Towards Automated Cranial 4D Flow Cranial Analysis

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Purpose

4D Flow MRI is a non-invasive imaging technique that enables the characterization of vascular anatomy and hemodynamics over a large imaging volume of interest. Detailed, multi-segmental analysis of the brain has been hindered by the complex cranial vasculature and long post processing times. Here we introduce an extension to a previously established 4D flow post processing tool[1] that automatically segments and quantifies hemodynamic parameters in all vessel segments without the need for user interaction. This simplified post processing pipeline allows for robust and repeatable analysis and provides users the ability to easily visualize and quantify complex cranial 4D flow datasets.

Methods

Ten cranial scans were acquired on healthy controls after patient consent and IRB approval. Imaging was performed on a clinical 3T scanner (MR750, GE Healthcare) using 4D flow MRI with an under-sampled radial acquisition, PC VIPR[2]. Imaging parameters included: image volume: 22x22x22 cm, isotropic spatial resolution = 0.68 mm; VENC = 80 cm/s; scan time: ~7 min, retrospective cardiac gating. The data was reconstructed into 20 cardiac phases with temporal radial view sharing[3] and image volumes of 320x320x320 voxels. Time-resolved flow analysis was completed in 13 locations: internal carotid arteries (ICA), basilar artery, middle cerebral arteries (MCA), posterior cerebral arteries (PCA), straight sinus, superior sagittal sinus, and transverse sinuses (TS).

An interactive 4Dflow processing tool (Figure 1) was implemented in Matlab2018b (Mathworks, Natick, MA) based on a previously established centerline flow processing scheme[1]. The interactive 4D tool provides improved angiograms, better centerline generation, quick vessel selection, automated background phase correction, easy visualization of quantitative parameters and less computer memory requirements. A quantitative flow comparison was completed between the original and the extended in-house tools by two individuals on PC workstations with 16GB and 32GB RAM. Analyzed outcomes included: ease of vessel selection (score), repeatability between users, time for flow analysis, and precision of local flow.

Results

The number of missed vessels reduced from 16.2% to 3.8% when analyzed in the extended 4D tool. The MCA, PCA, and TS accounted for 25 of the 26 missed vessels. Bland-Altman analysis of flow quantification between users had a reduction in mean difference and 95% confidence intervals (CI) from -0.1 [-1.88,1.68] ml/s with the old tool to 0.042 [-0.37, 0.45] ml/s with the new tool. The angiogram generation and centerline labeling times decreased from 48.6 sec to 13.2. The vessel selection and pulsatile flow verification times decreased from 15.2 min to 5.0 min (1.17 min and 0.38 min per plane), respectively. The average percent error in local flow quantification was 2.8±2.6% for the old tool and 2.9±2.2% for the new tool. A z score test on percent error between the 2 methods showed a mean and 95% CI of -0.071 [-0.5, 0.4] %.

Discussion

Both analysis tools showed a high repeatability between users with a slight improvement for the new 4D Flow tool. The extended 4D Flow analysis tool provided angiograms and centerlines with improved vessel visibility and selection capabilities for short and small vessel sections. Additional users and cases, which will be analyzed in the future, will help further investigate repeatability between tools. We have successfully added additional post processing functionality and visualization while reducing the time needed for completing a multi-vessel cranial analysis. The consistency of local flow measurements for both implementations showed an average error <3% maintaining the robust flow quantification at selected vessel locations. Future tool improvements are currently underway to allow the analysis of product 4D flow datasets from various clinical vendors (GE, Siemens, Philips). Such analysis tools with high repeatability and robustness will be needed for high volume and for long-term cranial flow studies.

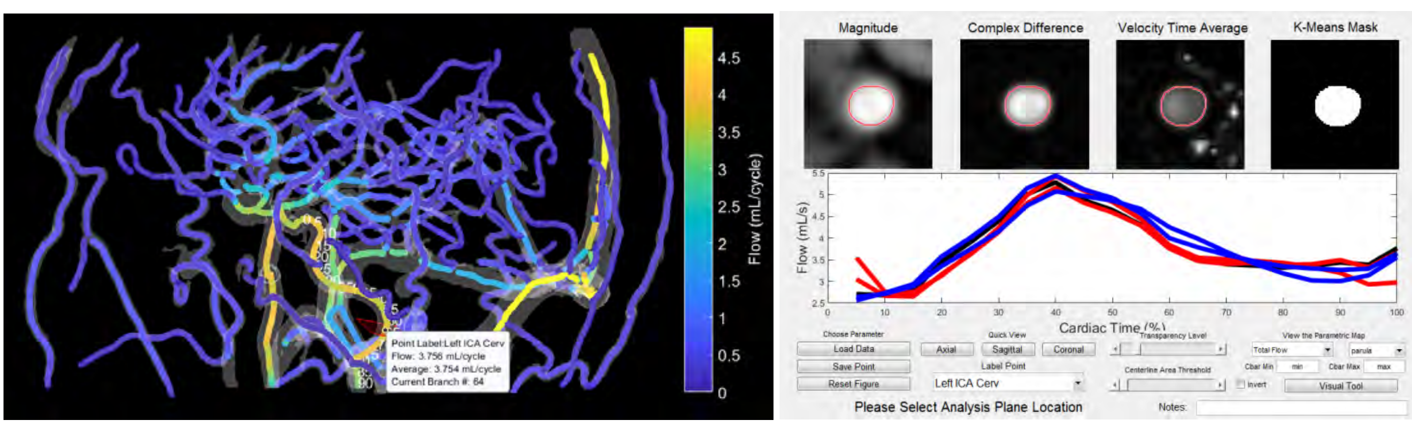

Figure 1 4D flow post processing tool with 3D interactive graphical user interface. Quantitative parameters (area, flow, pulsatility index, etc.) color encode the centerlines of all automatically segmented vessel. As the user moves the cursor in 3D the cross-sectional images and flow cycle are updated in real time.

References: [1] Schrauben, E. et al JMRI 2015;42:1458–64. [2] Johnson, K. M. et al MRM. 2008; 60(6), 1329-1336. [3] Liu, J. et al IEEE TMI 2006; 25(2):148-57.