Probabilistic Cerebral Vascular Territory Atlases

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TARGET AUDIENCE
This information is intended for scientists and clinicians interested in neurovascular anatomy and pathology.

PURPOSE
Physiologically accurate mapping of cerebral blood flow in multiple separate vascular territories has a wide range of potential research and clinical applications, including the investigation and diagnosis of numerous common disease conditions that affect cerebral perfusion, such as migraine, carotid stenosis, and extracranial-intracranial bypass before and after surgery. The identification of functional changes in vascular distributions, as well as quantitative measures of blood flow per voxel would be very useful for individualized surgical planning, such as predicting the risk of potential iatrogenic ischemic stroke. Moreover, anatomical variations of the cerebral arteries and knowledge of this variation is essential to avoid misdiagnosis. Probabilistic vascular territory atlases are well suited to take this vascular variation into account. Therefore, access to detailed vascular territory atlases may serve to advance our understanding regarding the pathophysiology of these diseases and the effects of interventions and treatments. To date, however, only crude cerebral vascular territory atlases exist based on digitization of colorized figures, with no available atlas generated by direct measurement of cerebral blood flow.

METHODS
The data obtained from 20 normal patients (4 male & 16 female, age range: 2~41 yrs.), with no evidence of disease or vascular abnormality at our institution. Data was collected on a 3T Siemens Skyra scanner with a 20 channel head/neck coil (Siemens AG, Erlangen, Germany). Vascular territory maps were obtained with a Fourier encoded ASL scan [1] using 2D EPI acquisition. Imaging parameters include 1.6 s tagging duration, 1.2s post-labeling delays, 22 ms/4 s TE/TR, 3.75 mm x 3.75 mm in-plane resolution, 5 mm slice thickness, 24 axial slices. Fourier encoding parameters were: 9 cm x 6.6 cm encoding FOV, 15 x 11 encoding steps (7 x 5 skipped steps), 6 x 6 mm encoding resolution, 56 repetitions, and 4 min scan time. The tagging plane to be spatially encoded was located below the confluence to the basilar artery so as to encode internal carotid and vertebral arteries. A high-resolution T1-weighted scan was also obtained for all subjects using a MP-RAGE sequence.

Source locations of the primary component from Fourier encoded ASL in x and y axis were processed using a territory segmentation algorithm [2], which utilizes mutual connectivity information from both image and label spaces. The segments of four major arteries were categorized into two internal carotid and two vertebral arteries based on the relative position in the tagging plane. Each segment was confirmed by visual inspection of the location.

T1-weighted images were processed for tissue segmentation and spatial brain normalization to the Montreal Neurological Institute (MNI) brain template using SPM8. The territory maps were coregistered to the structural T1 and normalized to MNI space using the transformation computed above. Per voxel basis probabilistic territory maps shown in Fig. C were computed by taking a ratio of the number of subjects having a certain source artery to the total number of subjects having any source artery. Vascular territory maps shown in Fig. B were generated by choosing the source artery having highest probability in a voxel.

RESULTS
The vascular territory maps indicate that the internal carotid arteries supply blood to anterior and middle cerebral artery regions while the vertebral arteries primarily supply to posterior cerebral artery region. However, the probabilistic territory maps from individual feeding arteries represent the subject variability, which may not be shown with conventional vascular territory maps. Two interesting findings were observed: 1) 15% to 20% of subjects show blood supply to the right ACA region from contra-lateral flow of left ICA via the anterior communicating artery, but not vice versa, and 2) there is supply from the internal carotid arteries to the PCA region via the posterior communicating arteries, but no flow from PCA through posterior communicating arteries to supply ACA or MCA territories. More data will be necessary to confirm these observations.

DISCUSSIONS
These methods provide a frame-work for generating detailed vascular territory atlases that may have utility as clinical diagnostic and basic research tools. The acquisition of more data for normal subjects and those with diseases secondary to cerebral vascular; however, will be necessary to determine the true utility as a clinical and research tool. As such, we will apply our vascular territory mapping methods to a larger number of subjects (>100) in future studies to further validate and expand our findings. With a larger sample size, gender-related and other group phenotypic variations may be explored. In addition, even though the cerebral vasculature is typically mature at birth, potential age-related variation may be of interest to pursue.

CONCLUSION
We demonstrate experiment-based vascular territory atlases of major arteries, which quantitatively map downstream cerebral perfusion, which may have important utility as a clinical diagnostic and basic research tool.

REFERENCES
1. Jung, 20th ISMRM: 581, 2012.
2. Jung et al., 21th ISMRM: 2154, 2013.

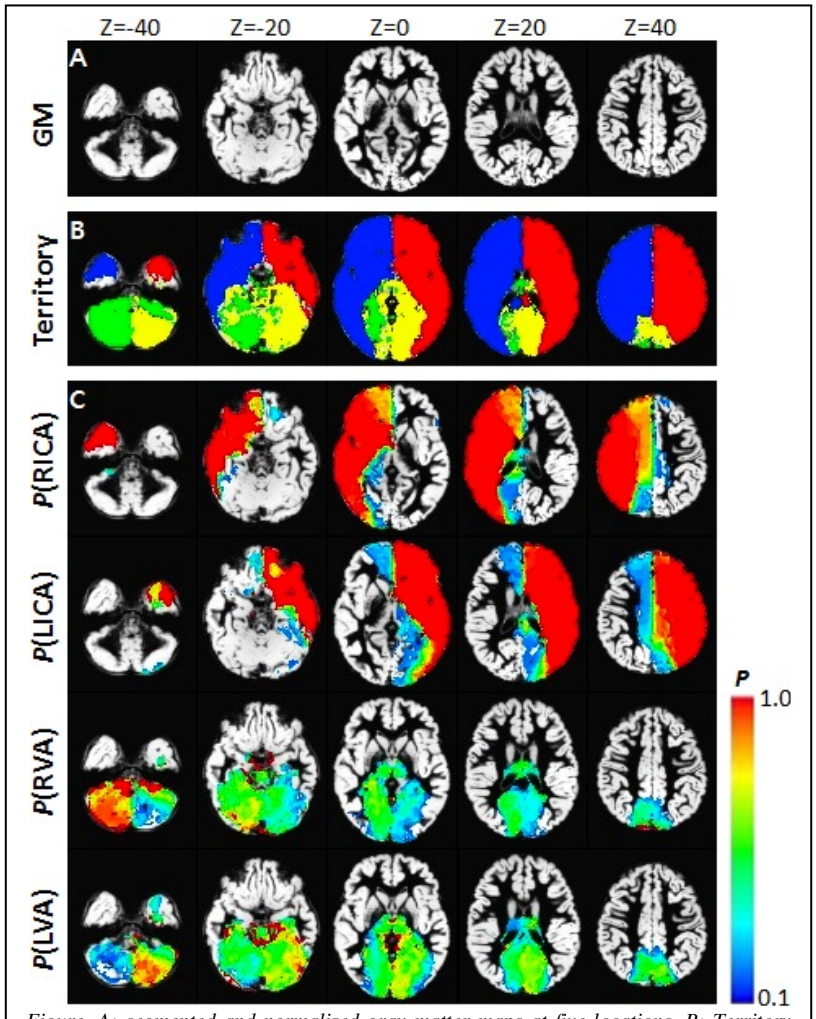

Figure. A: segmented and normalized gray matter maps at five locations. B: Territory maps of internal carotid and vertebral arteries (blue: right internal carotid, red: left internal carotid, green: right vertebral, and yellow: left vertebral artery territories. C: probabilistic territory maps of corresponding four major arteries.