Characterization of Normal Cerebrovascular Volumetric Flow Rate Dynamics by PC-MRI

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Introduction

Characterization of normal cerebrovascular volumetric flow rate dynamics is important for establishing baselines against which normal and pathological changes can be assessed, and for providing necessary inputs to computational and in vitro models of the cerebrovasculature. While a number of studies have looked at *time-averaged* flow rates in the internal carotid and vertebral arteries, little information is available on how volumetric flow rates vary over the cardiac cycle in these key feeding vessels. The aim of this study was to remedy this situation.

Methods

Retrospectively-gated cine phase contrast images were acquired from normal subjects (16M:2F; 30±9.2 years). Images were acquired on 1.5T (N=10) and 3T (N=8) scanners (GE Healthcare; Waukesha WI) using a 6 mm thick slice, 14 cm field-of-view, 256x128 acquisition of 32 cardiac phases; slices were placed transverse to the axis of the internal carotid and vertebral arteries [1]. Volumetric flow rates were calculated from these images using the PUBS algorithm [2]. Measurements were repeated for three subjects each imaged three times within the same scanning session.

To characterize the *shape* of the waveform independent of differences in mean flow rates, each waveform was first normalized to its respective mean. Then, following Holdsworth et al. [3], a number of feature points (identifying local maxima, minima and times between these; see figure) were semi-automatically extracted from each waveform. Waveforms were then registered so that their second feature point (the time to half maximum flow) was coincident. Feature points from the internal carotid and vertebral artery waveforms were then analyzed to identify the means and variations in both flow rate and time. A representative waveform for each vessel was then constructed by fitting a spline through these averaged feature points.

Results

Figure 1 shows the registered individual internal carotid and vertebral artery waveforms, over which are superimposed the feature points and spline-fitted average waveforms. Despite significant differences between mean flow rates in the internal carotid and vertebral arteries (274±56 ml/min vs. 89±44 ml/min), we observed remarkably little difference between the average shapes of the respective normalized waveforms. The larger vertical error bars clearly evident in the vertebral artery waveforms were attributed to the fact that these waveforms were normalized using lower mean flow rates, and hence the normalized flow rates were more sensitive to noise compared to the internal carotid artery flow rates. That this was indeed the case was also suggested by a subgroup analysis of the 1.5T and 3T groups, which revealed similar variations in the internal carotid artery waveforms, but more variation in the vertebral waveforms for the 1.5T vs. 3T group. The observed variations in normalized flow rate were also found to be significantly larger than those calculated from the intra-session acquisitions, suggesting that they may be attributed largely to inter-individual rather than measurement variability. Finally, the large horizontal error bars clearly evident during the diastolic, but not systolic phases, of both waveforms confirm the observation that variations in heart rate (here 69±7.9 bpm) are accommodated mainly by changes in the duration of the diastolic tail.

Subgroup analysis of left vs. right sides revealed little difference in the shape of the average normalized flow rate waveforms. Mean flow to the left:right internal carotid arteries was 51:49(±5) on average, which was not significantly different from 50:50 given the inter-individual variations. However, there were significant differences in mean flow rates to the vertebral arteries, with one vessel receiving on average 68±11% of the mean flow, and with no preference for left vs. right flow dominance. Nevertheless, despite these large inter-individual variations in mean flow, left vs. right waveform shapes were remarkably consistent.

Conclusions

Volumetric flow rate dynamics in the internal carotid and vertebral arteries may be characterized by the representative normalized internal carotid artery flow rate waveform presented here. Intra- and inter-individual variations in flow to these vessels may be accounted for merely by scaling this waveform shape by the respective mean flow rates, and by extending the diastolic tail of the waveform to accommodate variations in heart rate. This has distinct advantages for cerebrovascular modelling studies where multiple input or output waveforms may be required.

References

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[3] Holdsworth DW, et al. Physiol Meas 1999;20:219-240.

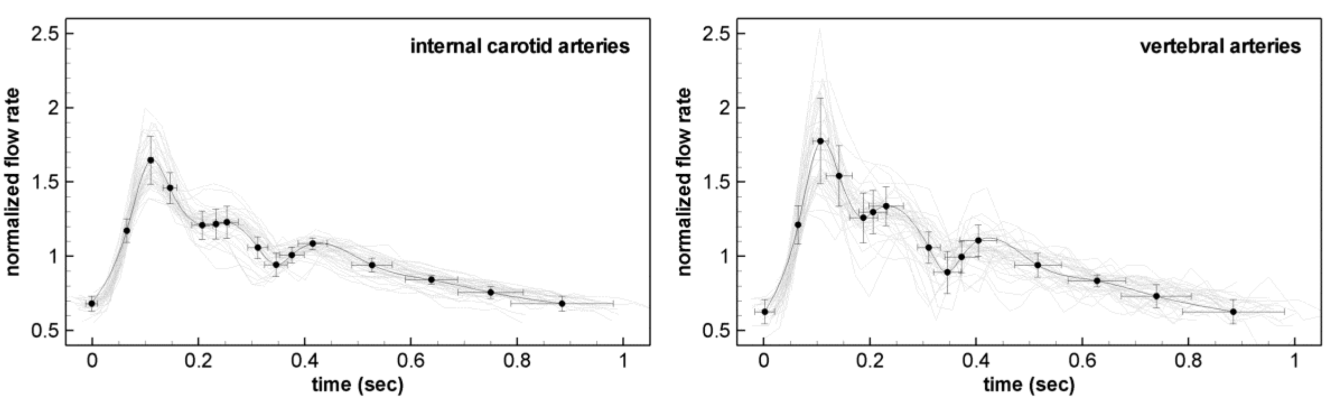

Figure 1. Individual (grey) and average (black) internal carotid and vertebral artery normalized flow rate waveforms. Bullets and error bars identify the means and standard deviations (in both time and flow) for each feature point used to characterize the waveforms.