INTERACTION OF A VENTRICULAR ASSIST DEVICE WITH PATIENT-SPECIFIC CARDIOVASCULAR SYSTEMS - IN-SILICO STUDY WITH BIDIRECTIONAL COUPLING

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Introduction

Ventricular assist devices (VADs) are used to assist the heart function of patients with advanced heart failure. Computational fluid dynamics is widely employed in the development and optimization of VADs, particularly for assessing factors such as blood damage. Ensuring the accuracy of these simulations requires precise incorporation of the VAD's operating conditions.
Patients relying on VAD support often exhibit residual cardiac pulsatility, causing the VAD to operate in conjunction with the still-beating heart. This interaction introduces pulsating flow conditions, leading to dynamic changes in operational points from partial load to overload and vice versa. Consequently, VADs may undergo significant variations in pressures and flow rates during operation. In certain patients, specific characteristics of the cardiovascular system can result in non-ideal operation points, potentially increasing blood damage. It is crucial to account for all these factors in flow simulations to accurately represent the complex dynamics involved in VAD operation.
Therefore, this study aims to address this issue by evaluating the flow in a VAD interacting with patient-specific cardiovascular systems in three different heart failure patients.

Method

This study introduces a novel numerical method incorporating a patient-specific cardiovascular system model bidirectionally coupled with a 3D flow simulation of the HeartMate 3. The cardiovascular system is represented by a lumped parameter model, utilizing clinical data from end-stage heart failure patients. Specifically, three heart failure patients with different cardiac activities are considered.
Various parameters of both the cardiovascular system and the VAD are examined. This includes an assessment of flow rates, pressures, VAD heads, efficiencies, and as crucial parameter—the blood damage potential of the VAD. The latter is accounted for using a transport equation for plasma-free hemoglobin.

Results

The head-flow rate curves of the VAD exhibit a pronounced hysteresis, with the degree of hysteresis increasing in correlation with the remaining heart activity. Additionally, a more vigorous heartbeat compels the VAD into less favorable operating conditions, particularly in overload and strong partial load conditions, where stresses and stress exposures reach their maximum, respectively. Both overload and, notably, partial load conditions during pulsating operation result in elevated blood damage potentials, see Fig. 1.

Conclusion

This study yields significant insights into the dynamic behavior of VADs in conjunction with patient-specific cardiovascular systems, highlighting the challenges posed by residual cardiac pulsatility. The findings emphasize the critical role of incorporating patient-specific characteristics in computational simulations for accurate assessments. The novel bidirectional coupling method holds promise in simulating realistic flow environments, closely resembling the actual operational conditions of VADs.

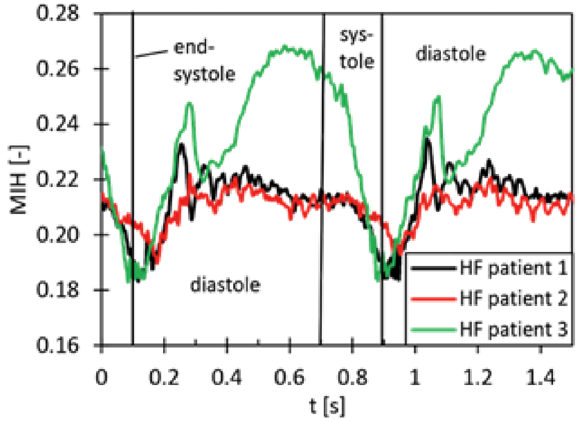

Figure 1: Temporal Progression of the Modified Index of Hemolysis (MIH) over two heartbeats for three VAD-supported Heart Failure (HF) Patients.

References

1. Hahne M, Crone V, Thomas I, Wolfgramm C, Liedtke FKP, Wurm FH, Torner B. Interaction of a Ventricular Assist Device With Patient-Specific Cardiovascular Systems: In-Silico Study With Bidirectional Coupling. ASAIO J. 2024 Mar 27. doi: 10.1097/MAT.0000000000002181