Vascular Territory Segmentation Using Mutual Clustering in Image and Label Space

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TARGET AUDIENCE This information is intended for scientists and clinicians interested in vascular territory mapping.

PURPOSE Pseudo-continuous ASL (PCASL) based vascular territory mapping enables the detection of source arteries without *a priori* knowledge of their locations [1, 2]. The source artery location at the labeling plane is estimated on a voxel-wise basis in the image volume but a territory often needs to be manually identified. The source location of a territory is often wide-spread due to noise and large vessel diameters; becoming more complicated when the labeling plane includes a large number of source arteries. We propose an automated vascular territory segmentation algorithm using connectivity information from both image space and label space.

METHODS The territory segmentation algorithm has two assumptions: (1) a territory may have multiple source locations depending on the detection resolution, vessel diameter, and vessel turns in the label plane but the multiple locations must be neighboring. (2) a single artery may supply multiple non-contiguous areas because of branching after leaving the labeling plane . The algorithm has five steps in order to segment an image volume into separate vascular territories:

Step 1: 3D connectivity clustering with a small cluster size (e.g. four neighboring voxels) is applied in image space on a voxel-wise basis. Each clustered territory has a source location in (x, y) coordinates and this step rejects voxels contaminated by noise.

Step 2: The source locations of territories from Step 1 are mapped in 2D label space and the sources are clustered based on the spatial connectivity. This is applied based on assumption 1.

Step 3: Territories corresponding to the source clusters from Step 2 are generated. Multiple 3D spatial clusters may stem from a single source based on assumption 2.

Step 4: From each territory identified in Step 3, the center of mass (centroid) to label space is calculated and tested to determine if multiple territories are from a same source. The distances between cluster centroids are computed and the clusters are regarded as having the same source if a distance is smaller than a detection resolution. The clustered source in Step 2 may be divided into multiple sources depending on the centroid test.

Step 5: Small territories (e.g., < 30 voxels) are rejected. Source locations of surviving territories can be validated at this stage using an MR angiogram obtained at the label plane to determine if multiple sources are from the same artery. Finally, the CBF map and MRA (if provided) are used to generate a CBF weighted territory map and source location estimation map.

We tested the algorithm using data obtained with Fourier encoded ASL (2) in the A/P direction and with a phase offset in the R/L direction. The detection resolution was 3mm in A/P and 9mm in R/L. A maximum intensity projection (MIP) image from a time-of-flight angiogram (1cm thickness) was used to overlay estimates of source locations and determine if multiple sources are from a single artery moving laterally within the labeling space.

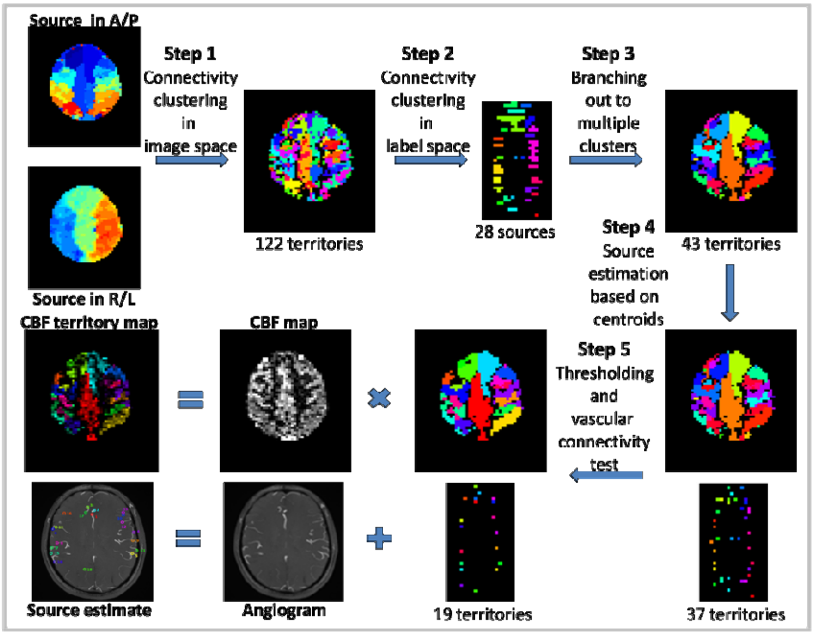
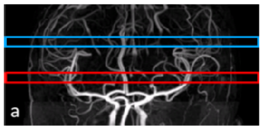


Fig. 1. Description of segmentation algorithm using source location in (x,y).

RESULTS Fig 2 shows results from placement of the labeling plane at two locations: a superior location where multiple branches of the middle cerebral artery supply cortical gyri (blue in Fig 2a), and a more inferior locations 2 cm above the circle of willis (red in Fig 2a).. The proposed algorithm segmented the images into 19 (Fig. 2b) and 12 perfusion territories (Fig. 2c), respectively. There was one territory in which two sources were actually arisen from a single artery due to lateral turn in the labeling space. Small branches from thalamo-perforators to the thalamus (orange and blue, source 9 and 10, Fig 2c) and lenticulostriates to the basal ganglia (green, sources 11 and 7, Fig 2c)) are identified. The algorithm was able to resolve separate territories even with the neighboring sources (purple and blue, sources 10 and 19, Fig 2b).



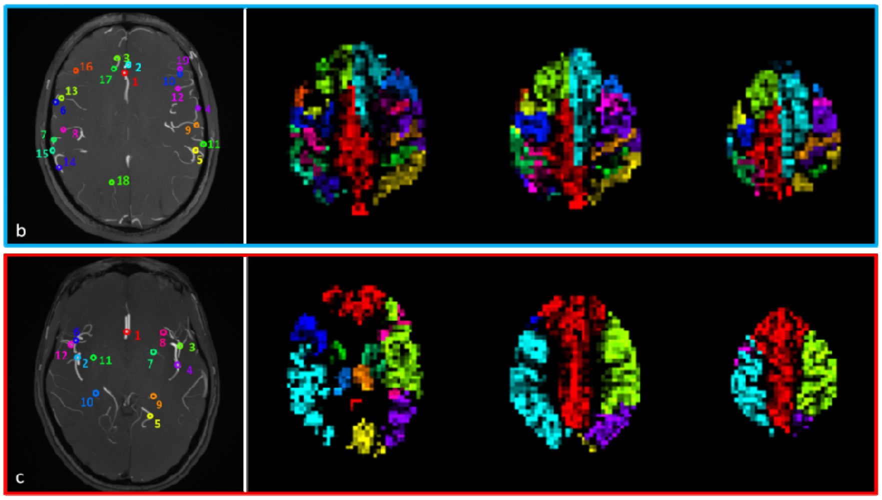


Fig. 2. (a) The label plane locations. The estimated source locations overlaid on MIP of the label location (left) and corresponding CBF weighted territory maps (right) from the upper (b) and the lower (c) labeling locations. Numbering were ordered based on cluster size.

DISCUSSIONS Because the algorithm uses mutual connectivity in both image and label space, the capability of segmenting two neighboring territories is limited when they are clustered in Step 2 and 3. A high detection resolution is required to guarantee a separation in this case. Verification of the vascular connectivity in Step 5 required some manual editing. The inspection may potentially be automated through the use of a high resolution MRA and a region growing algorithm.

CONCLUSION

We demonstrate an automated vascular segmentation algorithm based on vascular territory mapping.

REFERENCES

1. Wong & Guo, MAGMA 25: 95-101, 2012.
2. Jung, 20th ISMRM: 581, 2012.