Blood Volume Flow Rates of Vessels in Healthy Human Cerebral Vasculature

M Ethan MacDonald, Parviz Dolati, John H Wong, Richard Frayne

Biomedical Engineering, Radiology, Clinical Neurosciences, and Hotchkiss Brain Institute, University of Calgary, Alberta, Canada
Seaman Family MR Research Centre, Foothills Medical Centre, Calgary, Alberta, Canada

UNIVERSITY OF CALGARY

INTRODUCTION

- Phase contrast (PC) magnetic resonance (MR) imaging can be used to obtain maps of flow velocity
- Hemodynamic parameters such as peak velocity (v_{peak}) and volume flow rate (VFR) can be derived from from these velocity maps
- Blood flow through the brain is known to be highly variable between subjects and even in repeated measurements of the same subject [1,2]
- Velocity mapping techniques have had limited clinical utility because knowledge of normal flow measurements is poorly characterized
- PC-MR can be acquired in 3D or 4D, higher spatial resolution is achievable with 3D imaging
- This work aims to establish v_{peak} and VFR in a broader range of cerebral vessels than in previous studies
- VFR is known to be affected by partial volume errors, resulting in an overestimation [3]

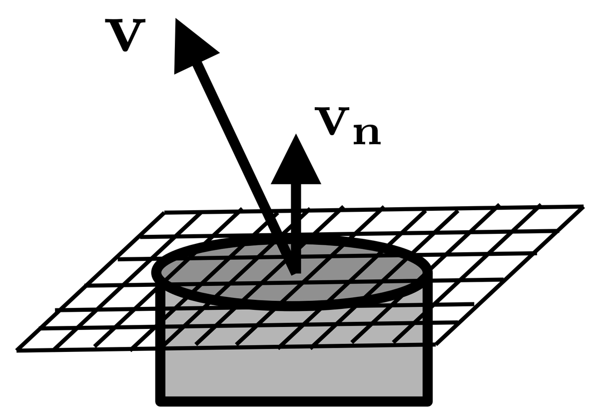
HYPOTHESIS

Because of implicit averaging across the vessel lumen, we expect a lower coefficient-of-variation (COV) in the VFR measurements compared to v_{peak}. We also expect the COV to increase in smaller caliber arteries.

METHODS

Subjects

- 30 healthy subjects without known cerebrovascular disease were prospectively imaged for this study
- Images were screened for incidental findings of cerebrovascular disease
- There were 17 males and 13 females
- Ages ranged between 18 and 64 years of age with at least 2 subjects in each decade
- The majority of the subjects (18/30) were between 20 and 40 years of age



$$v_{peak} = max\,(abs\,(\mathbf{v}))$$

$$\mathrm{VFR} = \sum_{\mathbf{v_{n\,k=1}}}^{N} \mathbf{v}(\mathbf{v_{n\,k}}) \cdot \mathbf{v_{n\,k}}$$

Figure 1: Diagram illustrating the peak velocity (v_{peak}) and volume flow rate (VFR) calculations. A cut plane (denoted by the grid) is placed across the vessel (grey). v_{peak} is found as the max of the absolute velocity on the cross section. VFR can then be found by summing the dot product of blood velocity with the vector normal to the cut plane.

MR Acquisition

- Imaging was performed on a 3-T MR Scanner (Discovery 750, General Electric Healthcare, Waukesha, WI)
- Velocity encoding was performed in three orthogonal directions
- Acquisition parameters included: (Time = 10 min 40 s)
  - FOV of 22.0 cm × 16.5 cm × 19.2 cm
  - Acquisition matrix size of 256 × 192 × 192
  - TR/TE/α of 8.3 ms/3.8 ms/10°
  - Venc of 150 cm/s

Analysis

- v_{peak} and VFR were calculated for each cut plane, illustrated in Fig 1
- Cut planes were placed in 26 vessel segments (Fig 2) with typical diameters >1 mm
- Bootstrapping was performed, whereby 10,000 permutations of the subject order were used to find how the standard deviation changed as a function of the number of subjects
- Mean, standard deviation and COV were calculated for the population for both metrics in each vessel

RESULTS

- The bootstrap analysis revealed that the average standard deviation measured in each vessel segment converged to within 95% of the cohort overall average standard deviation after inclusion of fifteen to twenty subjects (Fig 3)
- The mean, standard deviation and COV for v_{peak} and VFR are shown in Fig 4

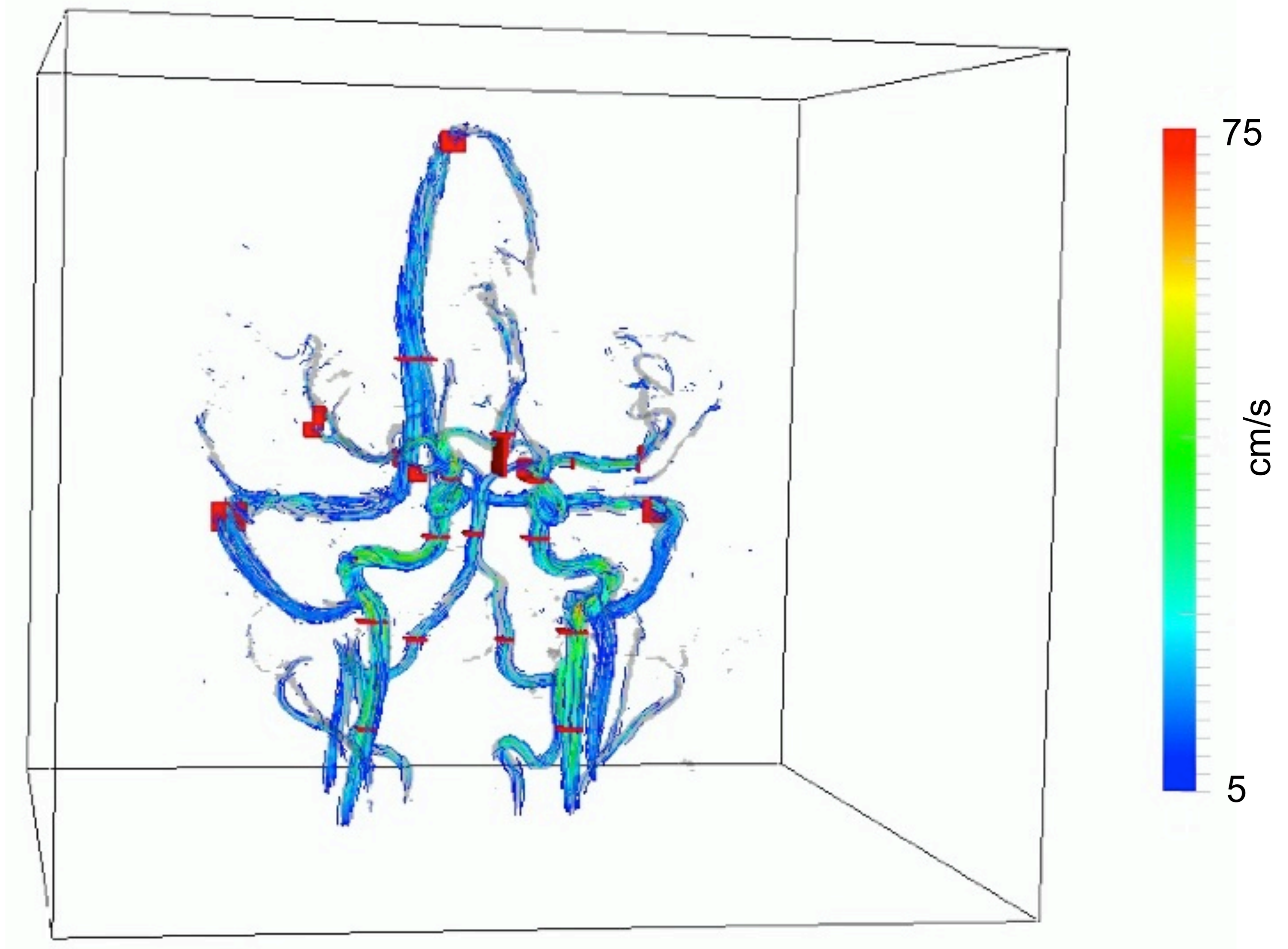


Figure 2: Streamline PC MR angiography image and cut planes derived from one 3D data set. Angiogram is rendered with streamlines color encoded with the blood speed. The red planes are representative of the twenty-six cut planes placed in the rest of the subjects.

DISCUSSION

- Images with sufficient quality for analysis were collected in all the subjects
- In only one subject (3.3%) was the scan repeated due to motion
- VFR COV was lower than v_{peak} COV in only 57.7% of the subjects, contrary to expectations
- The v_{peak} COV ranged from 0.26 to 0.40 in the larger arteries and was generally higher in the smaller arteries, range 0.30 to 1.37
- The VFR COV varied from 0.22 to 0.33 in the larger arteries and from 0.31 to 1.46 in the smaller arteries

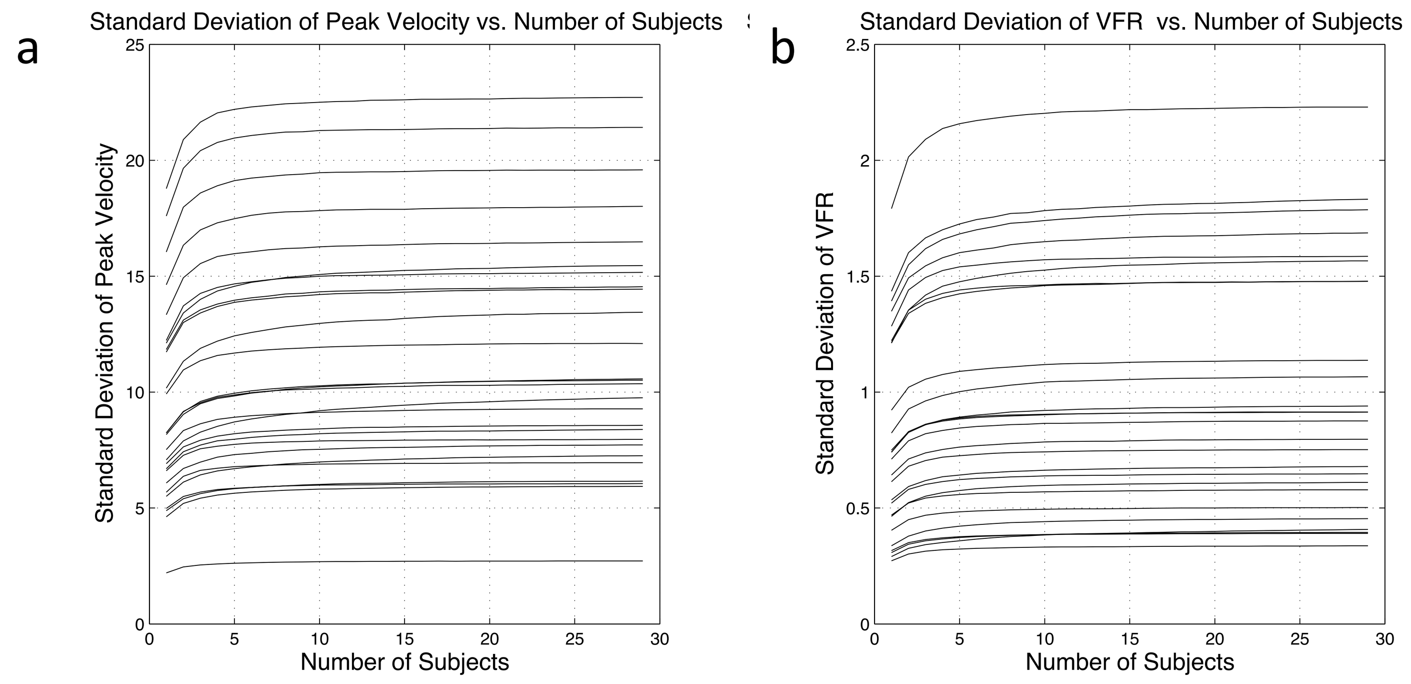


Figure 3: Study of the standard deviation change with subjects for (a) peak velocity (v_{peak}) and (b) volume flow rate (VFR). Each line corresponds to a vessel segment. The average standard deviation with respect to the number of subjects was plotted and demonstrated that, in each vessel, the average standard deviation converges after inclusion of fifteen to twenty subjects.

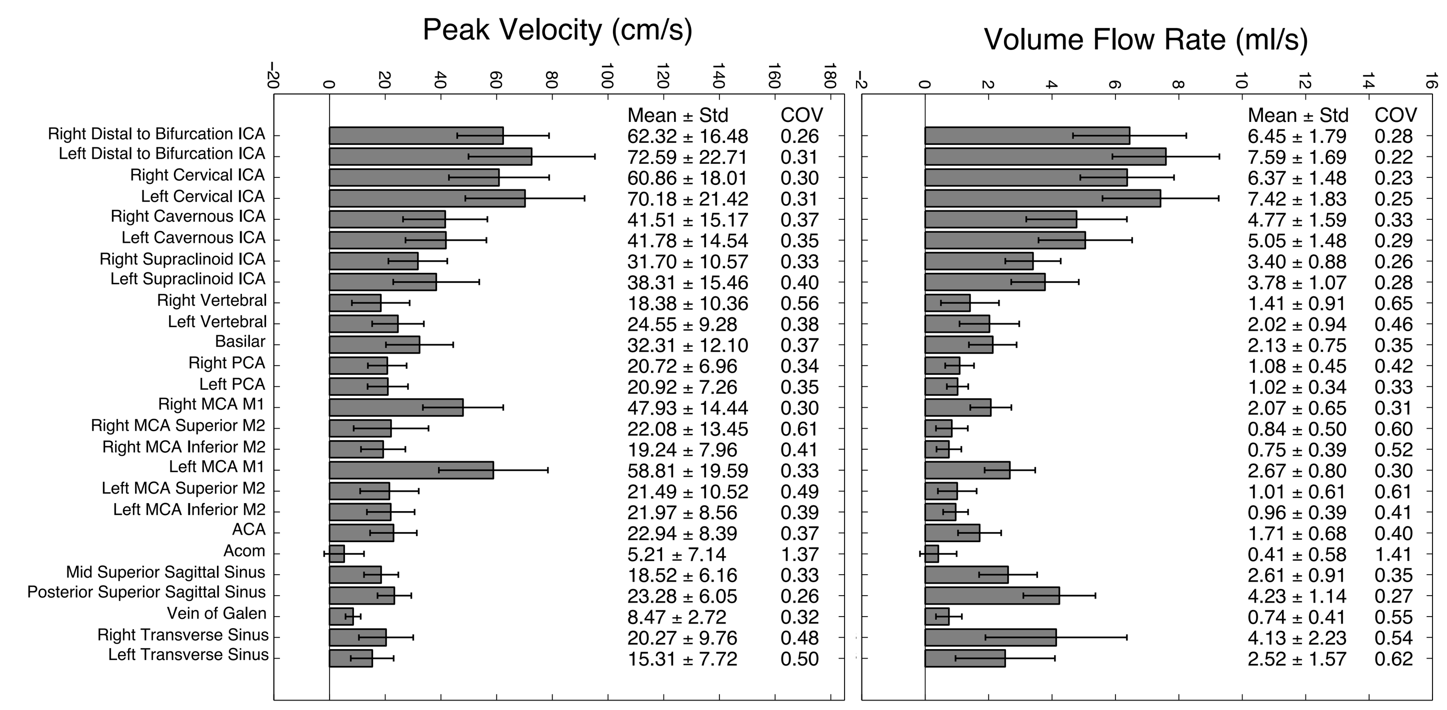


Figure 4: Peak velocity (vpeak) and volume flow rate (VFR) measured in each vessel segment. Mean and standard deviation, along with coefficient of variation (COV) are reported.

REFERENCES

1. Cameron, *et al.*, Life Sci, 1990
2. Henriksen, *et al.*, JMRI, 2012
3. Tang, *et al.*, JMRI, 1993

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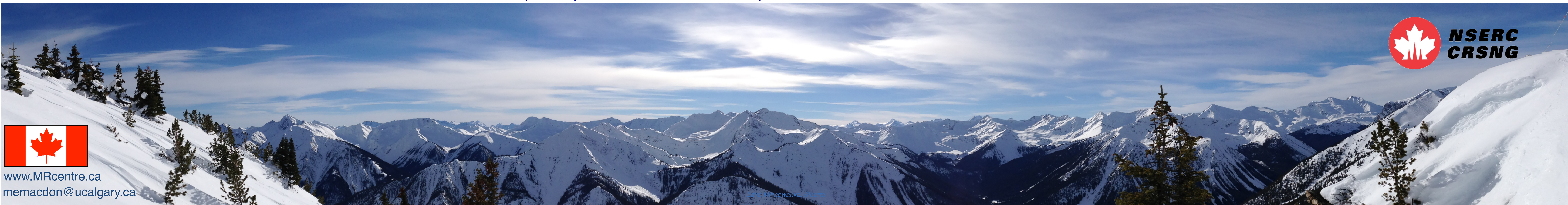

www.MRcentre.ca
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