Hemodynamic simulations of subjects with vertebro-basilar anomalies

A. K. Wake[1], J. C. Gatenby[2], and J. C. Gore[1]
[1]Vanderbilt University Institute of Imaging Science, Vanderbilt University Medical Center, Nashville, TN, United States, [2]Department of Radiology, University of Washington, United States

Background. The vertebro-basilar system (VBS) is unique in the human vasculature because two large arteries (left vertebral, LV; right vertebral, RV) merge to form the basilar artery (BAS). While conducting an MR study to characterize flow in the VBS, we encountered two subjects with a relatively "common" anomaly: a vertebral artery terminated in a posterior inferior cerebral artery (PICA) (occurred in four of 20 subjects in [1]). It is reasonable to expect that the lack of a second, contributing vertebral artery influences the flow field in the basilar artery, so we built subject-specific computational fluid dynamics (CFD) simulations of flow in the system to quantify pathophysiologically-relevant flow parameters (e.g. wall shear stress) [2].

Methods. Informed consent was obtained from subjects prior to their participation in the study, which was approved by the Vanderbilt University Institutional Review Board. A Philips Achieva 3T MR scanner (Philips Healthcare) and a 16-channel neurovascular coil with SENSE were used to obtain all MR data. Vertebral and basilar arterial geometries were measured using TOF angiography (number of slices=100; acq. voxel size=0.5 x 0.5 x 0.6 mm^3; recon. voxel size=0.4 x 0.4 x 0.6 mm^3; TR=23 ms; TE=3.45 ms; SENSE factor=2). The TOF data were used to define the location and orientation of phase contrast MR (PCMR) velocity measurements of blood flow. PCMR measurement planes were oriented perpendicular to the axial flow direction in the LV, RV (when present), and BAS; retrospectively ECG- or PPU-triggered PCMR was used to obtain the through-plane velocity distribution data at 21 or 25 time points per cardiac cycle at each location (acq. voxel size=0.33 x 0.33 x 5 mm^3; recon. voxel size=0.3125 x 0.3125 x 5 mm^3; TR=15 ms; TE=8.5 (21 phases) or 8.2 (25 phases) ms; VENC=100 cm/s). Using the TOF and PCMR data as the geometry and velocity conditions, subject-specific CFD simulations were conducted using Fluent 12.0.16 (Ansys, Inc.). Subjects 1 and 2 had RVs that terminated in PICA; Subjects 3 and 4 possessed typical VBS geometries.

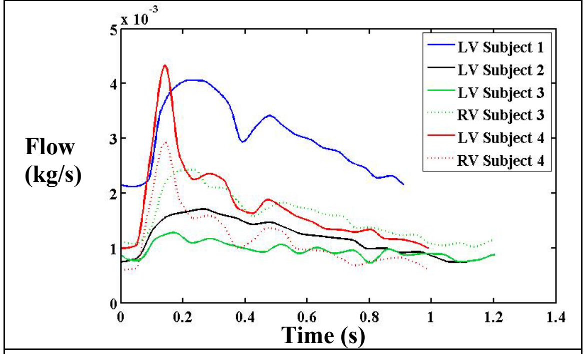

Figure 1. PCMR-measured flow rate (kg/s) in the LV and RV. The RVs of Subjects 1 and 2 terminated in PICA; Subjects 3 and 4 had typical LV/RV/BAS vertebro-basilar configurations.

Results and Discussion. The LV flow rates for Subjects 1 and 2 are commensurate with individual LV and RV flow rates of subjects with typical VBS configurations (Subjects 3 and 4) (Fig. 1). However, it is important to note that both the LV and RV contribute to the total flow in the BAS of the typical VBS, so the total BAS flow in subjects with a vertebral terminating in PICA will be relatively low compared to BAS flow in the typical VBS. Subjects 1 and 2 demonstrated time-averaged wall shear stress (WSS) distributions with trends similar to those expected for steady flow in a curved pipe: velocity profiles skew towards the outer wall of a curve; thus, areas of locally high, time-averaged WSS appeared at the outer wall of the major curve of the vessel [3] (Fig. 2). Although the degree of curvature varied between the subjects, the major curve of the vessel was reminiscent of the paths of the vertebral vessels as they merge into the basilar artery in a typical vertebro-basilar confluence (Fig. 2). However, the typical VBS WSS distribution is complicated by the merging flow of the two vertebral arteries. This merging flow, which has varying flow ratios, can produce a stronger, sweeping helical flow in the basilar artery. The flow in a typical VBS depends on the degree of dominance of flow in contributing arteries and in the angle of vertebral confluence [1,4]. In the subjects whose RV terminates in PICA, the helical nature of flow is purely dependent on the geometry of the curve as the LV becomes the BAS and the temporal nature of the flow.

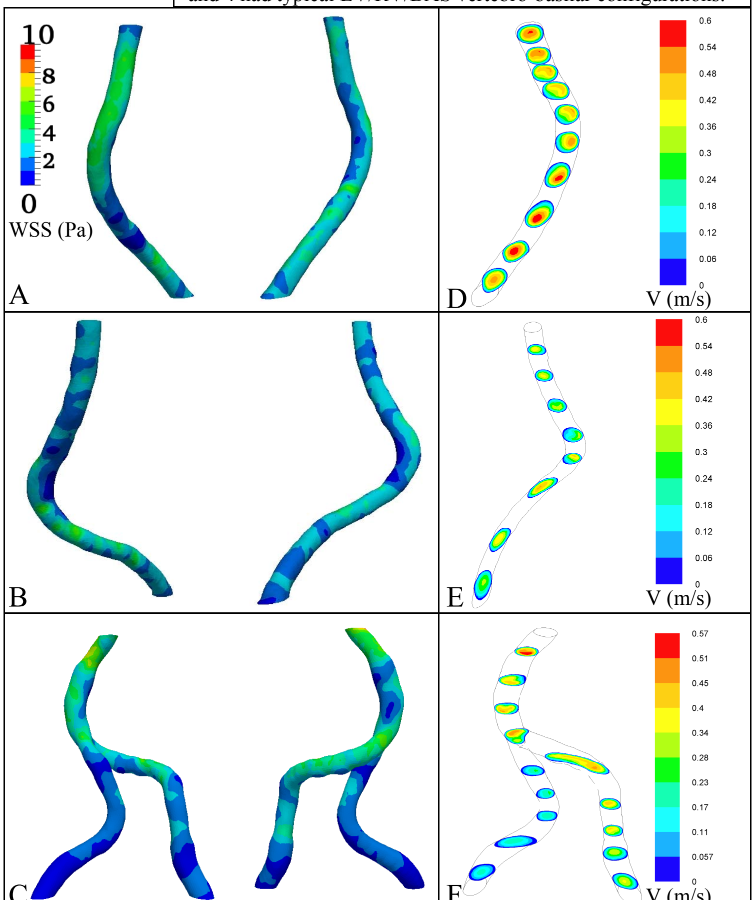

Figure 2. A-C) Time-averaged WSS distributions of Subjects 1-3, respectively (colorbar in A applies to A-C). D-F) Axial velocity contours in Subjects 1-3, respectively.

Conclusion. WSS distributions were calculated from subject-specific CFD models of flow in subjects with vertebral arteries terminating in PICA. Characterizing VBS hemodynamics in subjects with this anomaly will enable us to better understand the cerebral blood flow system in these subjects and in subjects with typical vertebro-basilar confluences.

1. Smith AS and Bellon JR, *Am. Soc. Neurorad.* 16:1587-1591, 1995.
2. Bassiouny, HS, *et al.*, *J. Vasc. Surg.* 15:708-717, 1992.
3. Berger SA, *et al., Ann. Rev. Fluid Mech*. 15:461-512, 1983.
4. Ravensbergen J, *et al.*, *J. Biomech.* 29:281-299, 1996.