To fenestrate or not: a computational model as decision support for Fontan palliation

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Objectives Fenestration of the Fontan circuit was introduced to decrease mortality rates in patients undergoing completion of the total cavopulmonary connection (TCPC). Fenestration allows venous blood flow from the vena cava inferior directly into the atrium, preventing a rise in central venous pressure (CVP) and preserving cardiac output when pulmonary flow is restricted, but at the cost of a decrease of arterial oxygen saturation. It is likely that the hemodynamic effects of fenestration depend on patient-specific characteristics, such as the ability of the ventricle to cope with the acute decreased volume load. Quantitative insight in hemodynamic consequences of fenestration is limited. Accordingly, we use a computational model of the cardiovascular system to evaluate the effect of a fenestration on postoperative hemodynamic parameters, i.e., CVP, ventricular function, cardiac output, and oxygen transport in rest and during raise of cardiac output.

Methods The multi-scale computer model used (CircAdapt) simulates beat-to-beat dynamics of the two cardiac cavities, the valves, and the systemic, cerebral and pulmonary circulation. The regulating effects of renal fluid retention and venoconstriction on mean arterial pressure have also been incorporated. The cerebral circulation includes arterial oxygen saturation induced autoregulation of cerebral blood flow (CBF). Rest and increased cardiac output (CO), induced by increased stroke volume mimicking exercise, were simulated to evaluate the effect of fenestration in both situations.

Results Fenestration of the TCPC decreased arterial oxygen saturation and thereby caused an increase of CBF due to cerebral autoregulation (Fig 1). The raise in CVP with increasing CO was less in a TCPC with than without a fenestration (Fig 2). The fenestration acts as a pop off valve for systemic venous return when increase of pulmonary flow is restricted. During exercise, fenestration preserves ventricular filling and prevents increase of CVP, but effective pulmonary flow (oxygen delivery) increases less than systemic cardiac output (Fig 2).

Conclusions Fenestration of the TCPC is beneficial for patients with limited capacity to increase pulmonary flow or with high CVP in rest. It preserves ventricular filling and prevents increase of CVP during exercise. Ultimately, we aim to reveal preoperative patient-specific parameters that may guide the decision to fenestrate or not.

Figure 1 Effect of fenestration size on oxygen saturation in a completed Fontan circulation during rest

Figure 2 Effect of a fenestration of 20 mm² on the relation between CVP and CO (black) and pulmonary flow and CO (grey) in a completed Fontan circulation.