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# APPLICATION OF THE MULTISCALE APPROACH TO INVESTIGATE FLUIDYNAMICS IN SURGICAL PROCEDURES FOR THE TREATMENT OF CONGENITAL HEART DISEASES

***Gabriele Dubini[1], Francesco Migliavacca[1], Giancarlo Pennati[1], Rossella Balossino[1], Katia Laganà[1], Edward L. Bove[2], Tain-Yen Hsia[3] and Marc R. de Leval[3]**

[1] Dept. Structural Engineering
Politecnico di Milano
Piazza L. da Vinci, 32
20133 Milan, Italy
gabriele.dubini@polimi.it
http://www.labsmech.polimi.it

[2] Dept. of Surgery,
University of Michigan School of Medicine, 1500 East Medical Center Drive, Ann Arbor, MI 48109, USA
elbove@umich.edu

[3] Great Ormond Street Hospital for Children – NHS Trust
Great Ormond Street
London WC1N 3JH, UK
hsiaty@musc.edu

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## ABSTRACT

*Introduction.* Multiscale computing is a challenging area in biomechanics. In particular, its applications to quantitatively compare postoperative haemodynamics in congenital heart diseases is very promising. In the treatment of hypoplastic left heart syndrome, which is a congenital heart disease where the left ventricle is missing or very small, the pulmonary and systemic circulations are fed via an interposition shunt. Two main options are available and differ from the sites of anastomoses: i) the systemic-to-pulmonary conduit (Blalock-Taussig shunt known as the Norwood Operation) connecting the innominate artery to the right pulmonary artery [1] and ii) the right ventricle to pulmonary artery shunt (known as Sano operation). The proposition that the Sano operation is superior to the Norwood operation remains controversial. In the present work the two options were investigated and compared adopting a multiscale approach.

*Methods*. Two different 3-D detailed models of Norwood stage I procedure based on finite volume method were developed: a Sano shunt operation (SO) and one systemic-to-pulmonary shunt (the modified Blalock-Taussig shunt, NO). Size of the conduits were 4, 5 and 6 mm for the SO models and 3, 3.5 and 4 mm for NO ones. The circulatory network and the cardiac function were simulated by means of a lumped parameter model built on the basis of data of 28 patient submitted to catheterization prior stage II [2]. A multiscale approach [3] was adopted to couple the 3-D models with the lumped circulation model (Fig. 1). The coupling was accomplished by means of interface conditions, appropriately related to the interface flow rates and pressures, in particular uniform, time-dependent pressures were imposed at the boundaries of the 3-D model, while the local velocity profiles were not forced, but calculated at each time instant. This allowed the detection of possible reversal flows at the interfaces.

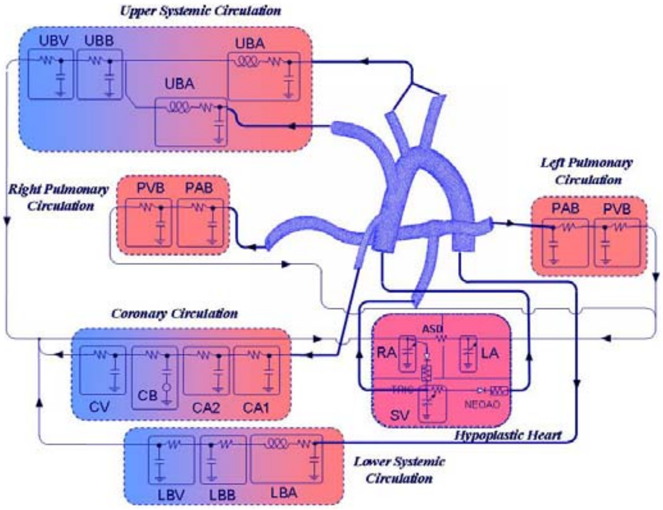


*Fig. 1 - SO shunt coupled model.*

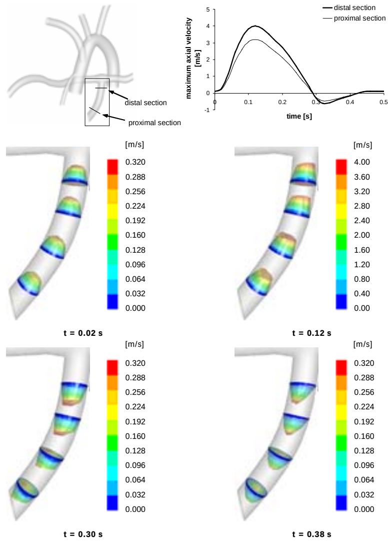


*Fig. 2 - Velocity profiles in the SO shunt.*

The main assumptions for all the mathematical models were as follows [2]: pulmonary vascular resistance (PVR) of 2.3 Wood Units (mmHg/l/min), systemic vascular resistance (SVR) of 21.6 Wood Units, heart rate of 120 beats per minute.

*Results*. The results showed that the SO models exhibit, when compared with the NO models at similar cardiac output, lower pulse pressure (difference between the maximum and minimum pressures in a cardiac cycle), lower pulmonary-to-systemic flow ratio, lower pulmonary artery pressure, lower ventricle systolic and diastolic pressures, higher coronary perfusion pressure (difference between the diastolic aortic and the diastolic right atrial pressure) which are consistent with literature measurements.

Mathematical models also predicted behaviours which are not confirmed at the moment by clinical evidence. Indeed, we observed in the SO models higher coronary blood flow. Figure 2 depicts the velocity profiles along the SO shunt at four different instants of the cardiac cycle.

In conclusion, The results of these models still do not support superiority of one technique over the other in terms of flow dynamics and ventricular energetics. Moreover, the close correlation between predicted and observed data supports the use of multiscale modelling in the design and assessment of surgical procedures. Indeed, reversal flows in the SO shunt were detected from Doppler measurements, too.

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