Decomposing cerebral blood flow MRI into functional and structural components

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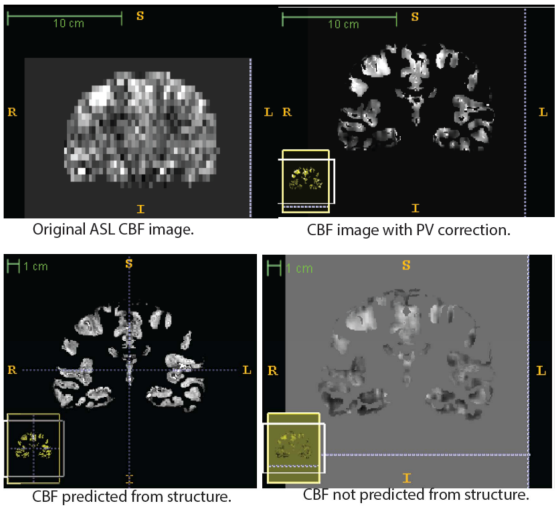
Target audience: We propose a method for decomposing cerebral blood flow (CBF) images, as measured by arterial spin labeling (ASL) MRI, into a CBF component that can be predicted from structural imaging alone and a component that cannot be predicted from purely structural information. This technique has widespread application and will be of interest to researchers utilizing various forms of functional imaging.

Purpose: Recent years have seen a proliferation of studies using ASL to measure CBF. Assessing the additional information gained by ASL in addition to standard T1 imaging is of crucial importance to evaluating ASL's future clinical benefit. Although some studies have been performed investigating various partial volume correction techniques, little work has been done examining the effect of more sophisticated and subtle structural patterns, such as cortical thickness and sulcal folding patterns, on measured CBF. Ignoring this information may underestimate how much CBF information is due directly to the underlying cortical structure. Therefore, we propose a novel method to take into account more cortical structural information in analyzing CBF images.

Methods: We designed a rotation-invariant patch-based dictionary learning approach, inspired by techniques for modality synthesis, to estimate the CBF in a given voxel given a T1 structural image. We take a random sampling of patches from around the T1 image and decompose them into the necessary number of "eigenpatches" to achieve 95% variance explained. The first several eigenpatches typically contain gradient information, and subsequent eigenpatches contain more subtle textural information. For each voxel, we construct a patch from surrounding voxels and project the patch onto the eigenpatches. The resulting projections are used as input into a linear regression that has CBF as the response variable and the structural projections as the predictors: CBF ~ Patch_projections. We compared using gray and white matter probability images as additional predictors (CBF ~ Patch_projections + gray_matter_probability) to examine the benefit of the patch-based predictors. For each subject, we trained the regression model on 2% of the cortical data and predicted on the other 98% of the data.

Imaging data: We used a test-retest dataset, with the second ASL scan one hour after the first. The cohort consists of 12 healthy young adult participants (mean age 25.5±4.5, 7 female). For each time point, high resolution T1-weighted anatomic images were obtained using 3D MPRAGE imaging sequence and the following acquisition parameters: TR = 1620 ms, TI = 950 ms, TE = 3 ms, flip angle = 15 degrees, 160 contiguous slices of 1.0 mm thickness, FOV = 192x256 mm^2, matrix = 192x256, 1NEX with a scan time of 6 min. Additionally, pulsed ASL (PASL) images were acquired with 80 alternating tag/control images and 2 M0 images all with 14 contiguous slice of 7.5mm thickness, FOV = 220x220mm^2, matrix = 64x64.

Results: The patch-based decomposition was able to predict significantly more of the CBF values than the probability maps. We found that the test-retest reproducibility, as measured by the R^2 value of predicting the voxelwise CBF at the second timepoint from the CBF at the first timepoint was approximately 0.45. The R^2 value for predicting CBF from probability maps was 0.1±0.05, and including the structural data increased the R^2 value to 0.30±0.04. This difference was highly significant ($p<1e-6$), and implies that structure accounts for greater than 50% of the reproducible CBF signal. A sample image including original CBF image, traditional partial volume correction, and our functional and structural decomposition is included at right.



Discussion: This research implies that significantly more information about cerebral blood flow can be inferred from structural information than traditional partial volume correction techniques assume. Using more sophisticated learning approaches, such as the one suggested here, can provide greater insight into the structural causes underlying observed CBF changes. In addition, the technique can highlight areas that have higher CBF values than would be expected from their structure, implying an unusually active cortical region.

Conclusion: There is likely a much tighter link between brain structure and CBF values than traditional partial volume correction methods imply, and further studies are needed to rigorously assess the contributions of CBF measures over structural imaging.