Mathematical models in aid of diagnostics and treatment of heart failure
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**Introduction**

Heart failure is "a complex of complaints and symptoms due to an inadequate pump function of the heart" [1]. Roughly 1 to 2 percent of the Western population suffers from a failing heart. And every year another 0.5 to 1 percent will be affected. Valve stenosis is one of the causes of heart failure. After initial favorable adaptive growth (hypertrophy), the heart muscle may finally fail.

![Figure 1: Concentric hypertrophy (left) and dilated hypertrophy (right) after valve stenosis compared to a normal heart wall (center).](image1)

**Diagnosis and Treatment**

For the diagnosis of heart failure a lot of diagnostic tools are available. At the moment the most important ones are the electrocardiogram and the echocardiogram (fig. 2). In spite of these tools the selection of the optimal (surgical) treatment remains difficult, just like the prognosis after treatment.

![Figure 2: Left: apical 4-chamber view obtained with echocardiography. Middle: Doppler blood velocity measurements. Right: Quantities derived from the echo system.](image2)

**Objective**

The goal of this project is to enhance the diagnostic toolbox for heart failure by combining existing diagnostic information with a mathematical model of heart and circulation.

![Figure 3: Left: a schematic representation of the complete mathematical model. Right: the ventricles consist of one fiber [2].](image3)

**Method**

The mathematical model describes the interaction between heart and circulation (fig. 3). The mechanical behavior of the ventricle is described by a one-fiber model, because the ventricles consist of one specially folded muscle band (fig. 3). The model translates clinical measurements (wall volume $V_w$, left ventricular pressure $P_{lv}$ and volume $V_{lv}$) into muscle fiber stress $\sigma_f$ and strain $\epsilon_f$, according to [3]:

\[
\sigma_f = P_{lv}(1 + 3\frac{V_{lv}}{V_w}) \quad (1)
\]

\[
\epsilon_f = \frac{1}{3}\ln(1 + \frac{V_{lv}}{V_w}) \quad (2)
\]

Moreover, from the course of stress and strain, myocardial material properties are derived. These quantities will be the input for an adaptation process to predict hypertrophy.

**The Case of Aortic Stenosis**

Patients with a severe aortic stenosis (valve opening of less than $1 \text{cm}^2$), who are recommended for valve replacement, cannot be told whether or not the heart muscle will return to 'normal' (geometry) after the intervention.

![Figure 4: Results of a simulation.](image4)

First simulations of an aortic stenosis (valve opening 0.75 cm$^2$ versus 2.5 cm$^2$ for normal) show the increase of cavity pressure and the decrease of stroke volume (fig. 4). These changes are reflected in the stress strain relation (fig. 4). Future simulations will be able to predict the future state of the heart with and without intervention.

**Conclusion**

A strategy has been elaborated, in which mathematical models can support diagnostics and treatment selection in heart failure.

**References:**

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