is unable to simultaneously fit the post-stimulus undershoot of the BOLD response under all baseline conditions. This study aims to elucidate the dependence of the venous viscoelastic terms on the baseline CBF.

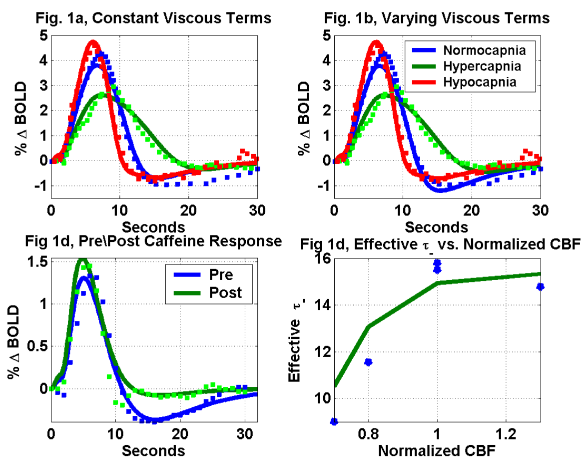
Background

Experimental studies have found that during dynamic changes the blood volume changes occur more slowly than the flow changes. This transient behavior is described by the Balloon model with viscoelastic effects, in which the venous compartment is treated as distensible balloon [5]. The flow into the balloon is determined by the compliance model[3], while the flow out of the balloon is modeled as: $f_{out}(v) = v^{1/\alpha} + \tau_v \dot{v}$, where v denotes the venous volume normalized by its initial value, τ_v is the viscoelastic time constant (equal to τ_+ and τ_- during inflation and deflation, respectively), and α is an empirical constant that determines the steady state power law relation between flow and volume [5].

Methods

In order to find the effective viscoelasticity as a function of baseline CBF, the compliance model was coupled with the Balloon model and used to fit previously published hypercapnic, hypocapnic, and normocapnic BOLD data. Additionally, data from a study investigating the effect of caffeine, a vasoconstrictor, on BOLD dynamics was fit [2]. The baseline CBF was estimated to be 1.3, 0.8, and 0.7 with respect to the resting normocapnic CBF for the hypercapnic, hypocapnic, and caffeinated conditions, respectively. Model parameters were first adjusted to reflect changes in resting CBF as described in [3] and then a descent based fitting algorithm was used to estimate the remaining parameters. With the exception of the viscoelastic time constants, Balloon model parameters were held constant between the different baseline states

Results



Figures 1a and 1b show the compliance model fit (solid line) and the normocapnia, hypercapnia, and hypocapnia data (dotted line) from [7]. The fit presented in figure 1a was made with constant viscoelastic terms across conditions whereas the fit in figure 1b was obtained under the assumption of varying viscoelastic constants. The viscoelastic parameters estimated in producing figure 1a were 0.17 and 11.35s for τ_+ and τ_-, respectively. The model simulations in figure 1b fit the post stimulus undershoot better than those presented in figure 1a. The viscoelastic terms for inflation under the normocapnic, hypocapnic, and hypercapnic condition were similar and found to be 0.55, 0.05, and 0.33s, respectively. However, the estimated values for τ_- were determined to be 15.79, 14.76, and 11.55s for normocapnia, hypercapnia, and hypocapnia, respectively. Figure 1c shows the fit of the pre/post dose caffeine data fit with varying viscoelastic terms. τ_+ was found to be .24s and .32s, and τ_- was estimated to 15.5s and 9.2s for the pre and post dose responses, respectively. Figure 1d shows the relationship between the estimated viscoelastic terms for deflation versus the normalized CBF values. A solid line shows the general trend of the data.

Discussion

The viscoelastic time constant for deflation appears to decrease with CBF. A smaller viscoelastic time constant at low baseline CBF suggests a relatively greater elastic response. This may reflect the non-linear nature of the veins in which they are fairly compliant and stiffen exponentially as CBF and radius increase [6]. Incorporation of the CBF/radius dependent viscoelastic term into the Balloon model may therefore improve its predictive ability.

References:

[1] TA Mulderink et al., NeuroImage 15:37-44 (2002) [2] TT Liu et al., HBM 2004 pg. TU148 [3] Y Behzadi et al. Proceedings of ISMRM, pg. 279, 2004 [4] Friston, K.J. et al, NeuroImage 12, 466-477, 2000. [5] RB Buxton et al. Proceedings of ISMRM, pg. 1401, 1998. [6] Fung, Y.C., Biomechanics-Circulation, 490-495,1996. [7] ER Cohen et al. J.Cerebral Blood Flow Metab 22(9), 1042-53, 2002