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Heart—Dynamics and Flow
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Degenerative
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Abdomen and Pelvis
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Simultaneous Measurement of Cerebral Perfusion and Oxygenation Changes During Neuronal Activation and Hypercapnia

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PURPOSE:

In this study, the effects of hypercapnia on baseline and activation-induced perfusion and blood oxygenation level dependent (BOLD) signal are simultaneously measured using a T2* - weighted "flow - sensitive alternating inversion recovery" (FAIR) sequence (1,2).

INTRODUCTION:

Previous studies using BOLD contrast fMRI have demonstrated that hypercapnia causes an increase in baseline signal (3-5) and significantly reduces the activation-induced signal change relative to the hypercapnia-elevated baseline (3,4). The effects of hypercapnia on baseline perfusion level and activation-induced perfusion changes have been characterized using techniques other than fMRI. One study using positron emission tomography (PET) has observed that hypercapnia enhances activation-induced changes in perfusion (6), suggesting that flow changes can continue to increase while oxygenation changes are readily saturated.

In this study, T2* - weighted FAIR was used to measure, simultaneously, changes in perfusion and blood oxygenation during activation, hypercapnia, and combined activation and hypercapnia. Comparisons of the ratios of perfusion and oxygenation changes in motor cortex during activation and during hypercapnia were also made. Brain activation is thought to increase metabolism, perfusion, and blood oxygenation. Hypercapnia is thought to increase only perfusion and blood oxygenation, but not metabolism. Differences in perfusion change / oxygenation change ratios may be an indicator of oxygen extraction rate changes with brain activation.

METHODS:

All studies were carried out on a Bruker Biospec 3T/60 scanner. Echo planar imaging was performed using a three axis balanced torque head gradient coil and a whole brain quadrature endcapped birdcage transmit - receive RF coil. Time series of a single axial plane containing the motor cortex were collected. In-plane voxel dimension = 3.8 x 3.8 mm, slice thickness = 7 mm. TE = 40 ms, TR = 2 sec. A presaturation pulse was applied before inversion. Selective inversion width = 20 mm. TI = 600 to 1400 ms. Pairwise image subtraction gave perfusion information and canceled T2* effects. Pairwise image averaging gave T2* information and canceled perfusion effects.

Cyclic (64 sec on / 64 sec off) self paced bilateral finger tapping was performed during breathing of room air (5 to 7 min), then 7% CO₂ (5 to 7 min), then again room air (5 to 7 min).

RESULTS:

Figure 1 shows the signal from an ROI in the motor cortex voxels that demonstrated both perfusion and BOLD signal changes. TI = 1000 ms. Table 1 summarizes the results. The first column shows the fractional signal changes with neuronal activation during the period prior to and after hypercapnia. The second column shows hypercapnia-induced fractional signal change of only the baseline. The third column shows activation-induced signal fractional changes relative to the hypercapnia-elevated baseline.

From Table 1, several points can be made: 1) With hypercapnia, both baseline perfusion and BOLD signal increase. 2) The activation-induced perfusion / BOLD change ratio is significantly larger than the hypercapnia-induced perfusion / BOLD change ratio. This result may indicate a larger oxygen extraction rate with activation than with hypercapnia. 3) Activation-induced perfusion and BOLD changes during hypercapnia are both damped relative

to the hypercapnia-elevated baseline, but the absolute level of change, relative to that during room air breathing, is enhanced. 4) The ratio of the activation-induced perfusion / BOLD change remains the same regardless of whether the subject was breathing room air or 7% CO₂.

CONCLUSIONS:

Simultaneous measurements of perfusion and BOLD signal changes during neuronal activation, hypercapnia, and combined neuronal activation and hypercapnia have been made. These preliminary results indicate that perfusion / BOLD coupling differs between neuronal activation and hypercapnia. One explanation for this result is an increase in oxidative metabolism during activation.

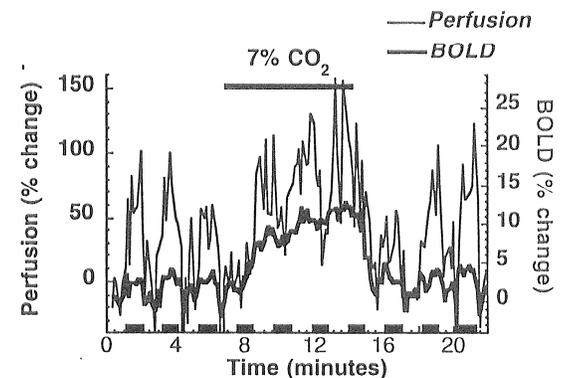


Figure 1: Simultaneous measurement, from the motor cortex, of perfusion and BOLD changes during cyclic finger movement and hypercapnia. The scales of the two plots were adjusted to match resting and hypercapnia state baselines.

	Activation	CO ₂	Activation (w/ CO ₂)
$\Delta\%$ Perfusion	47.9 \pm 4.3	59.1 \pm 7.8	22.4 \pm 5.6
$\Delta\%$ BOLD	1.7 \pm 0.2	7.9 \pm 0.5	0.9 \pm 0.4
$\frac{\Delta\% \text{ Perfusion}}{\Delta\% \text{ BOLD}}$	28.2 \pm 3.1	7.5 \pm 1.0	24.7 \pm 10.9

Table 1: Summary of the experiment shown in Figure 1. Top two rows: Activation-induced fractional signal change from a baseline of breathing room air, fractional baseline signal change with hypercapnia, and fractional activation-induced change relative to the hypercapnia elevated baseline. Bottom row: Ratio of the fractional signal changes.

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