Cerebral metabolism after one hyperbaric oxygenation session: $^1$H and $^{31}$P magnetic resonance spectroscopy study

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Abstract. The aim of this study is to elucidate the effect of one HBO session on the concentrations of metabolites detectible by $^1$H and $^{31}$P magnetic resonance spectroscopy. An activation of energy metabolism that manifested in the decrease of creatinephosphate (PCr), pHint and increase α-ATP signal after a HBO session is revealed. Other ATP resonances remain unchanged. Also the reduction of N-acetyl aspartate by 3% in mediolateral prefrontal cortex (MPFC) with $p<0.05$ and in posterior cingulate cortex ($p<0.1$) was found. Glutamate levels remained unchanged after HBO session. The demonstrated metabolic changes may signify the activation of power supply processes in order to compensate the energy expenses caused by the excess of O$_2$.

1. Introduction

HBO is a method of treatment with O$_2$ abundance, when patient is positioned in hyperbaric chamber filled with 100% O$_2$ with pressure more than 1 atmosphere. This causes increase of [O$_2$] dissolved in blood plasma. HBO has proven its clinical effectiveness, e.g. in case of ischemia, stroke and CO$_2$ poisoning [1]. However, mechanisms of the impact that oxygen excess has on cerebral metabolism require intensive research. One evidence that HBO might activate cerebral metabolism is the increase in glucose consumption in cerebral structures [2]. Also, HBO activates [2] the key electron-transport chain element – succinate dehydrogenase [2].

Nowadays the unique method that allows to reveal the shifts in cerebral metabolism in vivo is magnetic resonance spectroscopy (MRS).

The aim of this study is to elucidate the effect of one HBO session on the concentrations of metabolites detectible by $^1$H and $^{31}$P magnetic resonance spectroscopy.

2. Materials and Methods

MR scanner Philips Achieva 3.0T, 32-channel head coil and dual-tuned 31P/1H bird cage coil were used. HBO session was performed in Sechrist 3200 hyperbaric chamber. The diagnostic MRI scan that
included T1-, T2-weighted, DTI and FLAIR images was performed before the study and confirmed no pathology in each subject. The 1H MRS and 31P MRS were performed before the HBO session and immediately after it. Time between the end of HBO session and the second part of the study did not exceed 5 minutes.

1H MRS:

Twelve healthy subjects (6m + 6f, mean age 23), pulse sequence PRESS was used: TR = 2000 ms, FA=90°, number of signal acquisitions (NSA) = 64, except for WM spectrum, where NSA = 96, NSA of unsuppressed water reference signals = 16, TE = 115 ms. The spectroscopy volume of interest (voxel) was located in mediolateral prefrontal cortex (MPFC), voxel size 25x25x25 mm, in the region of posterior singulate cortex (PCC), size 40x20x20 mm, in the region of occipital lobe (V1), size 20x40x30 mm and in deep white matter of parietal lobe (WM), size 35x10x10 mm.

31P MRS:

Seventeen healthy subjects (9m+8f, mean age 35), 2D 31P MRS, ISIS pulse sequence: field of view (FOV) = 200x200 mm, voxel size 40x40 mm, number of excitations (NSA) =16, echo time (TE) = 0.3 ms, FA=35°. The spectroscopic volume of interest (VOI) separated on individual voxels was located under the guidance of survey localizer images and T2-weighted axial images. The VOI was rotated by 45° in axial plane to have as much voxels fully located in cerebral tissue as possible.

Data processing:

1H MRS

Spectra of each location before and after HBO session were processed in LCModel with basis set for TE=115 ms. [NAA], [Cr], [Cho], [Glx] and [ml] were obtained from spectroscopic data before and after HBO session. Relative changes of metabolite concentrations (after HBO/before HBO) were calculated for each subject.

31P MRS

The integral intensities of PME, Pi, PDE, PCr, γ-ATP, α-ATP and β-ATP resonance lines were obtained from averaged spectra (actually, from the brain tissue contained in the slice) and normalized on total phosphorus (∑31P=PME+PDE+Pi+PCr+γ-ATP+α-ATP+β-ATP). Due to the stability of ∑31P parameter, it was used as an internal standard. Relative changes of the parameters were found. The pHint was calculated and the pHafter/pHbefore value was calculated in each voxel.

Statistical processing

The statistical analysis was performed in STATISTICA program, the significance of relative changes in spectral parameters in response to HBO session was evaluated by Mann-Whitney criterion.
3. Results

Statistical analysis of spectral data demonstrates (see figure 1) the reliable decrease of PCr and pHint, and an increase of relative α-ATP signal. No changes are observed in γ-ATP and β-ATP. The decrease in NAA (see figure 2) with statistical significance (p<0.05) is observed in MPFC, and with p<0.1 is observed in PCC.

![Graph showing relative changes in NAA after HBO compared to the value=1.

* - p<0.05, ** - p<0.1. Vertical bars denote standard errors. MPFC – mediolateral prefrontal cortex, PCC – posterior cingulate cortex]

4. Discussion

In order to evaluate metabolic effects of single HBO session we calculated the changes in concentrations relative to the baseline values before HBO session. This is required in order to avoid deviations of results caused by the population variability in concentrations.

The decrease in [PCr] after HBO is a direct demonstration of energy metabolism activation. However, ATP concentrations remain constant after HBO, this happens since ATP is supported by creatine kinase reaction. The same process of energy consumption compensation was observed in neuroactivation [3]. The [PCr] decrease is accompanied by pHint decrease. The [NAA] reduction, which is the metabolic response to HBO session, also signifies the energy metabolism activation.

The change in α-ATP peak area while [ATP] is constant indicates on the change of concentration of another metabolite that is overlaid by a massive peak of α-resonance of the ATP molecule. We suppose that nicotinamide adenine dinucleotide (NAD(H)) is such a metabolite. NAD(H) is a key coenzyme that serves as a mediator between cytosol and mitochondrial biochemical redox processes, therefore plays the leading role in cell energy metabolism, is involved in antioxidant activity and oxidative stress. The increase in its concentration, as well as the direct energy metabolism activation might reflect the positive effect of even one HBO session on human brain.

References

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