Multi-voxel pattern analysis delineates selective ASL-collateral supply in patients with intracranial stenosis

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Introduction: Perfusion territories can be assessed by vessel-encoded (VE) pseudo-continuous arterial spin labeling (p-CASL). Mapping perfusion territories of arteries can be performed with a conventional encoding matrix as described by Wang E.C. (2007) [1]. Interestingly, VE p-CASL image processing methods can additionally be performed with k-means clustering and a Bayesian framework [2]. In the present study we investigated the features of a classification analysis performed with the framework of "searchlight" multi-voxel pattern analysis (MVPA).

Methods: All patients are participants of the Swiss Intracranial Stenosis Study (SAISS) that investigates clinical and hemodynamic effects of the best medical treatment of patients with intracranial stenosis. A total of 45 patients with proven intracranial stenosis were included into the study (mean age: 37.9 years ± 8.2; 22 male and 23 female). We assume a high accuracy in classification of perfusion territories due to tsensitive MVPA procedure. MRI was performed with a 3T Siemens TRIO TIM scanner, including an ***anatomical T1w sequence*** (MDEFT) [2] followed by a ***selective ASL scan*** using a vessel-selective pseudocontinuous ASL (VE p-CASL) sequence [3, 4] with a 12-channel head coil FOV=220 mm, matrix=64 x 64, axial slices=18, slice thickness=6 mm, gap=1.5 mm, TE/TR[ms]=17/4000, slice-selective gradient = 6 mT/m, tagging duration τ = 700 ms and postlabeling delay (w) = 1000 ms. The VE p-CASL was repeated 20 times in cycles of Label-Control-Anterior-Posterior-Left-Right tagging. In total, 120 volumes were collected during VE p-CASL scan. Matlab/SPM8 was used for preprocessing of imaging data and calculation of absolute CBF maps [5, 6]. ASL images were motion corrected and CBF was quantified using a single-compartment model (T1blood 1650ms, labeling efficiency 0.85, blood-tissue partition coefficient 0.9 [ml/g]). The "Searchlight" procedure [2] in combination with "Naïve Bayes Classifier with leave-one-sample-out cross-validation" was used to classify left, right and posterior territories in the trials after flipping the stenotic territory to the left. This procedure was used to predict the "label" of a trial. We used the VE p-CASL cycles as "labels" and as training set the trials described above. The learning success was evaluated on a test set. Accuracy maps for each subject were generated and shifted by -0.5 (in order to transform accuracy map to a mean zero distribution). We tested the null hypothesis of chance level accuracy (=0.5) across the subjects. Significance levels are corrected against multiple comparisons of type I errors with "false discovery rate" (FDR) approach.

Results: We found an optimal classification of left (stenotic), right (non-stenotic) and posterior (non-stenotic) territories. The accuracy of classification was high in the left- , in the right- and in the posterior perfusion territories (Fig 1). The extracted average CBF values from these regions were [stenotic side]: 75.0 ± 20.7 ml/100g/min; [healthy side]: 67.7 ± 16.0 ml/100g/min and [posterior]: 61.5 ± 15.3 ml/100g/min. The classification accuracy of these three perfusion territories did not depend on the grade and the segment of the stenosis (M1-M4). However, the collateral supplies of the non-stenotic (i.e. the right) territory could be reliably predicted by the algorithm. As a "proof of concept" we show the digital subtraction angiography (DSA) and its corresponding single case accuracy map of a selected patient. The observed collateral flow from the healthy into the stenotic side in DSA image is fully supported by the accuracy map (Fig 2).

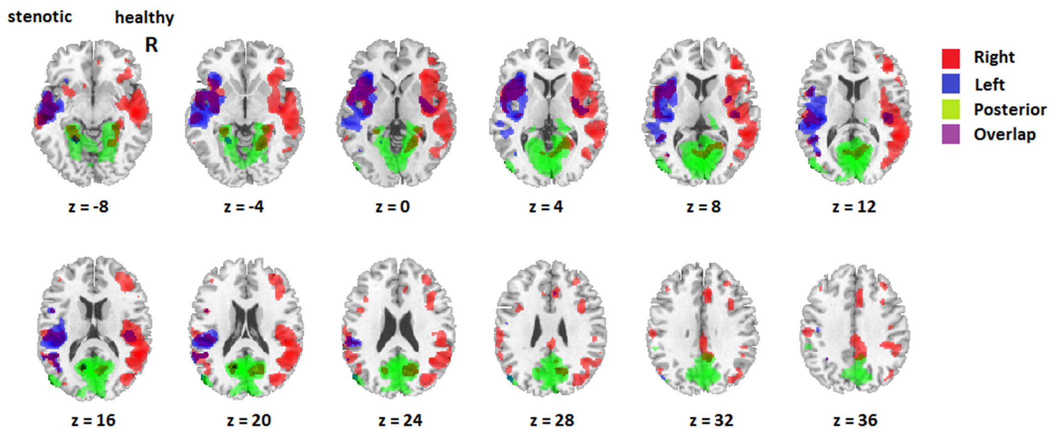
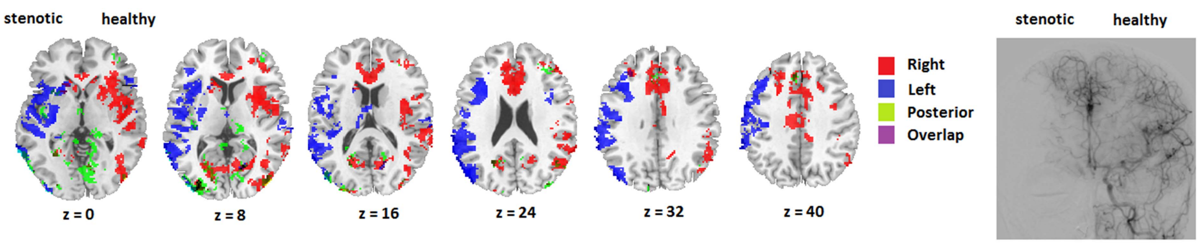


Figure 1: Accuracy maps produced by "Searchlight" procedure with the CBF-quantified selective ASL images. t-Maps (FDR .05) show consistent high accuracies for the left-, right- and posterior territories. On the left side (stenotic side) overlap classification is visible (violet color).

Figure 2 (below): The Digital Subtraction Angiography (DSA) of a single representative case shows collateral flow from the healthy into the upper left territory. The corresponding accuracy map (> 0.65) shows high classification accuracy for the left-, right- and posterior territories. Notably the right territories are ranging into the left hemisphere.



Conclusions: The study shows that the vascular territories indicated by VE p-CASL are in line with the "searchlight"/Naïve Byes classification method. The multi-voxel pattern analysis identified the amount and distribution of the collateral supply. In fact, the overlap brain regions can be interpreted as regions in which the selective labeling overlaps within regions that are normally supplied by a single artery. These findings suggest that the present classification method is sensitive to collateral flow. This is applicable in both, at group level and at single subject level (as demonstrated by DSA). It may be used to reliable classify the pattern and amount of collateral supply. Selective VE p-CASL offers the potential to inform clinicians non-invasively about these collateral patterns.

References: [1] Wong E.C. Magn Reson Med, 2007. **58**(6): p. 1086-91. [2] Pereira F. & Botvinick M. Neuroimage 2011. **56**(2): p. 476-96. [3] Deichmann, R., et al., Neuroimage, 2004. **21**(2): p. 757-67. [4] Dai, W., et al., Magn Reson Med, 2008. **60**(6): p. 1488-97. [5] Wu, W.C., et al., Magn Reson Med, 2007. **58**(5): p. 1020-7. [6] Orosz, A., et al., Neuroimage, 2012. **61**(3): p. 599-605.