COMPUTATIONAL ANALYSIS OF VENTRICULAR EXPANDER TO TREAT DIASTOLIC DYSFUNCTION

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Introduction

Heart failure with preserved ejection fraction (HFpEF) is a major global health condition with an increasing prevalence. Although this condition is characterized by a normal ejection fraction (above 50%), elevated left ventricular filling pressures and diastolic impairment are common [1]. Due to limited pharmacological success, cardiac devices have been developed to restore diastolic function. The CORolla is a transapical, spring-like expander that transfers energy from systole to diastole. It was tested on animal models and on only a select few patients [4,5]. Here, we present finite element analyses (FEA) of an HFpEF-induced swine for modelling device implantation in different configurations. Cardiac performance was evaluated for each scenario and compared to the preimplantation and healthy (pre-induction) configurations to determine device effectiveness and potential use [6].

Methods

A generic spring-like expander device that resembles the CORolla was modelled with dimensions that fit the subject-specific anatomy. The device is comprised of six elastic wires with six coils between them that create three "arms". A previously developed HFpEF-induced model was chosen for the implantation. Three configurations were considered: (1) basic implantation; (2) implantation after device rotation around the long axis; and (3) the second implantation orientation but with a less stiff device material. The results were compared to the corresponding untreated and preinduction healthy configurations (Figure 1) by plotting pressure–volume curves for each scenario.

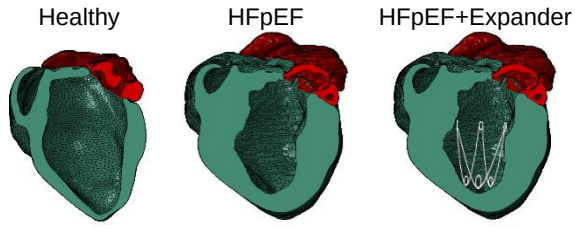

Figure 1: Healthy and HFpEF FEA of the porcine subject, and an illustration of a HFpEF heart with an implanted device.

To appreciate the global and local effects of the device, stress distribution was calculated for the basic implantation and the untreated configurations. Volume-weighted average stress was calculated as a function of time across the entire left ventricle (LV) and per segment, according to the AHA classification.

Results

A pressure reduction of up to 12% was observed following implantation. All implantations resulted in increased end diastolic volumes. A maximal increase was observed in scenario 3, where the diastolic volume was similar to the preinduction configuration (~55 mL). EF remained above 60% for all scenarios. The end-systolic pressure-volume relationship (ESPVR) was reduced after device implantation and brought closer to healthy conditions (Figure 2).

The device has facilitated an increase in diastolic average stress while having limited influence on the systolic one. Changes occurred largely in the apex region, where the coils and the LV wall were in immediate contact.

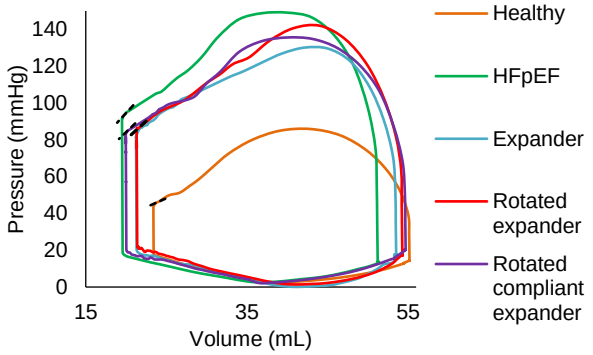

Figure 2: Pressure-volume curves for each implantation scenario. The dashed black lines denote the ESPVR slope corresponding to each scenario.

Discussion

The device has successfully increased the EDV without hindering heart contraction. The ESPVR was also improved. The EF remained within preserved values for all scenarios, demonstrating the device's safety profile. Arm rotation and device stiffness reduction have improved device performance without diminishing the compensatory high LV pressures. The device caused an increase in stress levels during diastole, with minor effects during systole. Stress distribution was mildly altered. An optimal deployment of the device and tailoring its dimensions are essential for reducing unnecessary elevations in LV stress and improving heart performance.

References

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