Do We Need Active Relaxation in Artificial Cardiac Muscles?

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Introduction

There are a number of researchers using artificial muscle wraps to assist failing hearts, some of which will be presented at this meeting. Our group has looked at the use of IPMCs, ultrasonic and EM actuation to achieve this and others are using pneumatic and SMA technologies. One of many issues with these devices is the mode of operation of the device during relaxation (diastole) of the myocardium. In the human heart, relaxation is an active process and hence there is a question as to whether a heart wrap should also be active (requires energy). As electrical power consumption is at a premium for any LVAD device, incorporating active relaxation involves a shortening of battery life. Conversely, using the heart to expand a device may be power efficient but may unduly hinder the hearts own performance. There is a question therefore as to whether external cardiac compressors should incorporate an active relaxation function into their design.

To answer this question we have used our custom-built hardware-in-the-loop heart simulator to assess a DCC device [1-3]. The simulator represented an axial slice through the heart, with an arrangement of computer controlled actuators used to mimic the motion and stiffness of the epicardial surface. The rig operated via a feedback control loop with a numerically simulated model of the cardiovascular system. It facilitated the in-vitro testing of a single contractive unit. The assistive pressure generated from the single band, as measured by a force transducer, was then assumed to be constant over the whole ventricular surface and used to calculate an additional internal ventricular pressure within the software model. This allowed the external compressive assist from the physical device to be evaluated in-vitro, under realistic diseased conditions.

A diseased weakened heart model for the investigation was created by decreasing the contractility of the left ventricle (LV) by 50% and the right ventricle (RV) by 33%. The heart simulator rig was configured within the model to run at 70 beats per minute.

Active diastolic relaxation was achieved through the application of a small negative voltage to the actuator at the start of ventricular filling in order to drive the actuator backwards. All results obtained were averaged over a ten beat period throughout the experiments.

Results

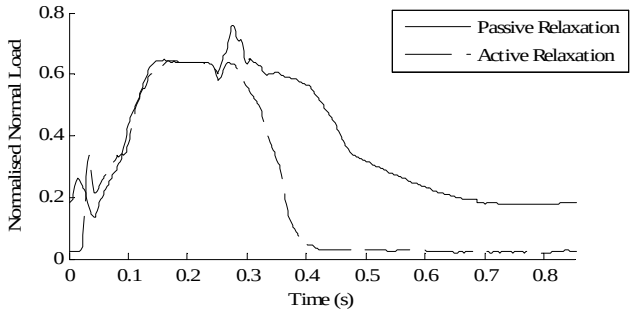

Fig. 1. External Normal force applied to the heart, with and without active relaxation. Systole relates to 0 to 0.24 s.

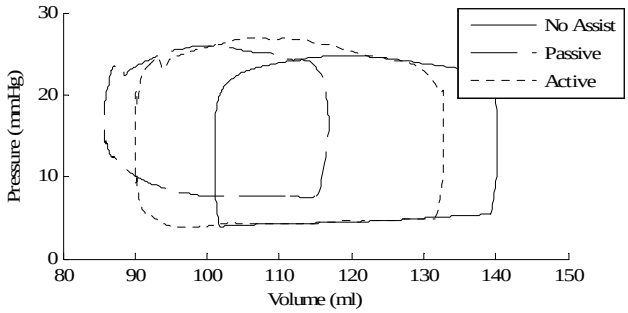

Fig. 2. Simulated pressure-volume loops for a diseased RV without assist and with passive and active DCC device relaxation.

Fig 1 compares the same level of assist, both with and without active relaxation at the onset of diastole. The force waveform clearly shows that the addition of active relaxation to device control had little effect during systole, but rapidly decreased the constrictive normal force during ventricular filling in early diastole.

The effect of active and passive device relaxation on diseased RV function is shown by Fig. 2. DCC assist without active relaxation reduces both end-systolic and end-diastolic volumes. The incurred greater diastolic constriction detrimentally raises ventricular filling (bottom segment of PV loop) pressure, which reduces stroke work below that of the unassisted diseased heart. With the addition of active relaxation, ventricular filling pressure is restored to approximately normal. This coupled with an increased systolic pressure, beneficially increases ventricular stroke work compared to the unassisted diseased heart causing improved hemodynamics.

Conclusion

Our in-vitro simulations would seem to suggest that active relaxation can have a positive effect upon the DCC assisted failing heart. The energy cost of such an implementation needs to be weighed against the benefits and may depend upon the hearts own condition.

References

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[3] B. M. Hanson, M. C. Levesley, K. Watterson, P. G. Walker, "Hardware-in-the-loop simulation of the cardiovascular system with assist device testing application", Medical Engineering and Physics, Vol. 29, (3), 2007, pp. 367-374..