A Novel Hydraulic Thick-Walled Phantom for the Assessment of Left Ventricular Function

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Introduction

Assessment of left ventricular (LV) wall deformation and its interaction with blood flow are of great importance in clinical evaluation of cardiac function. As such, biomechanical models of the human heart ideally need to account for realistic wall deformation. In previous experimental model investigations (Verdonck, 1992), wall deformation has generally been studied using thin-walled passive models, in which the effect of active muscle contraction and, hence, natural wall deformation cannot be simulated.

The aims of this study were, therefore, to (1) construct an experimental hydraulic model of the LV wall in which the wall deformation can be actively controlled, and (2) to validate this thick-walled LV model by measuring aortic pressure and flow and LV pressure.

Materials and methods

Control of wall deformation: We conceived the LV as a thick-walled hydraulic model (figure 1) composed of an anchor frame and a membrane that is shaped as a truncated ellipsoid. These are incorporated in the transparent exterior casing and sealed at the top by a valve-embedding component. Two mechanical heart valves were fixed in the valve housing.

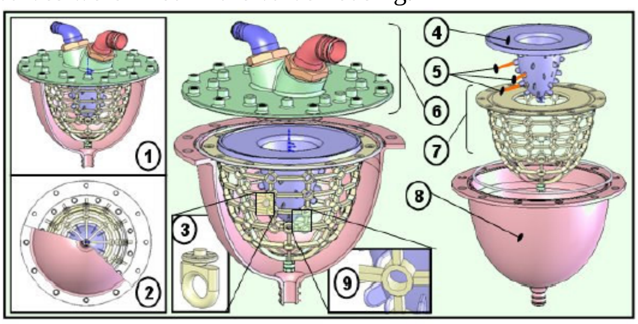

Fig. 1. The Frame Model: (1) font and (2) top views, (3) anchor points placed as inserts in the (4) membrane, (5) flexible sticks, (6) valve piece containing mechanical heart valves, (7) anchor frame with (9) anchor points, (8) transparent exterior casing.

By pumping water within the thick wall, the internal membrane deforms. This will result in a reduction of the LV volume. Wall deformation is controlled by 31 flexible sticks that connect the membrane to the anchor frame. The sticks can be tensed up or loosened by modular discs in order to control the wall deformation.

The "Frame model" was conceptualized by a combined application of Rapid Prototyping Techniques. These techniques use different materials: polyamid powder, UV polymerizing resin and a two-component polyurethane, respectively.

Description of experimental setup: The phantom was actuated by a piston pump that squeezes the test fluid out of the LV, through a mechanical heart valve into an artificial, two-component (resistance and compliance) vessel system.

Results

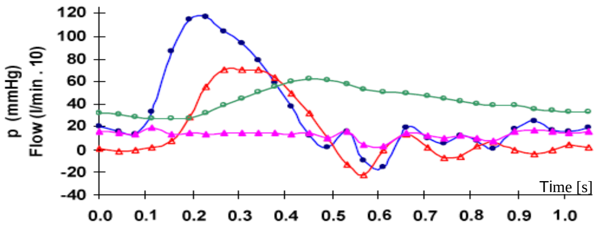

Fig. 2. Preliminary results of ○ aortic, ▲ atrial and ● LV pressure and △ aortic flow.

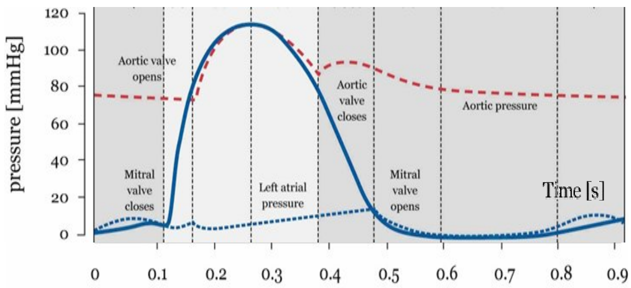

Fig. 3. Physiological data of aortic, atrial and LV pressure.

Overall, our preliminary results (figure 2) show promising agreement with physiological data (figure 3). As discrepancies, we observed a phase difference between LV and aortic pressure, and negative values of pressure and flow.

Discussion and conclusion

The design of this new hydraulic LV-phantom shows a notable improvement in wall deformation behavior over previous thin-walled membrane models. However, our experimental setup requires further optimization. Once optimized, this new LV model will likely provide useful insights in LV wall deformation and its interaction with blood flow.

References

Verdonck P (1992): Computer-controlled in vitro model of the human left heart. *Medical & Biological Engineering & Computing* 30: 656-659.