Estimation of left ventricular pressure in patients with a continuous flow LVAD

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Aim

Long-term ventricular support with a Left Ventricular Assist Devices (LVAD) requires intensive and frequent monitoring of the patient.

Left ventricular pressure (plv) is a good measure for LV function. In this study, we aim to assess dynamic left ventricular pressure, using the LVAD as a sensor.

Ex vivo model

The method was validated with a porcine ex-vivo beating heart model (figure 1)[1]. Measurements were done on four hearts supported with a Micromed DeBakey VAD and three hearts supported with a Heartmate II VAD.

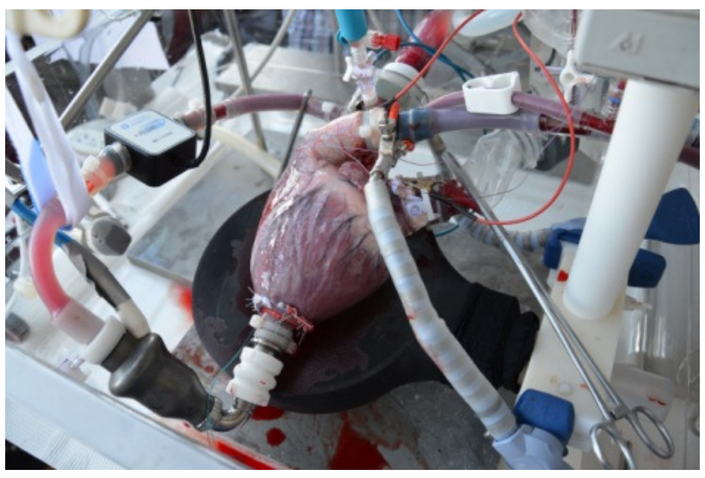

Figure 1 Experimental set-up of the ex vivo porcine heart model supported with a Heartmate II VAD. A similar set-up was used for the measurements on the hearts supported with a Micromed DeBakey VAD.

Estimation left ventricular pressure

Pressure head over the LVAD (dp_{lvad}) is estimated from pump flow with a static[2] and dynamic[3] pump model. From pressure head and aortic pressure, left ventricular pressure is estimated:

$$p_{lv,estimated} = p_{ao} + dp_{outflow\ graft} - dp_{lvad,estimated}$$

$Dp_{outflow\ graft}$ is the pressure drop in the outflow graft. Calculated as follows:

$$dp_{outflow\ graft} = R \cdot Q + L \cdot \frac{dQ}{dt}$$

Results

Mean left ventricular pressure was estimated using static pump characterisics (figure 2).

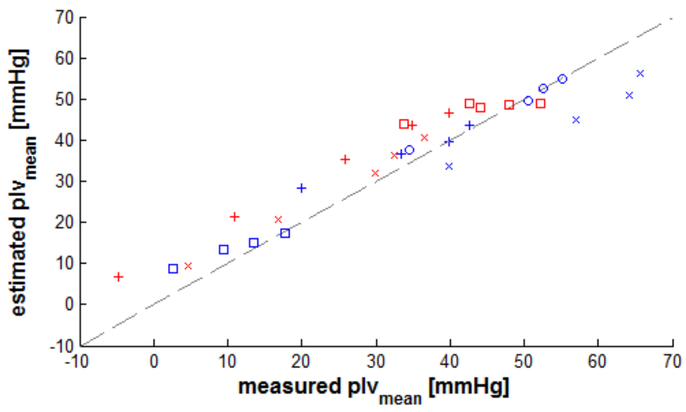

Figure 2 Estimated left ventricular pressure was compared with measured left ventricular pressure for the hearts supported with the Micromed DeBakey (blue) and the Heartmate II (red). Symbols: Heart 1 (+), heart 2 (□), heart 3 (x) and heart 4 (o).

Left ventricular pressure was also estimated as a function of time using dynamic pump characteristics (figure 3).

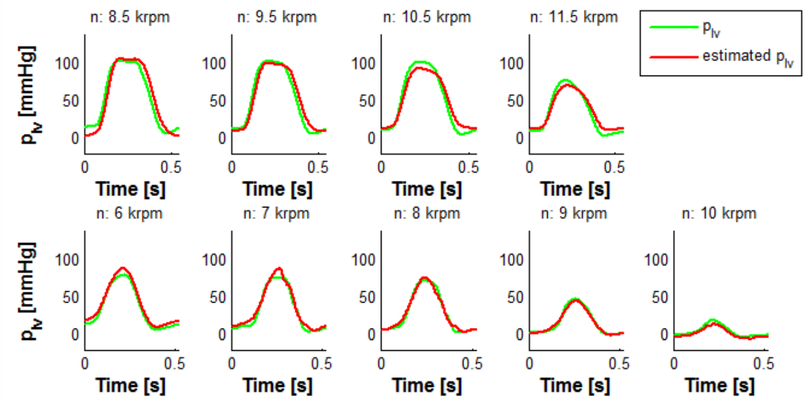

Figure 3 Measured (green) and estimated (red) left ventricular pressure for measurements with heart 1 supported by a Micromed DeBakey (top row) and heart 1 supported by a Heartmate II (bottom row).

dp/dt_{max}, maximum, minimum and mean left ventricular pressure were derived from the estimated p_{lv} (figure 4).

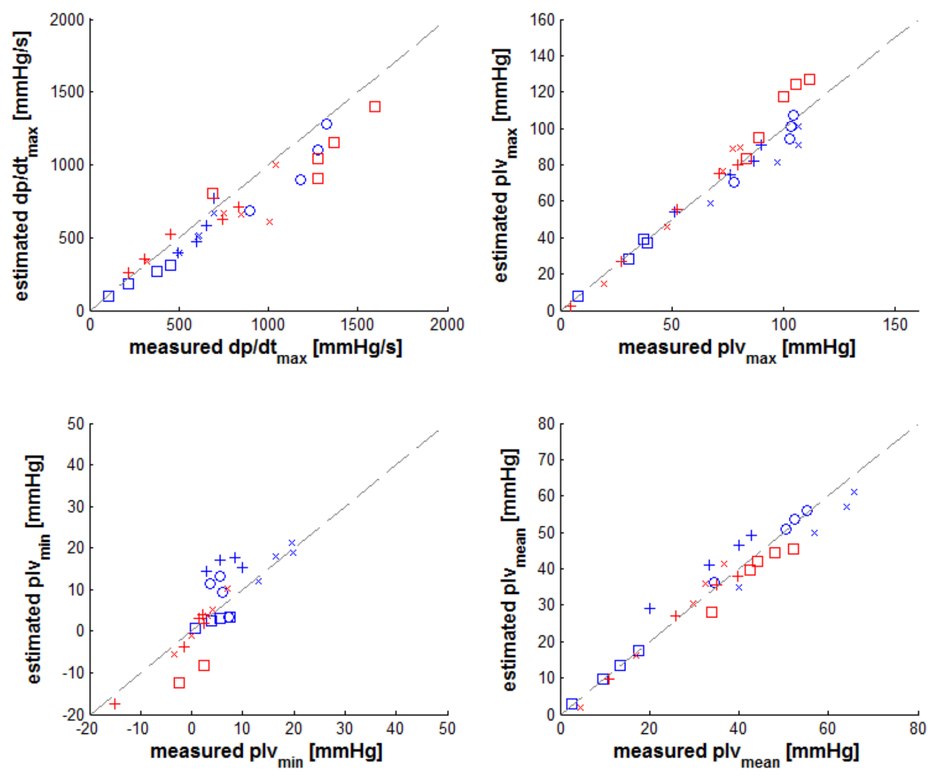

Figure 4 Estimated compared to measured dp/dt_{max} (top left), maximum p_{lv} (top right), minimum p_{lv} (bottom left) and mean p_{lv} (bottom right) for measurements on the Micromed DeBakey (blue) and the Heartmate II LVAD (red). Symbols: Heart 1 (+), heart 2 (□), heart 3 (x) and heart 4 (o).

Conclusions

In our beating heart experiments, a reliable estimation of left ventricular pressure was possible using static or dynamic pump characteristics.

Once combined with a focused clinical study we infer that left ventricular pressure in LVAD supported patients can be monitored sufficiently reliably in case pump flow and aortic pressure are measured. This will give a good indication for unloading of the ventricle and native heart function, in case of recovery of the heart or destination therapy during long-term support.

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[2] Pennings K, Martina J, Rodermans B, Lahpor J, van de Vosse F, de Mol B, Rutten M.. Pump Flow Estimation from Pressure Head and Power Uptake for the HeartAssist5, HeartMate II, and HeartWare VADs. ASAIO J. 2013; 59(4): 420-6.
[3] Pibodaghi T, Weber A, Carrel T, Vandenberghe S. Effect of Pulsatility on the Mathematical Modeling of Rotary Blood Pumps. J. Artif. Organs. 2011; 35(8): 825-32.