Modelling of a Single Cardiomyocyte Interaction with a Microcantilever Using COMSOL Multiphysics®

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Abstract

The mechanics behind contraction and expansion phenomenon of cardiomyocytes is still to be understood fully. Information on the contractile force of heart cells will be very helpful in understanding the precise mechanism of heart failure as well as the molecular alterations involved in diseased heart cells. One of the most commonly used techniques for quantification of beating forces exerted by cardiomyocytes is culturing them on a bed of vertical microcantilevers or microposts as shown in Figure 1. The position of the microcantilevers is observed through advanced imaging techniques and the displacements are observed over a period of time. The stiffness of the microcantilevers is known and thus the force can be calculated from the displacements observed.

In this paper, an effort is made to develop a computational model of the interactions between the cardiomyocytes and the microcantilevers based on the Fluid-Structure Interaction interface in COMSOL Multiphysics®. The cardiomyocyte along with its culturing medium is considered as a homogenous fluid exerting forces on the microcantilevers as they start maturing and finally start beating. For this case, the medium was modeled as an incompressible fluid with a density 1000 kg/m3 and viscosity $0.78\times10-3$ kg m−1 s−1 . The flow is governed by the continuity and Navier-Stokes equation. The flow is considered in both the directions with different velocities for the contraction and expansion phenomenon.The interactions between a culturing medium of cardiomyocytes with a single vertical microcantilever was modeled. The vertical microcantilever considered has dimensions of 500 um in length, 100 um in width, and 0.9 um in thickness with a nominal spring constant of 0.02 N/m. For these simulations, the Fluid-Structure Interaction interface in COMSOL Multiphysics® has been used.

The results obtained so far are simulations at t = 0s, 2s considering both the directions of the fluid flow. two dimensional fluid flow represents expansion and contraction of cardiomyocytes. Figure 2 shows the geometry and mesh at the top of the the microcantilever at t= 0 s. From the results obtained , the deflection of the cantilevers can be seen. Also from the deflections the force can be calculated which actually corresponds to the actual force measured using imaging techniques.

This is a new computational modeling approach for quantifying the contactile forces in cardiomyocytes based on 3D Fluid-Structure Interactions (FSI) using COMSOL Multiphysics®. A comparison of the experimental results with the proposed model showed that the new proposed model represented the real system well, and the differences between FSI results and the FEM results were small.

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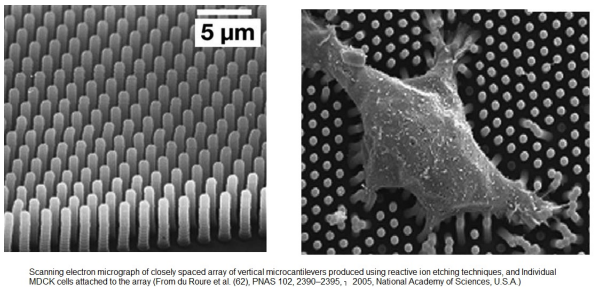
Figures used in the abstract



Scanning electron micrograph of closely spaced array of vertical microcantilevers produced using reactive-ion etching techniques, and Individual MDCK cells attached to the array (From du Roure et al. (62), PNAS 102, 2390–2395, ↑ 2005, National Academy of Sciences, U.S.A.)

Figure 1: Cardiomyocytes on vertical cantilevers

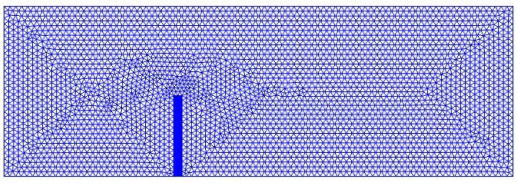


Figure 2: FSI Model of interaction of cardiomyocytes with a Microcantilever at t=0s