Modelling of the Nonlinear End-Systolic Pressure-Volume Relation and Volume-at-Zero-Pressure in Porcine Experiments

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Objective

- The End-Systolic Pressure-Volume Relationship (ESPVR) can be used to evaluate the contractile state of the heart, and is typically modelled as a linear relationship
- Extrapolation of the ESPVR can be used to determine V_0, which is important in normalising cardiac behaviour models, however this extrapolation can yield negative, non-physical values
- The focus of this research was to evaluate and compare models for the ESPVR on experimental data across a range of cardiac states without suppression of cardiac reflexes

Experimental Data

- Left ventricular volume and pressure data was gathered from a cohort of 6 pure pietrain pigs, using a micromanometer-tipped admittance catheter sampling at 1000 Hz
- The pigs underwent preload reduction via vena cava occlusion to provide a range of ventricular volumes and pressures for ESPVR curve construction, across a variety of PEEPs
- Ethics approval was granted by the Ethics Committee of the University of Liege Medical Faculty

Methods

- Two models were fitted to end-systolic pressure and volume to determine ESPVR and V_0. The first was the standard linear model:

$$P_{es} = E_{es}(V_{es} - V_0)$$

- The second was an exponential model:

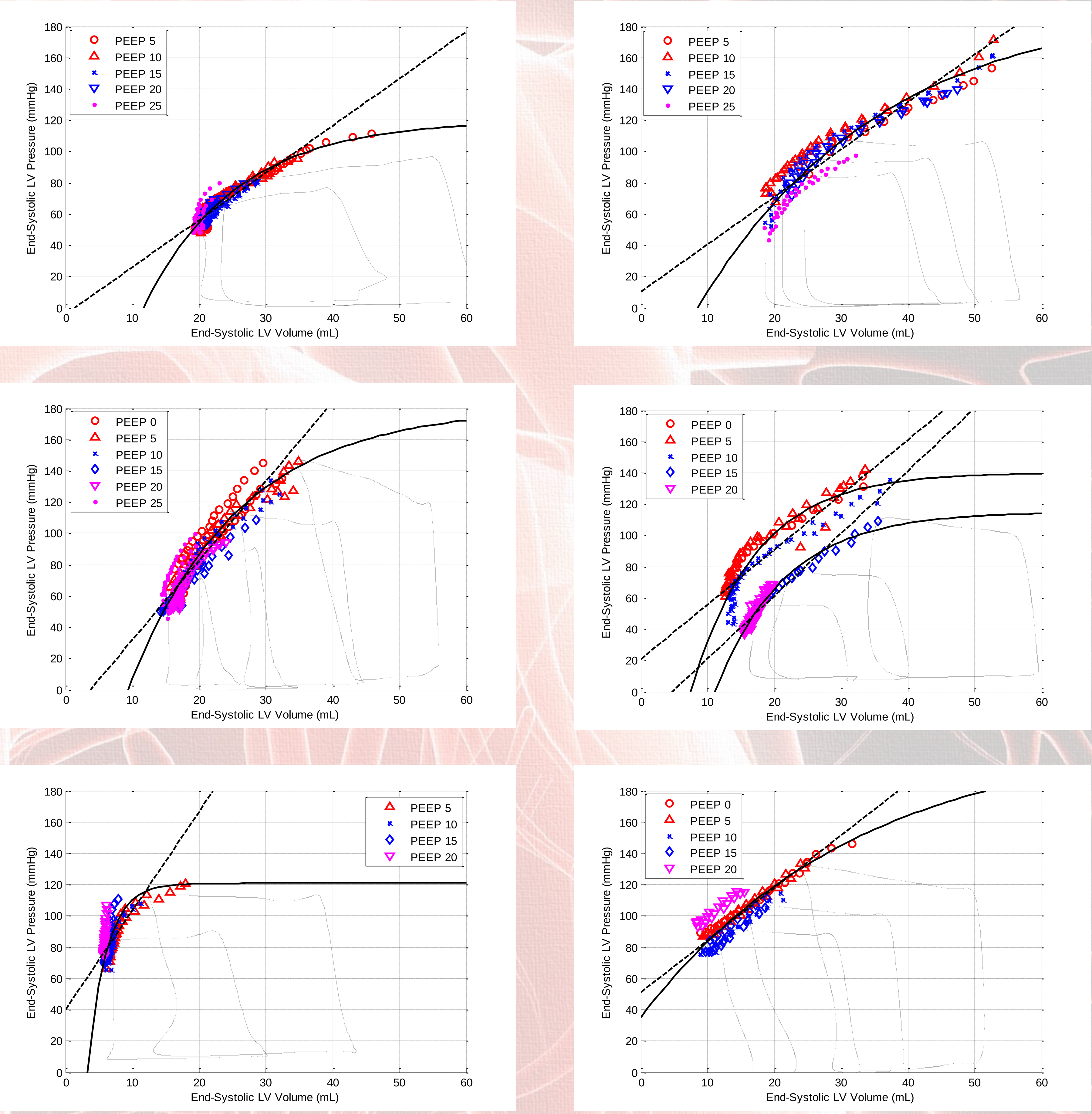
$$P_{es} = P_{\infty}\left(1 - e^{-m(V_{es}-V_0)}\right)$$

- Models were compared based off Pearson's Correlation Coefficients and Akaike Information Criterion (AIC) score:

$$AIC = n \log\left(\frac{RSS}{n}\right) + 2K$$

Results

- Combined end-systolic pressures and volumes for each pig, with linear and exponential fits, are shown below



Pig	Correlation Coefficient, R, Exp. Model	Correlation Coefficient, R, Linear Model	V_0 Exp. Model (mL)	V_0 Linear Model (mL)	Akaike Information Criterion, AIC, Exp. Model	Akaike Information Criterion, AIC, Linear Model	Number of Heartbeats
1	0.943	0.929	11.67	1.43	614.4	703.3	276
2	0.951	0.939	8.56	-3.29	560.9	595.2	154
3	0.929	0.923	9.38	3.78	981.3	1020.1	266
4_1	0.926	0.900	7.47	-5.87	428.5	467.1	111
4_2	0.978	0.947	11.1	4.73	146.8	216	89
5	0.717	0.708	3.31	-6.33	571.9	624.7	153
6	0.873	0.882	-5.72	-15.22	435.5	437.5	124

Conclusion

- Both exponential and linear models showed strong correlations, with modestly higher exponential correlation coefficients in 6 out of 7 cases
- The exponential model produced reasonable, positive values for V_0 in 6 out of 7 cases while the linear model produced positive V_0 values in 3 out of 7 cases
- The exponential model had significantly lower AIC values for pigs 1 and 4, and modestly lower values for the remaining pigs
- These combined results suggest that an exponential model of ESPVR may perform better than a linear one for patients where cardiac reflexes are not suppressed
- While the difference between the two models over the physiologically observed range is relatively small, this has interesting implications when extrapolating ESPVR to determine V_0