Arterial spin labeling in carotid artery stenosis – evaluation of partial volume effect and transit delay bias

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Background

- Arterial Spin Labelling (ASL) highly promising for non-invasive perfusion imaging in cerebrovascular diseases [1]
- Pseudo-continuous ASL (pCASL) showed ipsilaterally decreased cerebral blood flow (CBF) for patients with unilateral internal carotid artery stenosis (ICAS))[2-3]
- Apparent hypo-perfusion either driven by patho-physiology or due to inherent ASL limitations:
  - Partial Volume Effects (PVE) due to relatively large ASL voxel sizes[4,5]
  - Arterial transit time (ATT) delays[1,6]

→ PVE correction algorithm based on linear regression[7]

→ Evaluation of ATT artefacts by means of spatial coefficients of variation (sCOV)

Methods

- 15 asymptomatic ICAS patients (70.2±4.4y) and 24 Healthy Controls (HC) (69.9±7.3y)
- 3T Philips Ingenia MRI (Best, Netherlands), 32-ch head-neck-coil
- Single post label delay (PLD) pCASL (see Figure 1)
- Processing with SPM12 and custom Matlab® programs
- Evaluation of Grey Matter CBF (GM-CBF) based on structural imaging (MPRAGE)
- PVE correction (PVEc) of GM-CBF using linear regression including:
  - Analysis of PVEc effects on global CBF values
  - Vascular territories of the anterior cerebral artery (ACA), middle cerebral artery (MCA) and the posterior cerebral artery (PCA) analyzed by coregistration of MNI based atlas[8]
  - Differentiation of PVEc effects within perfusion territories of the anterior (ACA & MCA) and posterior (PCA) circulation
  - Calculation of asymmetry indices (AI)[2] for differences of PVEc between both hemispheres
- Calculation of sCOV and comparison between ICAS patients and HC
- Statistics: two-sample t-tests for PVEc, unpaired t-tests for sCOV, p<0.05

Aims

The aim of our study was to **evaluate potential bias in perfusion imaging of ICAS** patients using non-invasive **pCASL**. Therefore, effects of **PVE correction** were analyzed and **ATT delay artefacts** evaluated by calculation of spatial coefficients of variation (sCOV).

Thereby, we wanted to evaluate the reliability of pCASL based CBF mapping for clinical diagnostic MRI.

Conclusion

PVE correction (**PVEc**) showed **significant effects** on GM-CBF of ICAS patients, with **regional differences** between anterior and posterior circulation. These effects may be explained by parenchymal volume loss due to increased atrophy.[10] **No** severe **unilateral effects** were found. Compared to healthy controls sCOV was not affected, which indicates the **absence of severe ATT delay artefacts**.

Ipsilaterally reduced **CBF in patients** seems to be **driven by pathophysiology**, as we found neither effects of PVEc on AI nor severe ATT artefacts. Therefore, widely **available single PLD ASL** is **applicable for clinical perfusion imaging,** but we recommend PVEc to differentiate disease driven changes from PVE.

Figures

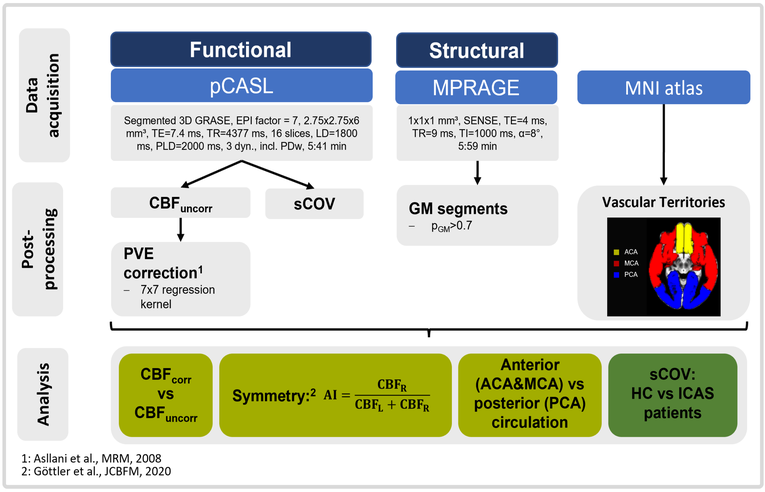

Figure 1: MRI protocol and derived parameters. Perfusion imaging used pCASL. PVE corrected CBF and sCOV were calculated. Vascular perfusion territories were derived using a MNI based atlas. Data analysis of PVE correction was based on global comparison of CBF values, asymmetry indices (AI), percentage perfusion increases across territories. sCOV was compared between healthy controls (HC) and ICAS patients.

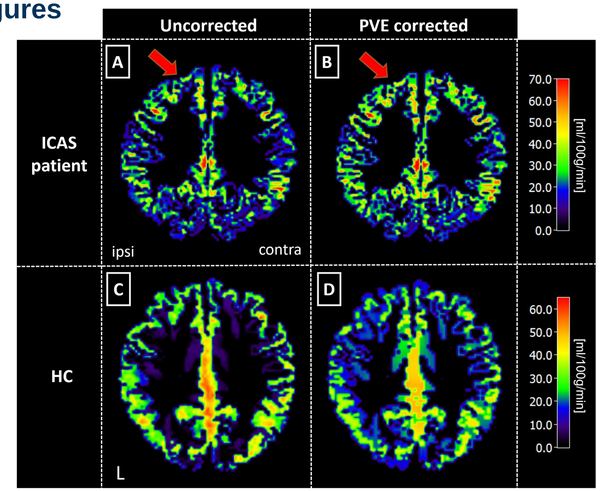

Figure 2: Effect of PVEc on CBF parameter maps for an ICAS patient and a healthy control (HC). An axial slice of an uncorrected (A, C) and a PVE corrected (B, D) GM-CBF parameter map is shown for a representative ICAS patient (A,B) and a healthy control (HC) (C,D). Note, that smoothing due to the regression kernel is supposed to better preserve the tissue structure, than conventional spatial smoothing, as it relies on the detailed structure of the local tissue fractions.

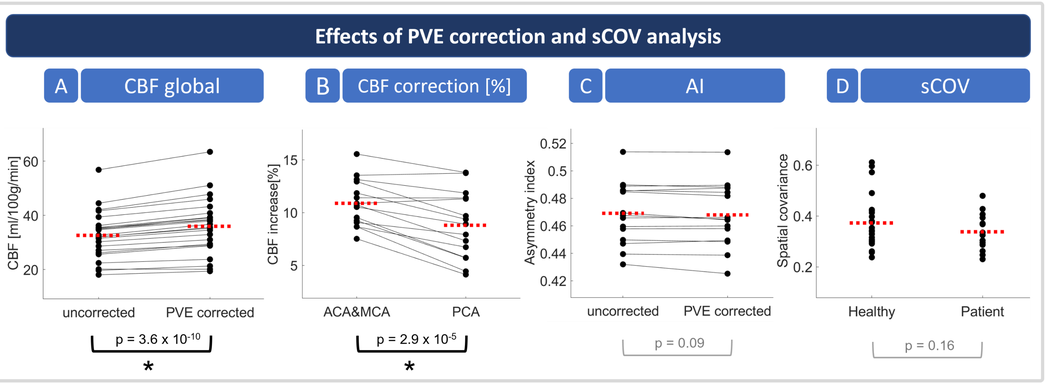

Figure 3: Scatterplots evaluating PVE and Arterial Transit Time (ATT) artefacts. Effects of PVE correction were evaluated by comparing patients' uncorrected and PVE corrected GM-CBF (A) and regional differences in the CBF correction between the anterior (ACA&MCA) and posterior (PCA) circulation (B). Furthermore, asymmetry indices (AI) were compared (C). The spatial coefficient of variation (sCOV) was calculated based on uncorrected CBF. Dots show subject-wise GM mean values. Red dashed lines indicate group mean values. Asterisks indicate statistically significant differences.

Results

- Exemplary data show PVEc induced GM-CBF increases, with strongest effects in frontal regions of ICAS patients (Fig. 2)
- Group analysis in ICAS patients showed globally increased GM-CBF (+10.3±2.5%, Fig.3A) due to PVEc
- Most pronounced effects in the anterior circulation (Fig.3B)
- CBF symmetry was preserved (AI≈0,47, Fig.3C).
- HCs' GM-CBF increased by PVEc (+9.1±3.1%), without regional differences (not shown).
- Spatial COV was 0.37 for HC and 0.33 for patients (Fig.3D), no significant differences were found

Discussion

- systematic underestimation of uncorrected GM-CBF in patients and HCs, in line with literature.[4, 9]
- PVEc recommended to better differentiate disease driven CBF changes
- Regional differences in PVEc only for ICAS patients
- Differences may be due to accelerated parenchymal volume loss in anterior areas (supplied by branches of a (stenosed) ICA), as ICAS is known to be related to atrophy[10]
- No unilateral effects or severe unilateral atrophy indicated by unchanged AI
- No severe delay artefacts indicated by analysis of sCOV
- Vessel-selective[11] as well as time-encoded ASL[12] could help to further differentiate regional effects and lower potential ATT-bias

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References

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