Analysis of LVADs in a controlled mock systemic circulation

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Introduction
LVADs are more and more used as bridge to recovery or destination therapy rather than bridge to transplant. For these applications, the timing and control of the device is critical with respect to the outcome of the therapy. To evaluate LVADs under different circumstances, a mock circulation system, featuring at least the Frank-Starling mechanism of the heart, may be helpful.

In this study, we developed a mock systemic circulation with a Hill-type heart contraction model. This contraction model performs better in describing the heart function in combination with a pump than the widely used elastance-based models (2). A further enhancement is the baroreflex heart rate control mechanism.

Aims
To evaluate the performance of pulsatile and continuous LVADs, using a controlled mock systemic circulation.

Materials and Methods
Circulation loop
The circulation loop (Fig. 1) consists of a piston pump with aortic and mitral valves, an aortic tube, a windkessel-type afterload and a preload. The design of the system allows for easy mounting of an LVAD between the ventricle chamber and the aortic tube.

Control strategy
The model is controlled by measuring the left ventricular volume \( V_{lv} \). With the heart contraction model this yields the left-ventricular pressure \( P_{lv} \). The difference between \( P_{lv} \) and the measured (output) pressure is fed into the controller, to adjust \( V_{lv} \). The systemic pressure \( P_{sv} \) is fed into the baroreflex heart rate control system (Fig. 2).

Control Loop

Heart model
Contraction \( \sigma \) is described as a function of time \( t \), sarcomere length \( l \) and contraction speed \( o \) (Fig. 3):

\[
\sigma = \sigma_{\text{passive}} + T_{\text{act}} \times f(t) \times g(l, t) \times h(o)
\]

Baroreflex model
The baroreflex function was taken from (1). It adapts the heart rate between 50 and 180 mmHg input pressure (Fig. 4).

Protocol
The model was tuned for a low cardiac output (2l/min). A Thoratec PVAD was attached and driven according to the manufactures specs, i.e. asynchronously. We also operated the PVAD synchronously, ejecting in systole or diastole (Fig. 5). An Impella 2.5LP was also attached and driven at 6 speeds (P0-P9, Fig. 6). In all cases, P-V-loops were measured. The impella data were evaluated further for cardiac output, systemic pressure and heart rate (Figs 7-9).

Discussion and conclusion
• Two LVADs were evaluated in a mock systemic circulation. Their function is clearly demonstrated.
• In synchronous mode, the PVAD reduces peak ventricular pressure in systolic ejection. When ejecting in diastole, ventricular stroke volume is reduced. In asynchronous mode both phenomena alternate.
• The Impella 2.5LP shows a clear increase in assist function with increasing pump speed. While a strong back flow exist with the pump switched off (P0), it takes over most of the cardiac output at higher speeds (P7-P9). Simultaneously, systemic pressure increases by 10mmHg.
• There is a too strong coupling between afterload and preload. This results in an overestimation of the ventricular volume reduction during assist.

References