Venous Vessel Size MRI in the Human Brain Using Transient Hyperoxia

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Introduction

Vessel size imaging (VSI) can be used to probe the microvascular architecture at a scale that is far beyond the spatial resolution limit of MRI [1]. This information is highly relevant for the diagnosis of pathological microvascular changes [2-3]. VSI utilises susceptibility-induced changes in R_2^* and R_2 that depend on the vessel radius. These can be generated by the administration of a contrast agent [3-5], or by BOLD signal changes induced by hypercapnia [6] or an fMRI stimulation task [7]. This study investigates the feasibility of using hyperoxia induced BOLD signal changes in VSI. The benefit of using hyperoxia is that pure O_2 is routinely available in a clinical environment. Furthermore, it is better tolerated than low doses of CO_2, which makes this technique particularly suitable for applications in critically ill patients.

Materials and Methods

Six healthy volunteers (ages: 21 - 37; 3 male) were scanned following informed consent. A specially designed unidirectional breathing circuit (Intersurgical Ltd, Wokingham, UK) was used to deliver either room air or 100% O_2. The experimental paradigm consisted of two 3-minute blocks of breathing 100% O_2 interleaved with three 2-minute blocks of breathing room air. Physiological parameters (heart rate, arterial oxygen saturation, end-tidal O_2 and CO_2) were continuously monitored. On a Philips Achieva 3T MR system (Philips Medical Systems, Best, The Netherlands) a single-shot dual echo EPI sequence was used for simultaneous acquisition of GE and SE EPI images. Imaging parameters were: TR = 3.5 s, TE_{GE}/TE_{SE} = 30/90 ms, flip angle = 90°, FOV = 200x200 mm^2, matrix = 68x67, number of slices = 28, slice thickness = 3 mm, slice gap = 1 mm. A total of 206 dual-echo volumes were acquired over a period of 12 minutes. Additionally, a T_1-weighted TFE sequence was used to acquire a high-resolution structural images with TR = 8.2 ms, TE = 3.8 ms, flip angle = 8°, matrix = 240x240x160 and FOV = 240x240x160 mm^3. Images were processed and analysed using the SPM8 software package (http://www.fil.ion.ucl.ac.uk/spm) and Matlab. GE and SE EPI volumes were spatially normalised (MNI standard space) and smoothed using an 8 mm FWHM Gaussian kernel. Parametric maps of ΔR_2^*, ΔR_2 and $q = \Delta R_2^*/\Delta R_2$ were calculated on a pixel-by-pixel basis. The calculated q values were converted into vessel radii using a calibration curve that was derived based on a previously described biophysical model [8].

Results

Figure 1 shows axial cross sections through a parametric map of the average venous vessel radius, R, in a representative subject. The colour bar shows the corresponding q-values and vessel radii. The individual mean q and R values for grey matter (GM) and white matter (WM) are shown in Table 1. The corresponding group averages were 6.5 ± 0.3 µm (GM) and 6.2 ± 0.3 µm (WM).

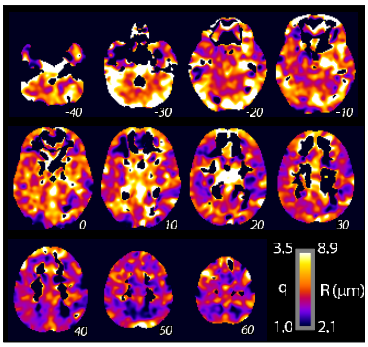

Figure 1. Parametric maps of the mean venous vessel radius, R, in a representative subject.

Discussion

We have demonstrated the feasibility of VSI based on hyperoxia-induced BOLD signal changes. The mean venous vessel radii for GM and WM measured in this study are larger than the typical microvascular vessel radii (3.4 – 3.9 µm) obtained by confocal laser microscopy [9]. However, the post-mortem approach is prone to underestimate vessel radii due to shrinkage in the anatomical specimen [9]. Compared to the values reported in a recent hypercapnia study (13.4 ± 1.7 µm for GM and 13.7 ± 2.1 µm for WM, [6]) our results are smaller. It has been shown that hyperoxia causes vasoconstriction while hypercapnia results in vasodilation. The average vessel radius is therefore expected to be greater during hypercapnia than during hyperoxia. Lu et al [10] have recently demonstrated this effect in a rat model. However, this effect is comparatively small and cannot fully account for the discrepancy between the vessel radii found in this study and the results reported by Jochimsen et al [6].

Subject	q_{GM}	q_{WM}	R_{GM} (µm)	R_{WM} (µm)
1	2.4 ± 0.9	2.3 ± 0.9	6.3 ± 3.5	6.2 ± 2.2
2	2.3 ± 0.7	2.1 ± 0.7	6.1 ± 1.8	5.7 ± 1.6
3	2.5 ± 1.0	2.5 ± 0.9	6.8 ± 4.1	6.6 ± 3.3
4	2.7 ± 1.3	2.4 ± 1.2	6.8 ± 6.6	6.4 ± 6.3
5	2.4 ± 1.1	2.3 ± 0.8	6.2 ± 5.3	6.2 ± 2.1
6	2.5 ± 1.0	2.4 ± 0.9	6.6 ± 3.5	6.3 ± 2.5
Mean ± SD	2.5 ± 0.1	2.3 ± 0.1	6.5 ± 0.3	6.2 ± 0.3

Table 1. Vessel size index, q, and mean venous vessel radius, R, obtained in grey and white matter ($R_{GM} > R_{WM}$, $p < 0.02$).

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