# A SELF-POWERED VENOUS BLOOD PUMP FOR SINGLE-VENTRICLE HEART DISEASE

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## Introduction

The Fontan procedure is the final stage of surgical palliation for single-ventricle heart malformations aimed at diverting the venous return directly to the pulmonary arteries. The lack of a subpulmonic ventricle leads to non-pulsatile pulmonary flow, systemic venous hypertension and eventually, failure. Although it is multifactorial, elevated IVC (inferior vena cava) pressure is accepted to be the primary cause of Fontan's high morbidity [1]. This study presents a novel self-powered venous ejector pump (VEP) to assist Fontan circulation. The proposed VEP exploits a fraction of aortic flow to generate a jet Venturi effect for the IVC flow and an atrial discharge to drain excess flow into the atrium (Figure 1). In vitro pulsatile experiments revealed the VEP's potential to significantly lower IVC pressure while maintaining high levels of arterial oxygen concentration and improving flow pulsatility.

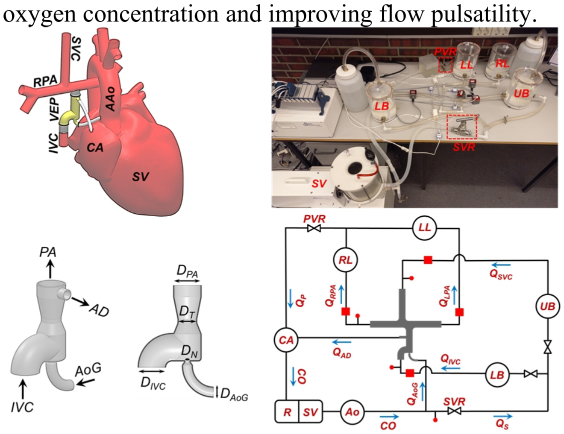


*Figure 1: Schematic anatomical illustration (top-left), 3D geometry (bottom-left), and in vitro circulation loop (right) of the assisted Fontan using the proposed venous ejector pump (VEP). Red squares and dots represent flow meters and pressure sensors, respectively.*

## Methods

Computational fluid dynamics (CFD) simulations incorporating turbulent models and clinically relevant boundary conditions were conducted in OpenFOAM to identify the optimal geometrical parameters in both idealized and patient-specific total cavopulmonary connections (TCPC). The identified designs with optimal performance were then realized through 3D stereolithography printing for experimental examination. A pulsatile in vitro single-ventricle mock-up circulation loop (Figure 1) was developed to evaluate the VEP performance using physiological pressure waveforms simulating post-Fontan conditions. A non-Newtonian blood analog that closely matches the blood viscosity of Fontan patients [2] was prepared and utilized as the working fluid.

## Results

Table 1 summarizes the in vitro key hemodynamic indices for different cardiac outputs and aortic pressures. The introduction of VEP into Fontan circulation resulted in reduced arterial pressure which was adjusted back to its TCPC state by increasing the CO through stroke volume. The VEP provided an IVC pressure drop of more than 2.6 mm Hg in all cases with an arterial oxygen saturation of greater than 86% and improved flow pulsatility.

| | CO (L/min) | $Q_{AoG}$ (L/min) | $P_{Ao}$ (mm Hg) | $P_{IVC}$ (mm Hg) | $C_{sa,O2}$ (%) |
|---|---|---|---|---|---|
| **TCPC state** | 2.40 | 0 | 85.1 (40.1) | 14.4 (0.4) | 95 |
| **TCPC+VEP** | 3.42 | 1.09 | 84.9 (40.2) | 11.6 (1.5) | 89 |
| **TCPC state** | 2.40 | 0 | 99.9 (40.4) | 14.4 (0.3) | 95 |
| **TCPC+VEP** | 3.60 | 1.23 | 100.0 (40.7) | 11.6 (1.9) | 89 |
| **TCPC state** | 3.40 | 0 | 85.1 (40.6) | 14.8 (0.6) | 95 |
| **TCPC+VEP** | 4.51 | 1.10 | 84.8 (40.6) | 12.2 (1.2) | 86 |
| **TCPC state** | 3.40 | 0 | 100.1 (40.9) | 14.8 (0.7) | 95 |
| **TCPC+VEP** | 4.61 | 1.20 | 100.1 (40.5) | 12.1 (1.4) | 87 |

*Table 1: In vitro mean and pulse pressure (in parenthesis) of the waveforms for both TCPC and VEP-assisted TCPC. CO: cardiac output, $Q_{AoG}$: aortic graft flow, $P_{Ao}$: aortic pressure, $P_{IVC}$: IVC pressure, $C_{sa,O2}$: arterial blood oxygen concentration.*

## Discussion

Self-powered Fontan venous assist is an emerging concept that eliminates the need for external power and thus limits the driveline infection. Previously proposed solutions are either clinically unfeasible or have complex and moving elements [3,4]. Our proposed VEP is clinically feasible, has no moving parts, provides significant IVC support while maintaining high levels of arterial oxygen concentration, and more importantly improves pulmonary flow pulsatility.

## References

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