Flow through the ductus arteriosus is a multifactorial phenomenon

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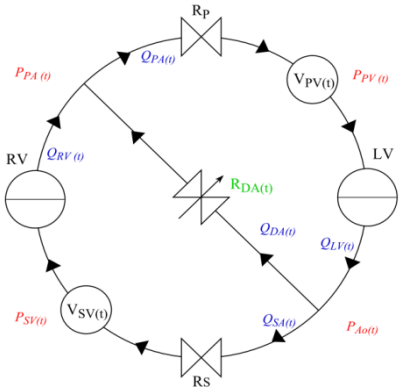
Introduction

In healthy neonates, the ductus arteriosus (DA), a vessel connecting the pulmonary artery to the proximal descending aorta, closes permanently within two or three weeks after birth. In some cases, the DA will remain open for a longer period of time constituting a patent ductus arteriosus (PDA). The effect of a PDA on circulation and gas transport is difficult to assess clinically. Therefore, it would be useful to explain and predict the effect of a PDA on hemodynamics via a model. The explanatory purpose calls for the simplest possible model that can be represented in a reasonable approximation the most salient phenomenon: return of systemic arterial blood to the lungs via the ductus. Here we propose a low order, non-pulsatile model of the average flow rate through the DA: $Q_{DA}(t)$.

Methods

The conceptual model, figure to the right, uses three types of components: resistances, compliances, and simplified non-pulsatile ventricle models. $Q_{DA}(t)$ as a function of the state variables, volume in systemic and pulmonary veins, $V_{SV}(t)$ and $V_{PV}(t)$, is given by:



$$(1)\ Q_{DA}(t) = \frac{(R_S K_{LV} - 1)\frac{V_{PV}(t) - UV_{PV}}{C_{PV}} - (R_P K_{RV} - 1)\frac{V_{SV}(t) - UV_{SV}}{C_{SV}}}{R_{DA} + R_P + R_S}$$

with UV_{SV} and UV_{PV} the unstressed volumes and C_{SV} and C_{PV} the compliances of the systemic and pulmonary veins, R_{DA} the resistance of the DA, R_S and R_P the resistances of the systemic and pulmonary circulation, and K_{LV} and K_{RV} the constants that determine how much flow the ventricles generate per unit of pre-load. A preliminary sensitivity analysis was performed using model parameters derived from the literature [1, 2].

Results

Equation (1) demonstrates that flow through the ductus is a multifactorial phenomenon (even within the limitations of this highly simplified model). This is confirmed by the preliminary sensitivity analysis, results of which will be presented at the conference.

Conclusion

The analytical solution and the sensitivity analysis confirm that flow rate through the DA is a multifactorial phenomenon, and cannot be predicted from a limited set of hemodynamic quantities. It may be possible to adapt the model parameters of this low order model to specific patients, in which case clinical predictive use would come within reach.

References

[1] Sa-Couto CD, Meurs WL Van, Goodwin J a, Andriessen P. A Model for Educational Simulation of Neonatal Cardiovascular Pathophysiology. Pediatr Res 2010; 67(2): 158-165.
[2] Sá-Couto CD, Andriessen P, Van Meurs WL, Ayres-De-Campos D, Sá-Couto PM. A model for educational simulation of hemodynamic transitions at birth. Pediatr Res. 2010;67(2):158–65.