Automatic Extraction and Matching of Neonatal Cerebral Vasculature from MRA-TOF Images

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Introduction Comparison and quantification of neonatal cerebral vasculature is motivated by markedly improved image quality in Magnetic Resonance Angiography (MRA) [1]. In this abstract, we present an automated method to extract and match neonatal cerebral vasculature for MRA-Time of Flight (MRA-TOF) images. Vessel extraction is first performed to find vessel centerlines from 3D MRA-TOF images and the extracted vessel segments are connected iteratively to compose a vessel tree. To study neonatal vasculature development from serial MRA examinations, a vessel matching algorithm is developed to determine topological correspondence between different branches. Because extensive vasculature evolution caused by rapid brain development of neonates can change vessel geometry, while vasculature topology usually remains unchanged except for the emergence of new peripheral branches, branch-by-branch correspondence is required because voxel-by-voxel mapping is often not possible.

Method Our approach consists of two steps: **a)** a modified ridge traversal method originally presented in [2] was developed to extract vessel centerlines. The method starts from a seed point near the vessel centre and moves to a ridge point by minimizing a "ridgeness" function $J(\vec{x}) = (\vec{v}_1 \cdot \nabla I)^2 + (\vec{v}_2 \cdot \nabla I)^2 \approx 0$ where I is image intensity and $\vec{v}_1$ and $\vec{v}_2$ are normalized eigenvectors corresponding to the k-th smallest eigenvalues of the Hessian of I at $\vec{x}$. To automate this process, we developed a seed production method based on the ZBS algorithm [3]. The algorithm computes a roughness that quantifies the variation rate of local Z-buffer or depth buffer for each point in maximum intensity projections. Because vessel regions normally have lower roughness than background, a threshold κ is used to pick up low roughness points as vessel seed points. The ridge traversal method generates a set of disconnected vessels from which we compose connected vessel trees using a modified minimum spanning tree algorithm [4]. **b)** Vessel matching starts from two root branches which have been manually matched. In each iteration, two subtrees stemmed from the current roots are extracted. Subtree depth is determined by the maximal possible length of matched paths. Note that due to possible neonatal vascular development and extraction imperfections, two or three branches in tree A may need to be merged and matched to one branch in tree B. Thus, a search depth P is defined as the current extracted subtree depth. Once two subtrees are extracted from current roots, the averaged spatial distance is computed for all possible matching pairs which should include all one-to-one matches and merged matches. Those closest matching pairs are selected as correct matches. Once the correct match at the current level is obtained, roots of subtrees for the next level are set to be leaf branches of current matching pairs. This process runs iteratively from root to leaf and stops when extracted subtrees only include leaf branches. Because spatial distances between two vessel branches are sensitive to misalignment, global rigid deformation needs to be removed beforehand. An indirect vasculature registration method [5] was used for this purpose. To further reduce mismatches, extracted subtrees during vessel matching are further registered to refine local alignment by a robust extension of ICP algorithm proposed [6].

Vessel trees pairs	1_LA	1_RA	2_LA	2_RA
No subtree registration	**2/23**	**1/23**	**1/30**	**5/25**
With subtree registration	**0/23**	**1/23**	**1/30**	**2/25**
Vessel trees pairs	3_LA	3_RA	4_LA	4_RA
No subtree registration	**0/12**	**0/13**	**1/9**	**8/11**
With subtree registration	**0/12**	**0/13**	**1/9**	**2/11**

Table 1. Summary of vessel matching results on 8 pairs of artery trees. For a specific vessel tree pair, the numbers before and after the slash shows the amount of mismatches and total manually established matches.

Results Four neonates were scanned twice at different ages (first scan: 6-50days, mean 22.8days; second scan: 41-90days, mean 70.3days). Left middle cerebral Artery trees (LA) and right middle cerebral Artery trees (RA) were extracted for all subjects. The tolerance for minimizing J was 1.0e-4, and κ was 1.5. Eight pairs of artery trees were correctly composed. The extracted ridge segments are precisely centered on the vessels (Figure 2). The segmentation obtained was quite exhaustive in all cases with even tip vessels extracted. The results of the vessel matching algorithm were compared to the ground-truth determined by manually matching all vascular tree pairs. The search depth was 3 in all experiments. All artery trees were successfully matched and results are reported in Table 1. Clear improvements in performance were obtained after the subtree registration exploiting the improved ICP algorithm.

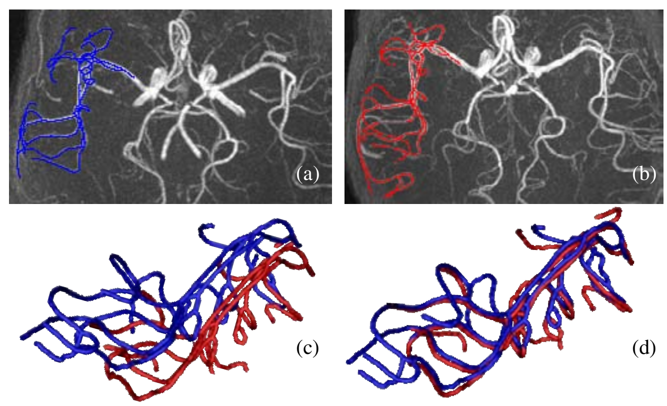

Figure 2. (a) and (b) show two middle cerebral artery trees are extracted and overlapped on the MIPs. Vessel trees are visualized in (c) and (d) with a constant radius of 0.2mm. This infant was scanned at the age of 7 days and 63 days. (c) Before registration, significant misalignment can be observed for two composed vessel trees. (d) Indirect registration method effectively decreases the misalignment between two vessel trees, which is necessary for correct branch matching. Local deformation left can be further reduced after the subtree registration.

Conclusion An automatic method for extracting and matching neonatal cerebral vasculature is presented and evaluated. This method is able to generate vessel tree structures with precise geometry and topology, and establish vessel topological correspondence to highlight neonatal cerebral vasculature development. Experiments on four neonates show this method is reliable and accurate.

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References [1] C. Malamateniou, et al., ISMRM 839, 2005. [2] S. R.Aylward, et al., *MMBIA*, 131–138, 1996. [3] D. L. Parker, et al., *JMRI* 11:378-388, 2000. [4] E. Bullitt, et al., Med Image Ana. 5: 157–169, 2001. [5] Hui Xue, et al., *MIUA, 151-154*, 2005. [6] T. Pajdla, et al., *ICCV*, 390–395, 1995.