Towards simulating the mechanically supported heart

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Towards simulating the mechanically supported heart

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Background
Heart failure is a disease often treated with the implementation of a left ventricular assist device (LVAD) to assist the heart's pumping function. The addition of one into the cardiovascular system induces external stimuli onto the left ventricle, which may lead to changes in the mechanical behavior of the heart and its function.

Goals
The goal of this project is to quantify the local myocardial mechanical load with respect to LVAD interaction. The heart is already a complex system, requiring, at the very least, modeling of its muscle fibers, hyperelastic material behavior, contraction, and coupling to a circulatory system. The addition of an LVAD brings along other challenges, such as choosing proper boundary conditions for the LVAD insert, and extending the circulatory system to include LVAD operational parameters. In the end, the goal is a patient specific model.

Boundary Conditions + LVAD
For the case without an LVAD, the following boundary conditions are applied:

- longitudinal motion is suppressed on the basal plane;
- tangential motion is suppressed at four points on the basal plane/endocardial surface;
- cavity pressure is applied to the endocardial surface.

For the case with an LVAD, an additional boundary condition needs to be applied to the LVAD insert. A couple of possible choices, based on physiology, are:

- insert is completely fixed, i.e., no motion is possible;
- allow longitudinal motion, but with extra stiffness.

Circulatory System + LVAD
Our circulatory system is modeled by a windkessel system. An LVAD can be implemented into the loop by adding an additional node to the system, in the same manner as [1]. This additional node is illustrated in Figure 2.

Patient Specific Model
We are collaborating with other VPH–CaSE partners to simulate LifeTec Group’s PhysioHeart platform, shown in Figure 2. This platform assesses the function of real hearts and is coupled with other experiments, such as ultrasound and electrical imaging, and LVAD operation. We will use this information to develop a ‘patient specific’ model of the heart, tune and validate our simulations, and then to investigate the changes in mechanical load as a function of LVAD parameters.

Current Status
The first step of this project was to transition from our former finite element method package to a newer, actively developed one, with a larger user base. With the new package, the left ventricle model, sans LVAD, can be passively filled with a verified isotropic material law implementation. A transversely isotropic material with a representative fiber structure has been implemented and is currently being verified. Afterwards, an electrical activation model [2] will be implemented and verified, and full heart cycles can be simulated and validated against experimental results.

References