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Design and evaluation of baroreflex model simulation in mock circulatory loop

G.M. Vazquez, N. H. Lovell and M.C. Stevens

***Abstract*—A baroreflex model with an unstressed venous volume chamber was implemented on a biventricular mock circulation loop to mimic a facet of native physiological hemodynamic control and maintain a set level of arterial pressure. The model was tested with volume shifts on different arterial pressure targets; the model effectively maintained a set level of pressure with lower error than normal operation.**

***Clinical Relevance*— This project improves bench testing for cardiac mechanical assist devices by replicating the native mechanism of blood pressure control in a benchtop simulation.**

I. Introduction

The increasing clinical relevance of ventricular assist devices (VAD) has made mock circulation loops (MCL) a prime *in vitro* platform for testing a wide range of hemodynamic scenarios and conditions. They provide valuable developmental information before clinical or animal trials. However, most MCLs lack native autoregulatory control of blood pressure, limiting their clinical relevance [1,2]. This study describes the incorporation of a baroreflex (BR) autoregulatory mechanism module to a MCL and its evaluation by simulating postural change. This will create a reliable platform for testing VADs by replicating a circulatory system with the capacity for native physiological hemodynamic control.

II. Methods

This study used a modified physical five-element Windkessel biventricular MCL of the version demonstrated by Timms et al [1]. The setup was modified to include a venous reservoir connected to the systemic vascular compliance chamber to simulate the unstressed venous volume (UVV). Two pneumatically operated pinch valves were used to simulate systemic and pulmonary vascular resistance (SVR & PVR). A 60 wt% water and 40 wt% glycerol mixture was used to approach normal blood viscosity.

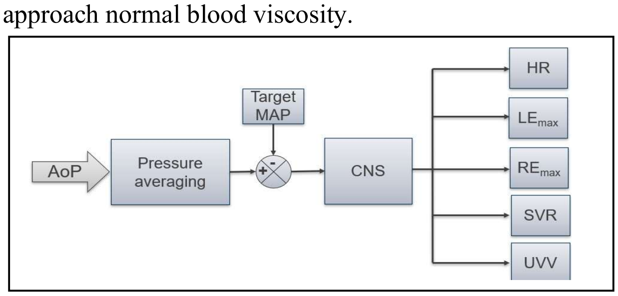

Figure 1. BR mechanism model diagram. Aortic pressure (AoP) is averaged each beat and compared with a mean arterial pressure (MAP) target this signal moves to a block representing the central nervous system (CNS) that regulates corresponding effectors. Previously not mentioned heart rate (HR), heart contractility left and right (LE_{max} & RE_{max}).

The BR software model was added into the Simulink (MathWorks, Inc., Natick, MA, US) MCL model. The BR model was created using five different linear time invariant system blocks using state-space representation with the AoP as input (Fig 1). The UVV chamber was connected to an electropneumatic regulator and a 3/2 solenoid valve that pressurized it or ran a vacuum to regulate the level.

III. Results

Testing of the BR model consisted of ±500 mL volume shift tests with four MAP targets and one without BR running stable at 90. The MAP was recorded for 120 seconds at 100Hz.

Effectiveness of the system was measured with the Integral absolute error (IAE) between measured and target MAP. The BR module performed better at maintaining a set MAP, yet model oscillations increased IAE along with the MAP target.

INTEGRAL ABSOLUTE ERROR (IAE)		
MAP Target (mmHg)	***Volume Shift***	***IAE***
No BR	500	1.19E+05
80	500	2.36E+04
95	500	2.83E+04
110	500	3.95E+04
120	500	8.82E+04
No BR	-500	4.41E+04
80	-500	1.42E+04
95	-500	1.97E+04
110	-500	3.40E+04
120	-500	5.47E+04

IV. Discussion & Conclusion

Studies using the BR in MCLs do not entirely simulate all the corresponding effectors [3] making this BR module addition with an UVV chamber a step into a testing platform with better capacity for physiological simulation.
Future studies would include a refinement of the effector control to reduce oscillations and move to experiment with VADs in order to fully contribute to the improvement of mechanical assist device testing.

References

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