8th International Congress of Serbian Society of Mechanics
Kragujevac, Serbia, June 28-30, 2021

FLUID-ELECTRO-MECHANICAL PARAMETRIC MODEL OF THE LEFT VENTRICLE

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Abstract:

Motion of the heart walls is achieved by mechanical forces generated within muscles in heart wall activated by the nervous system. This motion further iduce blood flow as, mechanically, solid– fluid interaction. There is a number of physical fields within the left ventricle of heart, such as velocities of motion of solid and fluid and, fluid pressure; additionally, electrical potential field is directly coupled to biochemical process of transforming the chemical into mechanical energy and further to active forces for the body motion. In order to simulate ventricle behavior during a cardiac cycle, we have generated a novel computational model feasible for electrophysiology using concept of smeared physical fields (Kojic Transport Model, KTM) according to [1,2]. Applicability of this model is illustrated on a simple left ventricle parametrical model with inlet mitral and outlet aortic valve cross-sections. Further, we calculate smeared electrical field and cell membrane potential in the heart wall, that gives us calcium concentration field from which we calculate active stress in muscle fibers.

Key words: left ventricle model, solid- fluid interaction, Holzapfel model, smeared concept

1. Introduction

Primary cardiomyopathies are frequent heart diseases with an estimated prevalence of 0.3-0.4% in the general population, significantly contributing to systolic heart failure and sudden cardiac death in the young [3].

The objective of this report is to present application of our finite element (FE) numerical procedure for strong coupling solid-fluid interaction in order to simulate cardiac cycle of left ventricle using parametric model which, combined with experimental and clinical data, helps in a better understanding of the mechanisms that cause the cardiomyopathy disease.

2. Methods

A heartbeat cycle includes three different physical aspects: electrophysiology, solid mechanics and fluid dynamics. In order to simulate blood flow process, we prescribe inlet velocity at mitral valve, as well as outlet velocity at aortic cross-section (Figure 1) as functions of time. During fluid injection (diastolic period), ventricle volume is increasing and aortic valve is closed. Contraction of the ventricle occurs during systole due to muscle activation so that blood flows out through aortic valve which is open.

Solid mechanics model includes evaluation of passive and active stress. Active stress represents the load on tissue and depends on the electrical field determined by the KTM methodology .For passive stress, the start of diastole is the stress-free configuration. Passive stresses are calculated directly from the recent experimental constitutive relations of Holzapfel [4].

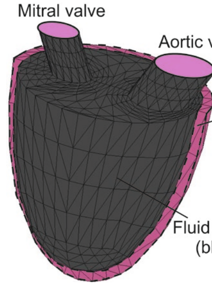

Fig. 1. Parametric model of the left ventricle: fluid domain (blood), mitral and aortic valves, and solid wall (dashed line).

3. Conclusions

The introduced coupled solid-fluid electromechanical parametric model of left ventricle can be used for computer modeling of the left ventricle. The calculation was executed using our PAK solver in which the KTM with smeared methodology is embedded, while the model generation is performed by the in-house CAD software. The presented computational model will serve as a basis for the in-silico simulation of the entire heart electrophysiology and coupled solid- fluid mechanics.

Acknowledgment: This work is supported by the grant NCI U54 CA210181, and by the SILICOFCM project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 777204. The research was also funded by Serbian Ministry of Education, Science, and Technological Development, grants [451-03-9/2021-14/200378 (Institute for Information Technologies, University of Kragujevac)] and [451-03-9/2021-14/200107 (Faculty of Engineering, University of Kragujevac)].

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