

Left Ventricle Pressure Time Decay Model Using Time Segmented Functions

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1. Introduction

The heart's efficiency is based on how much blood the Left Ventricle (LV) can pump to the entire body compared to how much energy the heart uses to pump the blood. The Diastolic or relaxation cycle of the heart can describe the efficiency of the heart by showing how much blood fills the LV prior to contraction. The heart's intent with the relaxation cycle is to fill as much blood as possible in the LV. The blood that fills the LV is eventually ejected from the heart during the systolic or compression cycle. So, the more blood that fills the LV, the more the efficient the heart becomes. If the LV's ability to relax were impaired, the LV would not be able to fill with enough blood to satisfy the body's demand for oxygen, causing stress on the heart. This cardiac stress drops the heart's efficiency and is an indication of heart failure. Currently, the only means to find how well the heart can relax is to catheterize the patient. The catheter contains small pressure transducers and is usually inserted through the femoral artery. Usually, the only reason for the catheterization is to obtain the maximum and minimum pressures inside the heart. The data is collected then plotted against time. This data shows how quickly, and how much the myocardium of the LV relaxes during diastole prior to contraction.

Modeling the LV pressure decay is somewhat of a small controversy. The most widely accepted model for the LV pressure waveform is the exponentially decaying model. Several papers have been written about finding, and using the pressure time constant, which is simply the time it takes the pressure curve to reach a certain value. One way to find the time constant is to calculate it using the exponentially decaying equation. Eucker et.al (1). and Karamanoglu et.al.(2) as well as Weiss et.al. (3) have all used the exponentially decaying function to describe the LV waveform, and to obtain the pressure time constant. Yet, Eucker et.al. (1) has concluded there are limitations to the accuracy of the exponential equation. The exponential function alone cannot adequately describe the entire waveform. The exponential function has a high accuracy rate with hearts that do not have any valve dysfunctions. Still, others have used models of polynomials and even natural logarithmic functions to describe how the pressure of the LV decays. The problem with all of these best fit mathematical models is they can only describe a small portion of the biological waveform before they begin to exhibit inaccuracies. However, where one mathematical model begins to drift another is more accurate. This phenomenon suggests combining pieces of each model at its most accurate segment to describe the pressure waveform of the LV. A time segmented best fit plot composed of several mathematical models could accurately describe the biologically generated waveform of the Left Ventricle.

2. Results, Discussion, and Significance

The data was organized into pressure and time and all of the potential models were calculated using Microsoft Excel. The data was then reduced and the portions of the data that did not correspond to the pressure drop of the LV were discarded. Specifically, the tail end data that signified Mitral valve closure, which were data points greater than time equal to 7.3, and the beginning data signified by Aortic valve closure or points less than time equal to 5.7. To increase the resolution of the plots, points of interpolation were incorporated into the baseline data. The basic linear interpolation formula of similar triangles accurately calculated the interior points of the waveform data due to the high density and close proximity of the original data points. This increased the number of data points that were used from around 40 to 93 points. The exponential function was calculated from the results of Eucker et.al. (5), while the other models were formulated by hand and tested against the base line data. Four potential models were used in the evaluation of the experiment. The Exponential model, a Sin(x) model, a Natural Logarithmic model, and a Polynomial were all plotted against the base line data.

The raw data for the base line curve was reconstituted from a chart located in the power point presentation of Stevens (4) and is shown in Figure 1. This chart represented cardiac pressure data from a human heart in the LV and the Aortic Valve. Due to the unlisted scale of the chart's abscissa, direct measurements were taken of the chart using an engineer's scale.

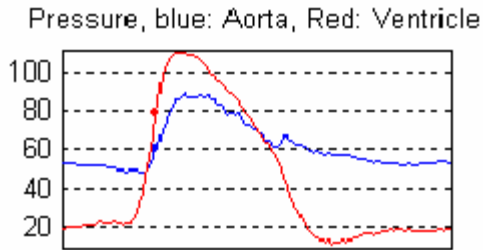


Figure 1: Raw Pressure Data Chart taken from S.Stevens PPT.

The above graph is the base line curve for the experimental curve fit models. Each of the four models were challenged with accurately describing the LV Pressure curve. The models that were formulated are shown in Figure 2. All of the models have accurate areas and inaccurate areas. The fortunate occurrence of Figure 3 is that where one model is inaccurate another model becomes accurate. Each of the most accurate sections of the formulated models were sectioned into another curve fit plot that described the LV pressure decay wave form. Another interesting note is how all of the functions became more accurate as they reached the asymptote of the data. In this case the asymptote of the functions was 17.

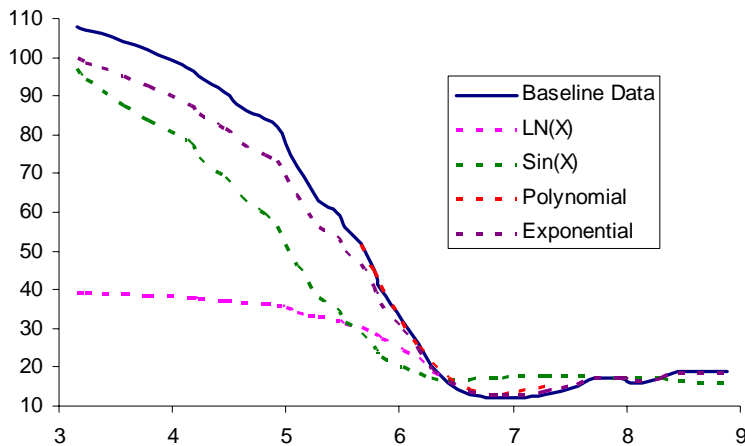


Figure 2 Functions used for the Segmented Model

3. Conclusion

The idea of constructing a highly accurate model of the diastolic LV pressure decay using segments of several mathematical models will need to be further explored. Currently, there are too many limitations and discrepancies to be used to describe the pressure decaying phenomenon with the segmented model developed here. Researchers, in general, accept the exponentially decaying time function as the most accurate and easy to use mathematical function for describing pressure drop. This paper tends to reinforce that acceptance with regard to pressure-time function of left ventricle.

4. References

- [1] S. A. Eucker, J. B. Lisauskas, J. Singh, S. J. Kovacs: **Phase plane analysis of let ventricle hemodynamics.** *Journal of Applied Physiology*: 2001, 6:2238-2244
- [2] M.Karamanoglu, S. J. Kovacs: **Thermodynamic phase plane analysis of the ventricle contraction and relaxation.** *BioMedical Engineering Online*2002,3:6
- [3] J. L .Weiss, James W Frederiksen, Myron L Weisfeldt: **Hemodynamic determinants of the time-course of fall in Canine Left Ventricle Pressure.** *Journal of Clinical Investigation*:1976,58:751-760
- [4] S. Stevens: **The Instantaneous Pressure-Volume Relationship of the Left Ventricle.** *PowerPoint Presentation, PennStat,e 2004.*