Development of a Pulsatile Left Heart Simulator

Abstract

The purpose of this design project is to develop a pulsatile left heart simulator that tests mechanical and bioprosthetic replacement heart valves while accurately simulating the natural pressure and fluid flow conditions of the heart. Requested improvements to the current flow loop design in the tissue mechanics laboratory include a method for easy implementation of valves and an aortic root, camera ports that will allow clear images of the replacement valves to be obtained from both inlet and outlet sides during testing, and a horizontal orientation. Through the use of a flow meter and pressure sensors located throughout the system, physiological cardiac waveforms are obtained as a result of each test. Because the replacement valves have already been bench marked in previous tests in Dr. Sun's laboratory, we compared our results to those already obtained to ensure that our flow loop functions properly. Research and tests of replacement heart valves are both crucial to the implementation of replacement heart valves in patients with heart valve disease. Although a few devices have been developed in this area of research, our pulsatile flow loop design provides an innovative way to further enhance replacement heart valve testing methods.

Background Information

- The American Heart Association has reported that about 5 million Americans are diagnosed with heart valve disease each year.
- Heart valve disease – condition in which one or more heart valves do not function properly
  - Valvular stenosis – stiff or calcified valve
  - Valvular insufficiency – leaky valve
- Conditions are very serious and may lead to death if untreated.
- Heart valve replacement surgery is one effective treatment.
  - Mechanical or bioprosthetic valve is implanted into the heart in place of the defective one.
- Testing of valves is crucial before implantation because valve failure can result in death of the patient.

Acknowledgements

- Dr. Wei Sun – Client and Advisor
- Eric Sirois – Graduate Student in the TML
- Peter Glaude and Serge Doyon – UConn Machine Shop
- Sarah Brittain – Teaching Assistant
- Dr. John Enderle – Professor and Advisor
- Jennifer Desrosiers – BME office

Results

As shown in Fig. 3, the normal cardiac cycle has a diastolic left ventricle pressure (LVP) close to 0 mmHg and a systolic LVP pressure that peaks at approximately 120 mmHg. The systolic aortic pressure (AP) also peaks around 120 mmHg but during diastole only drops to about 85 mmHg.

The curves produced by our flow loop (Fig. 4) very closely resemble the shape and magnitude of the normal cardiac cycle. There are spikes in both curves between the systolic and diastolic phases. In the left ventricle, these spikes are due to the location of the pressure tap. When the latex sac in the ventricle inflates and deflates, it directly impacts the pressure sensor because it is directly above the sac. The spikes in the aortic pressure are due to the impact of the water hitting compliance chamber I (Fig. 6d) before it makes the turn into compliance chamber II (Fig. 6a).

Advantages of New Design

- Horizontal orientation
- Much less expensive
- Able to view inlet and outlet of both valves
- Two flowmeters helps monitor flow better
- Versatile valve housing
- Separate components – able to switch out or change easily
- Adjustable compliance, pump, and throttle valve allows high control of waveforms

References


Figure 1. Anatomical depiction of human heart

Figure 2. Image of ViVitro Pulse Duplicator

Figure 3. Normal Pressure Waveforms

Figure 4. Pressure Waveforms from Pulsatile Heartbeat

Figure 5. Schematic of Flow Loop

Figure 6. SolidWorks Model of Flow Loop

Figure 6a. Increasing pressure raises AP. Also softens or adds spikes to pressure curves.

Figure 6b. Increasing systolic pressure increases LVP, AP, and flow rate. A more negative diastolic pressure increases flow rate. Increasing BPM increases flow rate. Increasing systolic duration extends the curves horizontally (with respect to time).

Figure 6c. Opening throttle valve increases flow and decreases AP. Closing it increases AP but decreases flow.

Figure 6d. Changing pressure changes the shape of the pressure curves, softening curves or adding spikes.

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