Calibration of ASL Quantification Based on Hypercapnia and Sensory Motor Activation

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Introduction

To evaluate the feasibilities of quantifying cerebral perfusion with dynamic magnetic resonance artery spin labeling (ASL) sequence, numerous techniques of ASL quantification have been proposed in the last several years\(^1\),\(^3\),\(^4\). In fMRI, the blood oxygenation level-dependent (BOLD) effect depends on the cerebral blood flow (CBF), blood volume (CBV) and metabolic rate of oxygen (CMRO\(_2\)) changes. Thus, rCMRO\(_2\) maps relative to baseline can be estimated by measuring CBF and BOLD\(^4\). The previous studies\(^2\),\(^4\) shows that the positive correlations between CBF and CMRO\(_2\) changes in hypercapnia activation. In our study, we measured correlations of CBF and CMRO\(_2\) changes not only in hypercapnia activation with breath holding (BH) but also sensory motor activation with a check board (CB) visual stimulation. For evaluating the correlation of CBF and CMRO\(_2\) changes, we applied M coefficient which is a constant and proportional to CBV. The correlations of CBF with CMRO\(_2\) and M with CMRO\(_2\) are evaluated based on CBF and M quantification. Very weak positive but non-significant correlations between CBF and rCMRO\(_2\) are observed in BH task, correlations between M and CMRO\(_2\) changes is not shown in our analysis. In CB task, both of positive correlations of CBF with CMRO\(_2\) and M are obvious. Based on those results, we confirmed that BH task increased CBF and it is not significant or weak effects to CMRO\(_2\) changes. CB task does not increase the GM CBF as much as BH task but CMRO\(_2\) is increased significantly due to CBF and M increasing in specified areas such as vision and motor areas.

Materials and Method

In this work, 4 subjects (30.75 ± 11.7 years old) were studied at Siemens Trio 3.0T MR system. A breathing holding (BH) task was used for hypercapnia activation and a visual flashing check board which subjects respond to with a finger press (CB) for sensory motor (SM) activation. CBFs were calculated in rest and activation (BH & CB) situation. For evaluating gray matter (GM) CBF and rCMRO\(_2\) changes, we applied FreeSurfer (FS) segmentation to get the GM mask from a T1 anatomic structure image. Instead of CBV measurement, we evaluated M coefficient which is proportional to CBV. The ASL images were acquired during normal relaxed breathing initially, then during CB and BH activation in 20s ON/OFF repetition. For the image acquisition paradigm, 48 (24 controls and 24 tags) ASL images were acquired during the rest status, 148 (74 controls and 74 tags) and 184 frames (92 controls and 92 tags) images during BH and CB activation. Image parameters were a TR of 2500ms, TE of 50ms, slice thickness of 14mm, matrix size of 64x64 and FOV of 24x24(cm). For measuring M and rCMRO\(_2\), the following equation (1) and (2) proposed by T.L. Davis\(^3\) were applied. Here, M indicates baseline tissue dHb content that can be thought of as the baseline dHb concentration, proportional to CBV, \(\alpha\) and \(\beta\) are measured at 0.38 and 1.5 respectively\(^3\). Fh and Bh are CBF and BOLD ratios for activation versus baseline. F and B are normalized CBF and BOLD; linear normalization was used here. CBF was measured during baseline, rest and activation period with the method proposed by JJ Wong\(^4\), then M and rCMRO\(_2\) were calculated in rest and active status. 2 ROIs are located at left and right motor area, 2 are located at vision area and 1 is located at frontal lobe, totally 7 ROIs at each subject are used to analysis.

Result and Discussion

Figure 1 shows maps of baseline and activation CBF, M, and CMRO\(_2\) in BH and CB task, and Table1 shows the % change of CBF, M and CMRO\(_2\) based on ROI analysis. The large standard deviation of \(\Delta M\) and \(\Delta\text{CMRO}_2\) means the variance is strong in M and CMRO\(_2\) quantified values due to the noise which those noises is obvious at Figure 1. In BH and CB activation, respectively, CBF increased 32.39% ± 9.6% and 14.90% ± 11.13%, M increased 29.31% ± 18.77%, and CMRO\(_2\) changed by 5.67% ± 7.93% and 7.93% ± 18.54%. In the hypercapnic BH task, a weak positive correlation between CBF and CMRO\(_2\) changes was shown in Figure 1. In BH task, the correlation of \(\Delta\text{CMRO}_2\) with \(\Delta\text{CBF}\) and \(\Delta M\) is 0.34 (\(p=0.09\)) and 0.14 (\(p=0.38\)), respectively. Thus, a weak positive correlation between CBF and CMRO\(_2\) was showed in BH activation in our study. For CB activation, the distribution are shown by Figure 3, correlated coefficients are 0.43 (\(p=0.056\)) and 0.42 (\(p=0.12\)) between \(\Delta\text{CMRO}_2\) and \(\Delta\text{CBF}\), \(\Delta\text{CMRO}_2\) and \(\Delta M\) respectively, suggest a weak significant positive correlation between CMRO\(_2\) and CBF, CMRO\(_2\) and M in CB activation task. CBF increased 32% in BH activation study; this is a little bit lower than the evaluated value previously reported\(^2\), due to the weak CBF change in Subject1. Noise decreasing methods should need more consideration in the future works, such as apply a Gaussian normalizing instead of linear due to the noise smoothing effect in Gaussian filtering.

References

5. Comparison of quantitative perfusion imaging using arterial spin labeling at 1.5 and 4T. MRM, 41:1152-1161(1999).

Fig.1 Functional ASL quantified maps

Tab.1 CBF, M and CMRO\(_2\) changes in BH and CB activation

<table>
<thead>
<tr>
<th>Breath Holding</th>
<th>Check Board</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta\text{CBF} (%))</td>
<td>(\Delta\text{CMRO}_2 (%))</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Subject1</td>
<td>16.93</td>
</tr>
<tr>
<td>Subject2</td>
<td>30.42</td>
</tr>
<tr>
<td>Subject3</td>
<td>44.46</td>
</tr>
<tr>
<td>Subject4</td>
<td>58.41</td>
</tr>
</tbody>
</table>

Figure 2 shows total 28 ROIs mean values distribution of \(\Delta\text{CMRO}_2\) with \(\Delta M\) and \(\Delta\text{CBF}\). In BH task, the correlated coefficient of \(\Delta\text{CMRO}_2\) with \(\Delta\text{CBF}\) and \(\Delta M\) is 0.34 (\(p=0.09\)) and 0.14 (\(p=0.38\)), respectively. Thus, a weak positive correlation between CBF and CMRO\(_2\) was showed in BH activation in our study. For CB activation, the distribution are shown by Figure 3, correlated coefficients are 0.43 (\(p=0.056\)) and 0.42 (\(p=0.12\)) between \(\Delta\text{CMRO}_2\) and \(\Delta\text{CBF}\), \(\Delta\text{CMRO}_2\) and \(\Delta M\) respectively, suggest a weak significant positive correlation between CMRO\(_2\) and CBF, CMRO\(_2\) and M in CB activation task. CBF increased 32% in BH activation study; this is a little bit lower than the evaluated value previously reported\(^2\), due to the weak CBF change in Subject1. Noise decreasing methods should need more consideration in the future works, such as apply a Gaussian normalizing instead of linear due to the noise smoothing effect in Gaussian filtering.

Fig2. Distribution relations of rCMRO\(_2\) and CBF, M in BH

Fig3. Distribution relations of rCMRO\(_2\) and CBF, M in CB