An Educational Simulation of Hypoplastic Left Heart Syndrome

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Introduction

- Hypoplastic left heart syndrome (HLHS) is the archetype of a heterogeneous group of congenital cardiac lesions with similar but complex single ventricle physiology.
- Correct management of patients with HLHS and other single-ventricle lesions requires an understanding of the many interrelated components that influence systemic oxygen delivery.
- We describe a new educational computer simulation of unrepaired HLHS which allows the learner to experiment with varying multiple physiologic parameters to visualize their effect on circulatory balance and oxygen delivery, as well as clinically measured circulatory variables such as arterial pressure and pulse oximetry.

Methods

- The underlying algorithm is a simple hydraulic flow model functionally identical to that described by Barnea [1].
- A single ventricle pumps into two parallel circuits (systemic and pulmonary) with flow distributed according to the relative resistances of the two circuits, each of which can be varied by the user with slider controls. The ductus arteriosus is assumed to be widely patent and without significant resistance.
- Total cardiac output is determined by heart rate and stroke work which are user-adjustable, as well as total afterload, determined by systemic and pulmonary vascular resistances.
- Systemic oxygen delivery is determined by cardiac output, systemic oxygen consumption (VO_2), pulmonary to systemic blood flow (Q_p:Q_s) ratio, pulmonary venous oxygen saturation ($S_{pv}O_2$) and hemoglobin concentration. These can all be altered by the user to simulate changing clinical conditions.

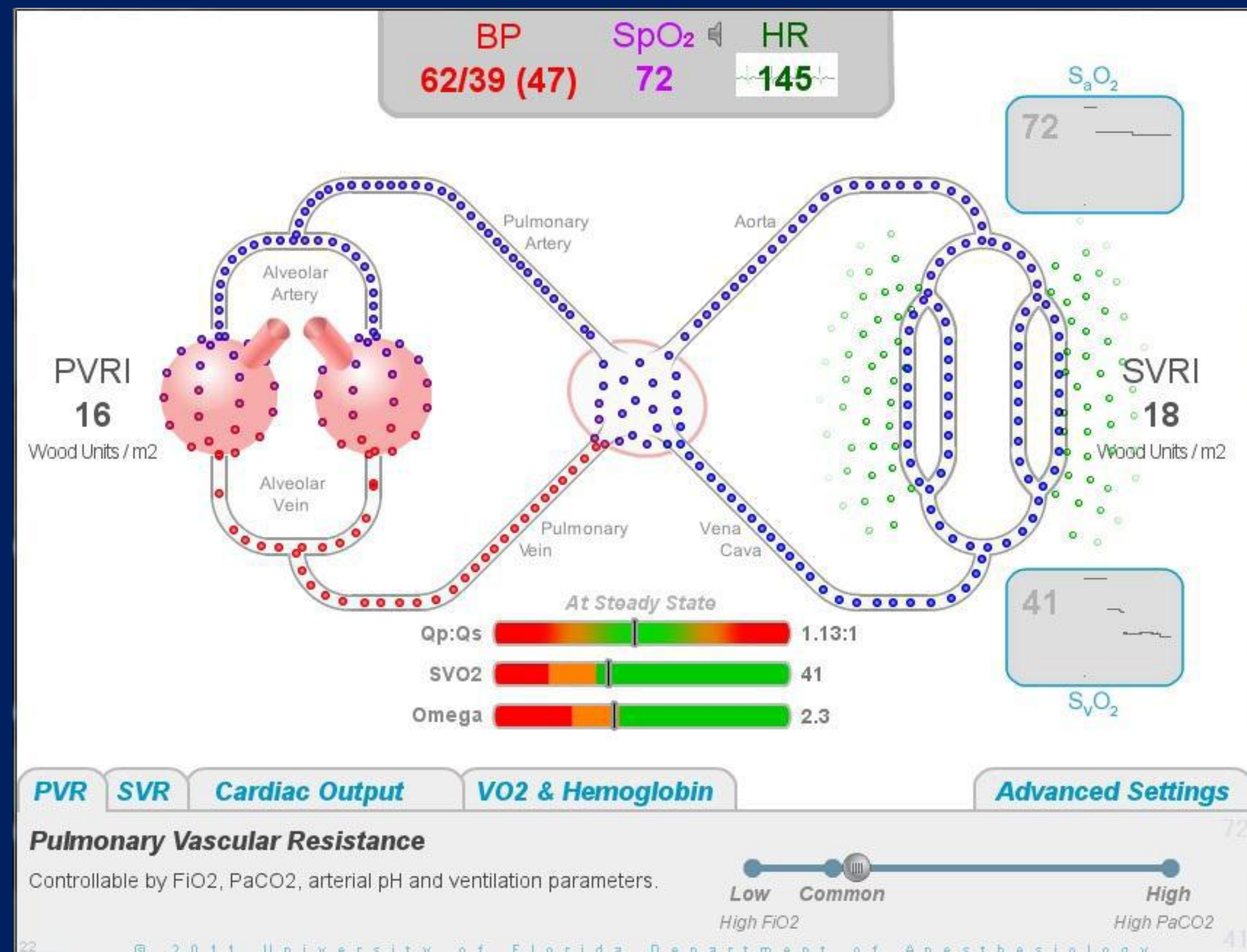

Figure 1. The display shows a well-balanced single-ventricle circulation with approximately equal pulmonary and systemic blood flow. Moving colored dots graphically represent blood saturation and flow to the two circulations with "chart-recorder" displays for systemic arterial and mixed venous oxygen saturations. The user can vary pulmonary (as seen here) and systemic vascular resistances, cardiac output, oxygen consumption and hemoglobin concentration to see the effects on systemic oxygen delivery. The adequacy of systemic oxygen delivery is displayed by Omega (ratio of oxygen delivery to consumption) and systemic mixed venous saturation.

Results

- Conventional monitored parameters (systemic arterial pressure, arterial pulse oximetry and heart rate) are displayed as if on a real monitor.
- The main component of the display is a graphical representation of blood flow and oxygen flux (see Figure 1) which represents dynamically the balance of cardiac output to the two circulations.
- The simulation also displays systemic mixed venous saturation and the ratio of systemic oxygen delivery to consumption (Omega), as described by Buheitel [2].
- These two parameters give information about the adequacy of systemic oxygen delivery that informs users about the effects of their simulated interventions.

Conclusions

- This simulation emulates the complex circulatory behavior of a neonate with HLHS, displaying both commonly monitored parameters and a representation of circulatory distribution designed to aid the user in visualizing and understanding the effect of various interventions on this unique physiology.
- An educational outcome study is planned to test the efficacy of this simulation as a learning intervention for anesthesiology, neonatology and pediatric critical care residents and fellows.

References

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2. Buheitel G, Scharf J, Hofbeck M, Singer H. Estimation of cardiac index by means of the arterial and the mixed venous oxygen content and pulmonary oxygen uptake determination in the early post-operative period following surgery of congenital heart disease. Intensive Care Med 1994;**20**:500–503.

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