ACCURACY OF THE HEARTMATE 3 FLOW ESTIMATION

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Introduction

Despite advances in fully magnetically levitated left ventricular assist devices (LVADs) [1], the lack of hemodynamic sensors limits the understanding of the patient's cardiovascular condition. However, for advanced diagnostics (e.g. cardiac function, aortic valve opening) and automated speed adaptations, assessment of hemodynamic parameters is crucial. The aim of this study was to evaluate the accuracy of the flow estimator of the clinically available LVAD, the HeartMate 3 (HM3), and evaluate its performance across static and dynamic conditions.

Methods

Experiments were performed at five speeds (3-7 krpm) and three fluid viscosities (2.5, 3.5 and 4.5 mPa*s) using a previously described hybrid mock circulatory loop (HMCL).[2] For static measurements, pump flow was increased stepwise from - 1 L/min until no head pressure was generated. Realistic partial and full support scenarios were investigated by coupling virtual patients with the HMCL. Pressures, flows and pump parameters were recorded. Relationships between these parameters and specifically the estimated and measured flow were derived to understand the underlying working principle of the flow estimator and its accuracy. The Pulsatility Index (PI) as an indicator for flow waveform amplitude was investigated.

Results

Static measurements showed that at each speed (for each viscosity within this speed) the correlation between estimated pump flow and motor current was high ($r^2 > 0.99$, $p<0.001$), indicating that estimated flow is based on speed, current and viscosity. The current exhibits a non-monotonic behavior at higher flows (Figure 1), which is reflected in the estimated pump flow signal, leading to large deviations between estimated and measured pump flow in this region (e.g. -3.5 L/min at 6 krpm and 2.5 mPa*s). Accuracy of the flow estimator in terms of the root-mean-square-error (RMSE) was 1.63 L/min. In typical full support scenarios, the virtual patient's mean flow was overestimated by 1.41±0.44 L/min (41%), in partial support conditions by 0.65±0.41 L/min (18%) on average. During partial support, PI values are up to 48% smaller than they would be with a monotonic current that does not decrease at higher flow values.

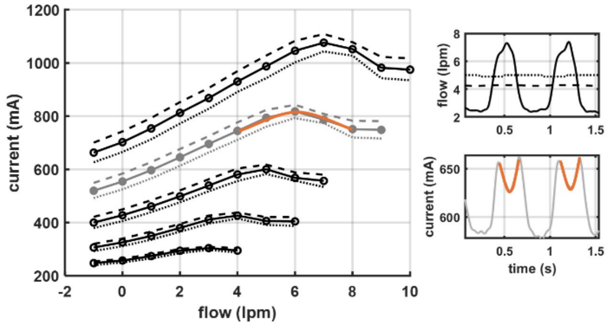

*Figure 1 left: Static relationship between measured pump flow and current (bottom to top: 3k, 4k, 5k, 6k, 7 krpm; dotted: 2.5; solid: 3.5; dashed 4.5 mPa*s. Right: Measured (solid black), mean (dashed) and estimated (dotted) flow and current (grey) at 80 bpm, 5.4 krpm and a viscosity of 3.5 mPa*s during partial support. Non-monotonic behavior of current marked in orange.*

Discussion

The HM3 flow estimator calculates flow based on current, speed, and viscosity. The flow signal is overestimated at low flows and underestimated at high flows by up to +2.3 L/min and -3.5 L/min, respectively. These discrepancies can be explained by a non-monotonic relationship between current and pump flow, which renders flow estimation challenging. This non-monotonic behavior also affects PI calculation as an indicator for the amplitude of pump flow: whereas the PI may indicate trends in pulsatility in the linear portion of the relationship (i.e. in full support conditions), it does not adequately represent pulsatility in partial support conditions. The clinically used HM3 parameters should be interpreted with caution and have limitations regarding the assessment of parameters related to cardiac function.

References

[1] Mehra *et al.*, *JAMA*, 328, no. 12, 1233–1242. 2022.
[2] Bender *et al.*, *IEEE Trans. Biomed. Eng.*, pp. 1–12, 2023,

Acknowledgements

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