THE INFLUENCE OF FLOW FREQUENCY PARAMETER AND REYNOLDS NUMBER ON FLOW IN THE AORTIC ARCH AND ITS BRANCHES

H. A. Dwyer, A.Y. Cheer, T. Kim, and A. Barakat

Dept. of Mechanical & Aero. Engineering
University of California, Davis
Davis, California 95616

INTRODUCTION AND SUMMARY

A three-dimensional and pulsatile blood flow in a human aortic arch and its three major branches has been studied numerically for peak Reynolds numbers of $250 \leq Re \leq 2500$ and for frequency (or Womersley) parameter values of $.1 \leq \alpha \leq 15$. The simulation geometry was derived from the three-dimensional reconstruction obtained in vivo using CAT scan imaging [7]. Shown in figure (1) below are the mesh geometry, the flow pulse shape [4], and the area variations in the main aorta and its branches. The numerical simulations were obtained using a projection method, and a finite-volume formulation of the Navier-Stokes on a system of overset grids [2-4] and [5-6]. Our results demonstrate a strong dependence on frequency parameter at lower values as well as Reynolds number. For higher values between eight and fifteen, the primary flow velocity is skewed towards the inner aortic wall in the ascending aorta, but this skewness shifts to the outer wall in the descending thoracic aorta. Within the arch branches, the flow velocities were skewed to the distal walls with flow reversal along the proximal walls. Extensive secondary flow motion was observed in the aorta, and the structure of these secondary flows was influenced considerably by the presence of the branches. Within the aorta, wall shear stresses were highly dynamic, but were generally high along the outer wall in the vicinity of the branches and low along the inner wall, particularly in the descending thoracic aorta. Wall pressure was low along the inner aortic wall and high around the branches and along the outer wall in the ascending thoracic aorta. For lower values of the frequency parameter the influence of curvature plays a more significant role, and the flows have a more steady state nature. The full paper will include the wall shear stress variations as well and dynamic pressure variations as shown in figure (2).

METHOD OF APPROACH AND RESULTS

The numerical methods we have used in the paper have played a major part in our ability to obtain the solutions, and they consisted of the following:

- Finite volume formulation of the basic equations
- Second methods in space and time
- Overset grids to resolve boundary layers and bifurcations
- Matrix free GMRES with pre-conditioned ADI
- Pressure field acceleration with use of unsteady potential flow correction

Besides yielding excellent resolution of the high gradient region of the flow, the overset grid methods allow for an excellent structured matrix, which can be solved with efficient ADI type methods.

REFERENCES

1. Hamakiotes C.C., Berger S.A., 1990, "Periodic Flows through Curved Tubes: the Effect of the Frequency Parameter", J Fluid Mech, 210, pp. 353-370.
2. Dwyer, H.A., Cheer, A.Y., and Rutaginira, T., 1998, "Highly Unsteady Flows in Curved Pipes", 16th Inter. Conf. On Numerical methods in Fluid Dynamics, Arcachon, France, 6-10, Lecture Notes in Physics, Springer-Verlag Publications.
3. Dwyer, H.A., Cheer, A.Y., and Rutaginira, T., and Shahcheraghi, N., 2001, "Calculation of Unsteady Flows in Curved Pipes", ASME J. Fluids Eng., 123, pp. 869-877.
4. Pedley T.J., 1980, The Fluid Mechanics of Large Blood Vessels, Cambridge University Press.
5. Cheer A.Y., Dwyer H.A., Barakat A.I., Sy E., Bice M., 1998, "Computational Study of the Effect of Geometric and Flow Parameters on the Steady Flow Field at the Rabbit Aorto-Celiac Bifurcation. Biorheology, 35, pp. 415-435.
6. Shahcheraghi, N., Dwyer, H.A., Cheer, A.Y., Barakat, A.I., and Rutaganira, T., "Unsteady and Three-Dimensional Simulation of Blood Flow in the Human Aortic Arch", ASME J. of Biomechanical Engr., 124, pp. 378-387.
7. Chandran K.B., 1993, "Flow Dynamics in the Human Aorta", J Biomech Eng, 115, pp. 611-616.

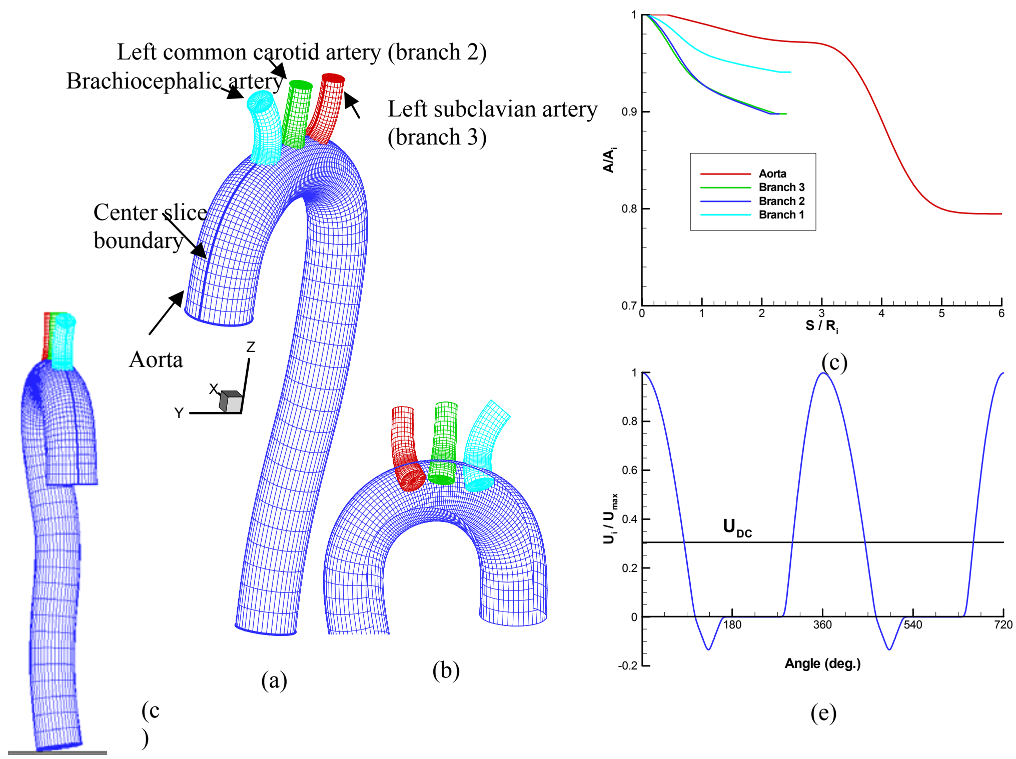

Figure (1) Basic Aorta Geometry, Flow Pulse, and Area Variations

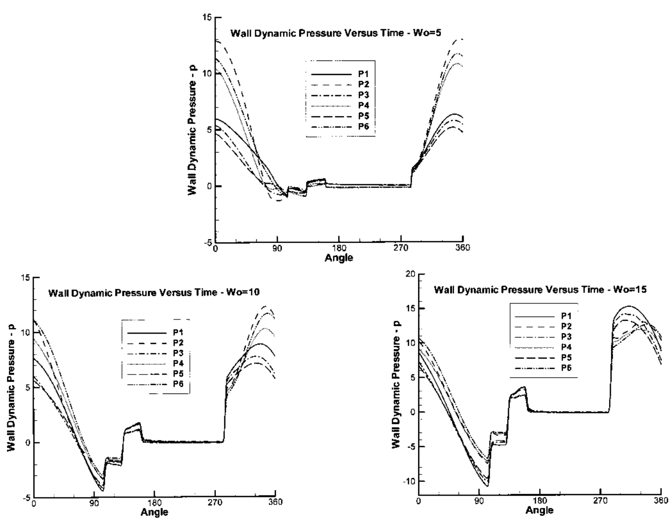

Figure (2) Wall Pressure Variations at Frequency parameters of 5, 10, and 15 for a peak Reynolds Number of 2500