BAROREFLEX CONTROL IMPLEMENTATION AND PERFORMANCE EVALUATION OF A CARDIOVASCULAR HYBRID MOCK CIRCULATION LOOP.

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Introduction

Mock circulatory loops (MCL) are used to multiple purposes like training and research including the in vitro assessment of VADs and other cardiac assist devices. Usually, conventional hydraulic MCL are used but the versatility is limited because whenever different patient conditions need to be tested, hardware changes are re-quired. Numerical MCL instead allow for a wide reproducibility and controllability of the cardio-vascular system features by means of lumped parameter modeling. The concept of merging numerical and physical models was exploited in the last years leading to a new concept of circulatory models called hybrid MCL (H-MCL). The aim of this work is the development of a H-MCL providing realistic hemodynamic waveforms in different scenarios including rest, exercise, infarction, with and without cardiovascular device support.

Methods

The mock circulatory loop here presented is a hardware-in-the-loop system. The numerical model of the human circulatory system, implemented in MATLAB Simulink, provides a real-time simulation. The lumped parameter model is made by the following blocks: Left and Right Heart (time-varying elastance model with internal resistance for both atrium and ventricle), Pulmonary and Systemic Circulation (each described as a five Windkessel element model for the arterial system and a classic Windkessel model for the venous one), and the baroreflex control. The baroreflex control implemented is meant to act on arterial pulmonary resistances, systemic peripheral resistances, venous unstressed volume and heart rate according to the Colacino [1] and Ursino [2] model.

The hydraulic part is mainly composed of two cylindrical PMMA tanks. The tanks can be any anatomic district of interest. In our case, we use a numerical model of the CVS and for that reason the two chambers are meant to be the left ventricle and the aorta, if the left cannulation is chosen, or right ventricle and pulmonary artery in case of right cannulation choice.

The validity of the numerical model was assessed changing real-time HF and CF when baroreflex control is activated. Then, different patients' conditions were simulated varying pressure tracings consistently with the input parameters chosen by the user.

The accuracy in the experimental measures has been evaluated considering two functional indexes: pressure error difference and stroke work.

Results

The model we implement is capable of restoring the physiological pressure tracing (if the myocardium is not severely impaired) a few cycles after the real-time modifications of HR and CF, when the baroreflex control is activated. PV loop analysis (Figure 1) gives additional worth to the numerical model. Increasing the HR, the end-diastolic volume reduces, leading to a reduction of the SW. Varying the CF from healthy to pathological, SW decreases with the reduction of contractility causing reduced ejection, lower blood pressure, higher end-systolic volume and as a consequence reduced ventricu- lar filling. The comparison between experimental and numerical pressure shows that the controller is capable of making the experimental pressure wave-forms follow the numerical tracings.

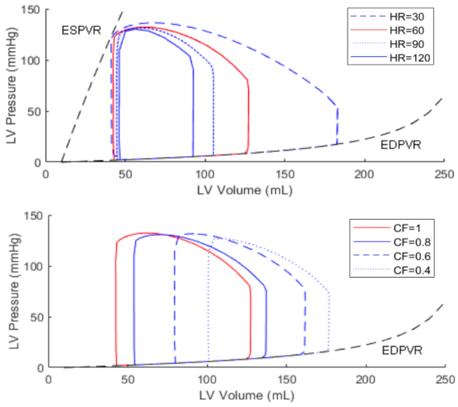

Figure 1: PV loop variations considering HR variability (upper figure) and CF variability (lower figure)..

Discussion

The flexibility of our mock loop has been checked: several parameters can be changed and monitored, mimicking several clinical scenarios. This is an extremely useful tool for clinicians, allowing them to understand which device or selected device configuration is most appropriate for the simulated patient.

References

1. Colacino et al., Asaio Journal, 53(3):263–277, 2007. .
2. Ursino et al., American Journal of Physiology-Heart and Circulatory Physiology, 275(5):H1733–H1747, 1998..