



Designing an ex-vivo left-heart simulator



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Background

Valvular heart disease is a prevalent condition among the elderly and an emerging issue due to population ageing. Current treatments include valve replacements and repair procedures. Our long-term goal is the computational simulation of valve repair, requiring advanced experimental tools for validation. One such tool would be a simulator reproducing physiological blood pressure and flow conditions, and allowing one to quantify the function of original as well as surgically repaired mitral and aortic valves. This poster reports on the early design and testing of a completely novel ex-vivo left heart simulator.

Methods

Concept (Fig. 1):

The left atrium of a porcine heart is cannulated and fed saline solution from the sump under atmospheric pressure. The saline solution exits the left ventricle through the aortic valve and the cannulated ascending aorta. The in-vivo elasticity of the aorta is mimicked by a pressurized compliance chamber filled with air. The systemic resistance to flow is implemented through a tunable resistance component. A mechanical drive cyclically squeezes and relaxes the ventricles of the heart. Saline solution eventually goes back to atmospheric pressure in the sump. To help increase the cardiac output of the system, a centrifugal pump connecting the sump to the apex of the left ventricle may be used.

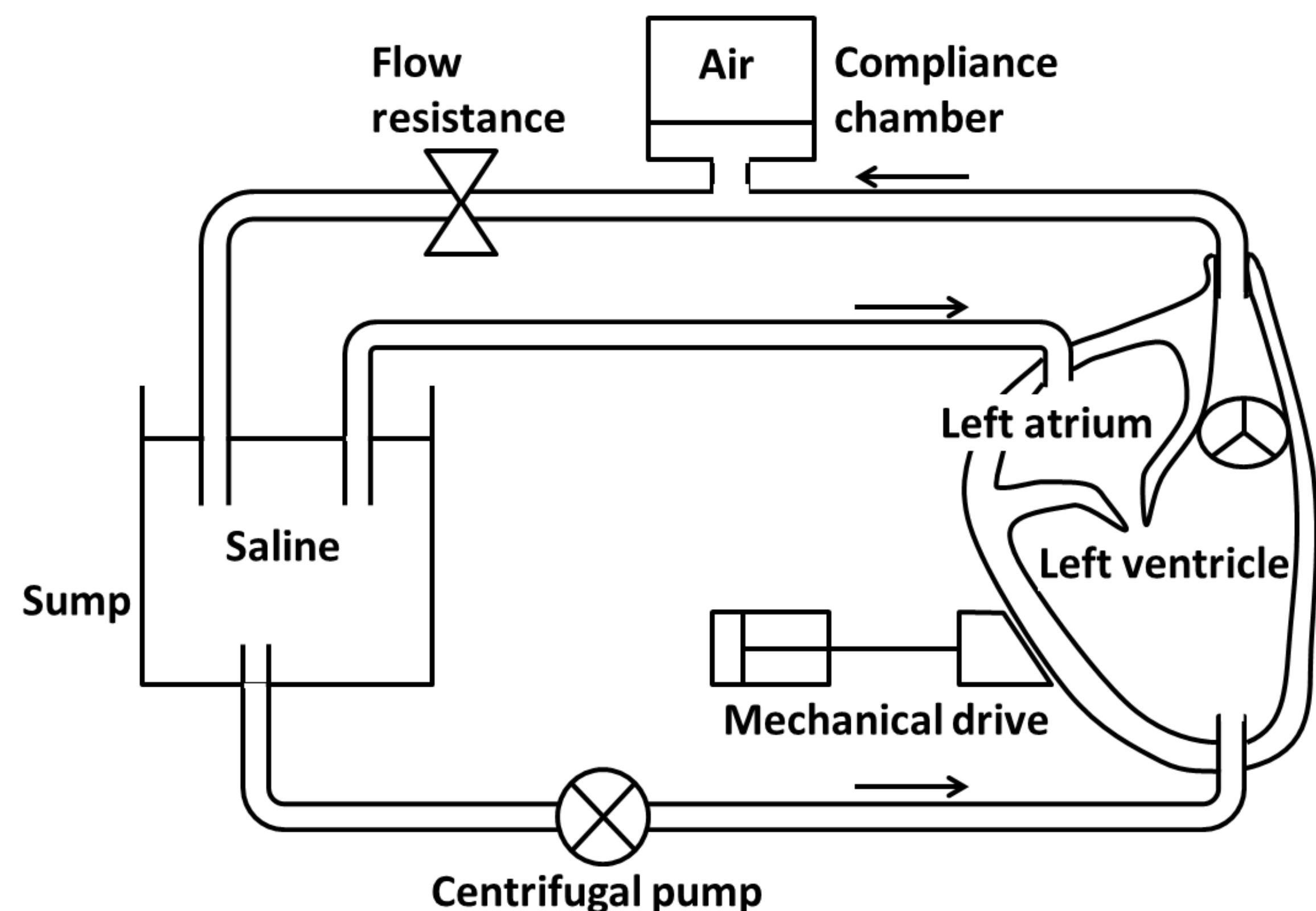


Figure 1: Concept and fluid pathway in ex-vivo left-heart simulator.

Heart preparation (Fig. 2):

Porcine hearts provided from a local abattoir were rinsed and cleaned for removal of blood clots. Vessels feeding into and leaving the right side of the heart were tied off using tie-wraps. The aorta was trimmed a few centimetres above the aortic valve. Each heart was cannulated as explained above. The cannulas were used in combination with an endoscopic camera to study the movements of the mitral and aortic valves.

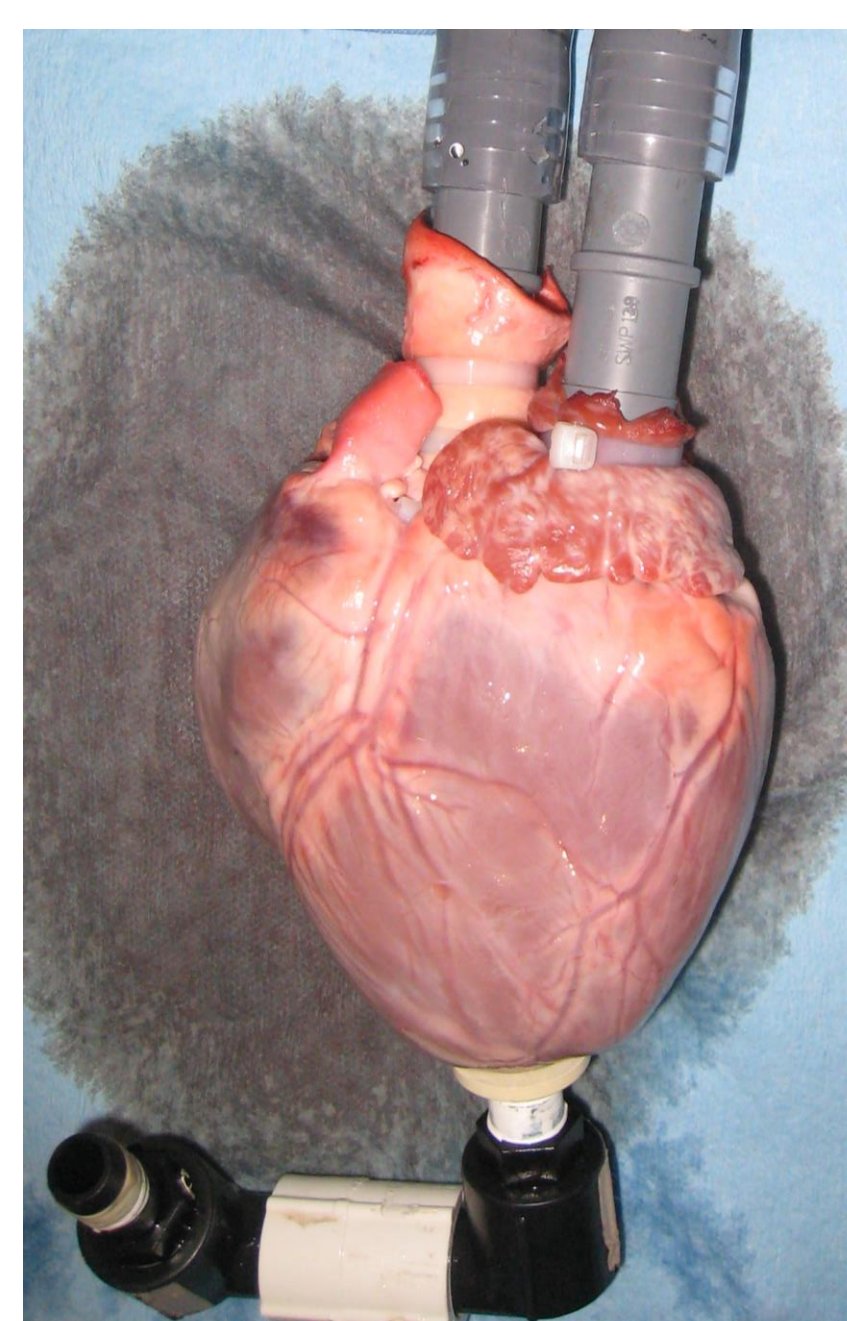


Figure 1: Cannulated heart.

Mechanical drive and frame (Figs. 3, 4)

Two pairs of steel orthogonal jaws were fastened to a frame and imparted a cyclic squeezing motion to plates pressing on the ventricles of the heart. The whole apparatus was driven by one electrical linear actuator at a frequency of 70 beats per minute.

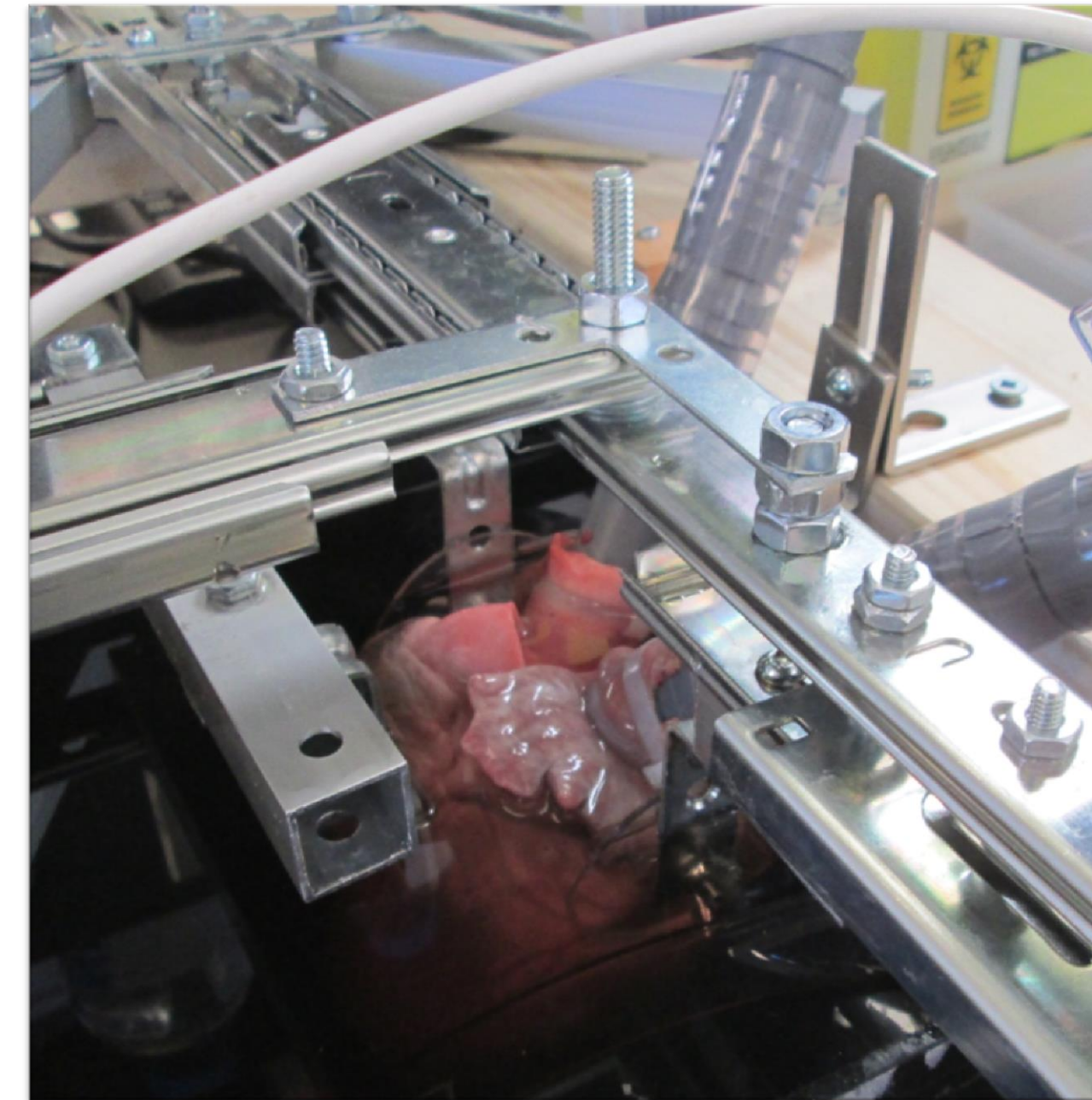


Figure 3: Close-up view of the heart.

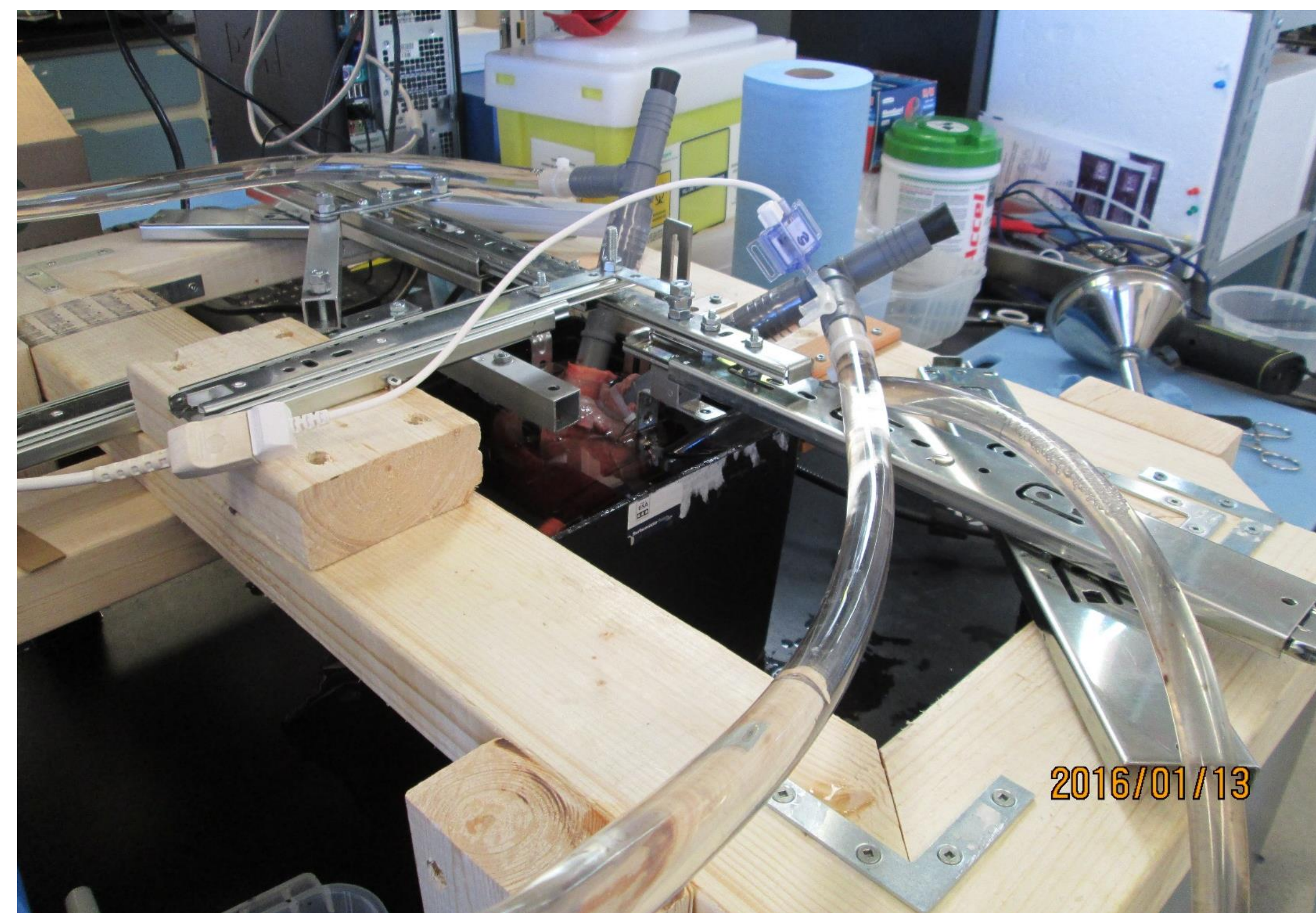


Figure 4: Mechanical drive and frame of ex-vivo left-heart simulator.

Results

The simulator, with the assistance of the centrifugal pump, was able to produce cardiac outputs of up to 4 L/min as tabulated in Table 1 from trials in three different porcine hearts. Aortic pressures of 120/80 mmHg were also achieved, along with successful closing and opening motion of the aortic and mitral valves.

Heart	Cardiac output (L/min)
1	4.0
2	3.2
3	3.3

Table 1: Cardiac output data measured from 3 porcine hearts.

Using an endoscopic system, opening and closing of both mitral and atrial valve leaflets were successfully imaged, as can be seen in Fig. 6.

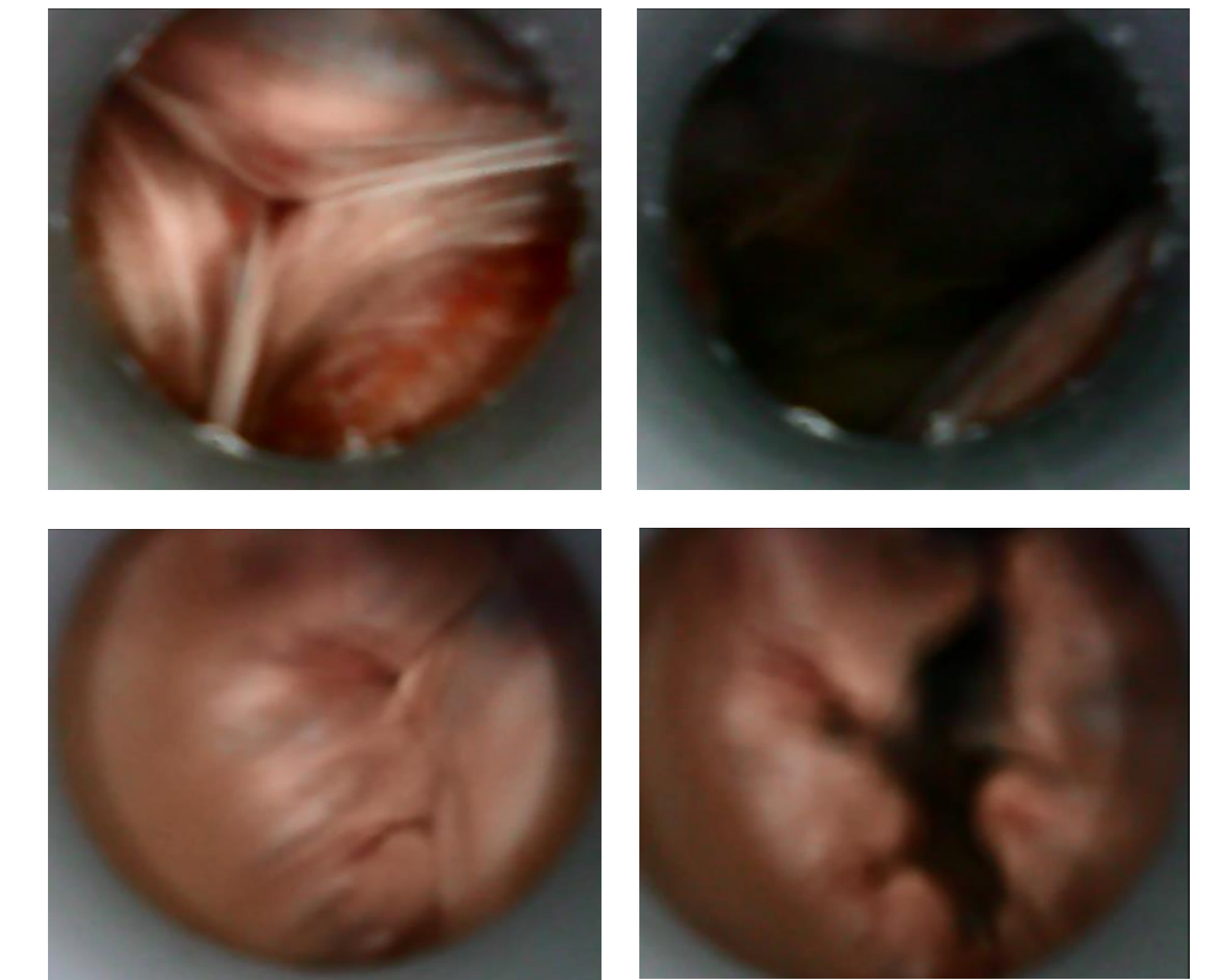


Figure 6: Snapshots extracted from a video recording. Top: Closed/open aortic valve. Bottom: closed/open mitral valve.

The simulator was also able to reproduce good approximations of normal aortic and atrial pressure pulses. However, it failed to produce physiological left ventricular pressure pulses (Figs. 7, 8).

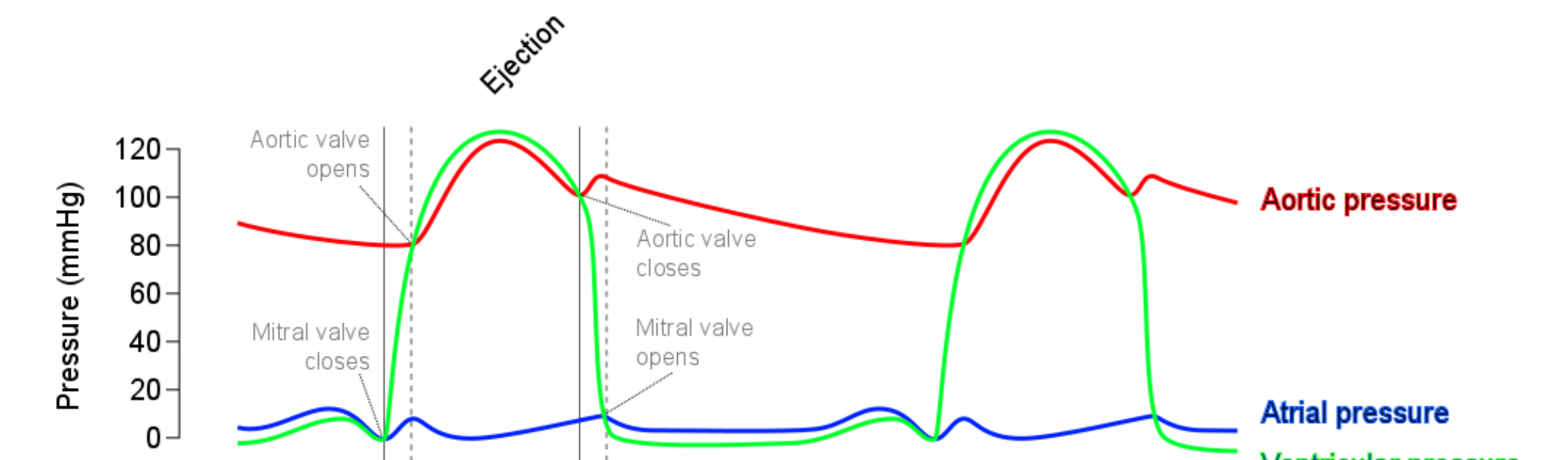


Figure 7: Pressure pulses vs. time expected in normal heart.

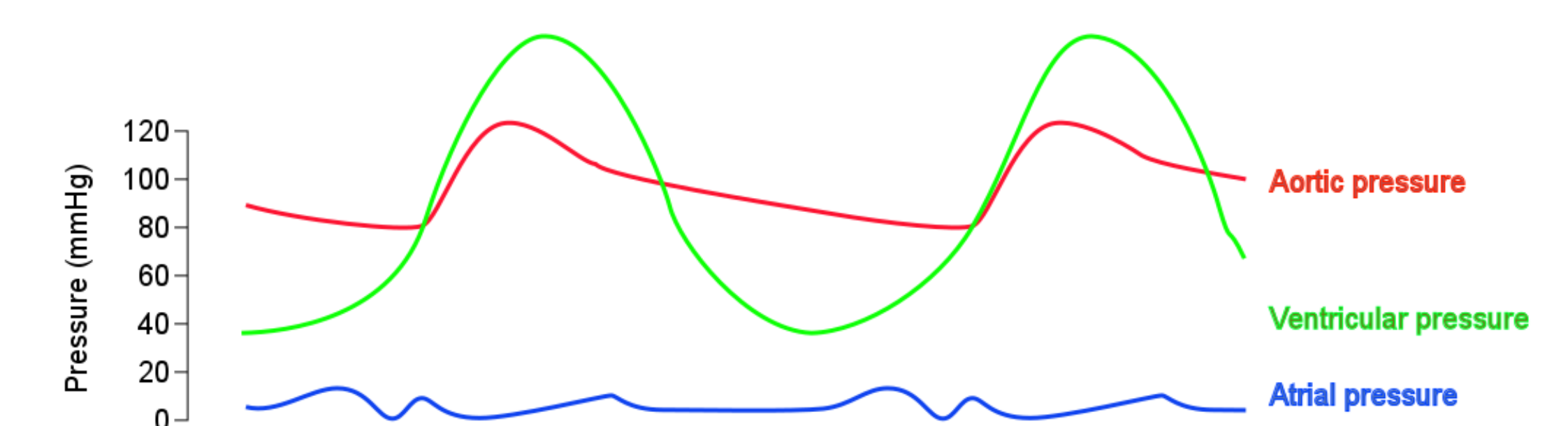


Figure 8: Pressure pulses vs. time as obtained in setup.

Conclusion

Testing of our design of the left heart simulator demonstrated promising early results in terms of cardiac output and overall motion of the aortic and mitral valves. However, the ventricular pressure pulse to date has not been physiological enough and needs attention. If this problem can be overcome, the next issue to be addressed will be the presence of air bubbles that make 3D echographic imaging difficult.

Reference

Leopardi, A. M., Vismara, R., Van Tuijl, S., Redaelli, A., Van de Vosse, F. N., & Fiore, G. B. (2015). A novel passive left heart platform for device testing and research. *Medical Engineering and Physics*, 37:361–366.