Assessments of Oxygen Extraction Fraction in Canines with Internal Carotid Arteries Ligated on Both Sides

Peng Wu[1], Feiyan Chang[2], Sheng Xie[2], and Hua Guo[1]

[1]*Center for Biomedical Imaging Research, Department of Biomedical Engineering, School of Medicine, Tsinghua University, Beijing, China,* [2]*Department of Radiology, China–Japan Friendship Hospital, Beijing, China*

Target audience: Neuroscientists and radiologists interested in quantification of oxygen extraction fraction.

Purpose: Oxygen extraction fraction (OEF) is an important indicator of the metabolism in the brain, which can reveal the blood supply to the brain tissue. Also, studies have shown that a changed OEF value can be used to predict the occurrence of stroke [1]. Positron emission tomography (PET) is regarded as the golden standard for OEF quantification. But it is harmful to patients due to its radiation. Several MRI-based OEF quantification methods have been proposed in last two decades [2-4, 6]. This study aims to show the feasibility of OEF measurements based on the model proposed by Haccke and Yablonskiy [2], and validate this method on canine models.

Methods: Six canines with internal carotid arteries ligated on both sides were studied. All MRI scans were performed on a 3T whole-body scanner (MR 750, GE Healthcare, Milwaukee, USA) pre- and post-ligation. An asymmetric spin echo EPI (ASE-EPI) sequence was used to acquire magnitude images with different time shift τ, which represents the time shift of the 180° pulse relative to the original position. Other imaging parameters were: TR/TE =4000/77.2ms, FA=90°, FOV=120mm，slice thickness =5mm, slice gap=6mm, number of partitions=10, acquisition matrix=64×64, reconstruction matrix=256×256, NSA=2, 4 echoes with τ=0 and 19 echoes with τ=1,2,3,…,19ms, 23 echoes in total. The magnitude images were used to estimate two parameters (reciprocal of reversible transverse relaxation rate R_2' and deoxygenated blood volume λ) by fitting them to the model proposed by Haacke and Yablonskiy [2, 3]. Then $\delta\omega$ map can be calculated using:

$$\delta\omega = R_2'/\lambda \qquad \text{(Eq.1).}$$

After that, OEF value was estimated using the following equation[2,3]:

$$OEF = \delta\omega/(\gamma \cdot 4/3\pi \cdot \Delta\chi_{do} \cdot Hct \cdot B_0) \qquad \text{(Eq.2),}$$

where γ is the gyromagnetic ratio, $\Delta\chi_{do}$ represents the susceptibility difference between fully deoxygenated blood and fully oxygenated blood, and is 0.18ppm. Hct is the hematocrit value, and is supposed to be 0.42[3]. Regions of Interest (ROIs) were drawn manually in order to avoid regions of noisy data. A paired T-test was used to decide whether the OEF values changed significantly pre- and post-ligation. Diffusion weighted images were also acquired to confirm the edema caused by ischemia. Triphenyl tetrazolium chloride (TTC) staining was conducted for the brain tissue after the canines were sacrificed to detect the ischemic brain tissue.

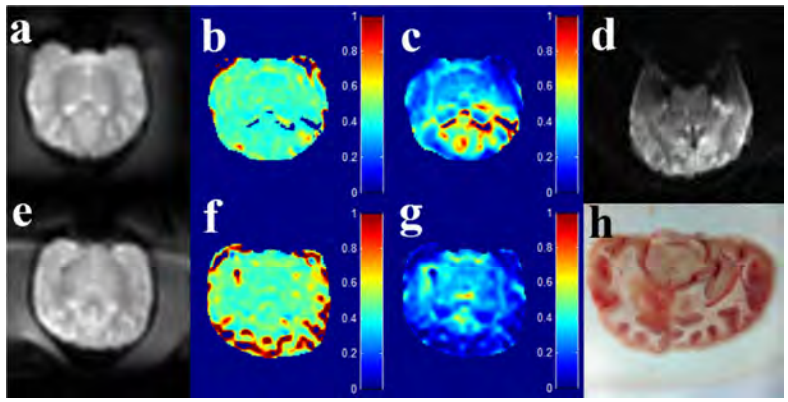

Fig 1. Anatomical images (a, e), OEF maps (b, f), and deoxygenated blood volume λ maps (c, g) of pre- (first row) and post-ligated (second row) conditions. DWI image (d) shows there is edema caused by ischemia in the cortex area and this is confirmed by TTC stained section (h).

Table 1. OEF values for all canines pre- and post-ligation.

Canine	1	2	3	4	5	6	mean±SD
Pre-ligation (%)	44.2	45.7	45.2	49.6	46.7	45.4	46.1±1.9
Post-ligation (%)	49.1	51.3	50.0	56.2	49.1	46.6	50.4±3.2

Results: Fig. 1 shows the anatomical images, OEF maps and λ maps of one canine (pre- and post-ligation). It can be observed that the OEF value increased significantly after the ligation, accompanied with a decreased deoxygenated blood volume value. The high intensity in the DWI image shows edema in the cortex area, indicating ischemia in the brain tissue. This is further confirmed by the TTC stained section. This result is consistent with that the decreased deoxygenated blood volume is accompanied with increased OEF in the cortex area. Table 1 shows the OEF changes for all six canines. From these data, paired T-test reveals that this increment is statistically significant (P=0.004).

Discussion: Theoretically, after internal carotid arteries are ligated on both sides, the blood supply to brain tissue should decrease, and OEF value increases in order to meet the demand of cerebral oxygen consumption [5]. The results of our study are consistent with this theory. A significant increment of OEF values was observed after the canines' internal carotid arteries were ligated. The mean OEF of the cerebral tissue for the pre-ligated conditions is 46.1±1.9%, while for the post-ligated, it is 50.4±3.2%. This study simulated the OEF changes before and after intracranial artery stenosis or occlusion, and may provide information for studies of brain tissue metabolism changes in stroke. In addition, by using a fixed TE in the ASE-EPI sequence used here, the R_2 effect can be ignored since it has the same weighting on all images. So it can reduce the total number of fitting parameters compared to the gradient echo sampled spin echo (GESSE) sequence [6].

Conclusion: It is applicable to assess OEF by using Haccke and Yablonskiy's model. This is validated by the significant OEF changes in the canine models by ligating of internal carotid arteries.

References:

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