COLLEGE OF ENGINEERING AND COMPUTER SCIENCE
FLORIDA ATLANTIC UNIVERSITY

Announces the Ph.D. Dissertation Defense of

YUHAO QIANG

for the degree of Doctor of Philosophy (Ph.D.)

"Mechanical Fatigue Testing of Human Red Blood Cells Using Electro-Deformation Method"

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Engineering West, Room 101
777 Glades Road
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ABSTRACT OF DISSERTATION

Mechanical fatigue arising from cyclic deformation is a key factor in the degradation of properties of engineered materials and structures. Fatigue can also induce damage and fracture in natural biomaterials such as bone and in synthetic biomaterials used in implant devices. However, the mechanisms by which mechanical fatigue leads to deterioration of physical properties and contributes to the onset and progression of pathological states in biological cells have hitherto not been systematically explored. Human red blood cells (RBCs) or erythrocytes must undergo severe deformation to pass through narrow capillaries and submicronic splenic slits for several hundred thousand times in their normal lifespan. Studies of erythrocyte biomechanics have been mainly focused on cell deformability and rheology measured from a single application of stress and mostly under a static or quasi-static state using classical biomechanical techniques, such as optical tweezers and micropipette aspiration. Mechanical fatigue effect on erythrocytes in response to cyclic stresses that contributes to the membrane failure in blood circulation is not fully understood. In this research, a new experimental method for mechanical fatigue testing of erythrocytes is developed using amplitude-modulated electro-deformation technique through dielectrophoresis in a microfluidic platform. This technique allows for full control on the extent and the rate of deformations in cell membranes, which is suitable to explore effects of different loading configurations on cell deformation. Transient loads of shear stress on RBC

membranes were calibrated using a triaxial ellipsoid model and Maxwell stress tensor method. A viscoelastic membrane model is used to extract the nonlinear elasticity and viscosity properties of individually tracked cells under the uniaxial stretching as well as upon relaxation of the loading. Preliminary results demonstrate the capability of this new technique using a low cycle fatigue analysis of normal human erythrocytes and ATP-depleted erythrocytes. Cyclic tensile stresses are generated to induce repeated uniaxial stretching and extensional recovery of single erythrocytes. Results of morphological and biomechanical parameters of individually tracked erythrocytes show strong correlations with the number of the loading cycles. RBCs progressively lose their ability to stretch with increasing fatigue cycles. Further work is carried out on the effects of different loading configurations on the cellular mechanical behavior as well as fatigue behavior. Different loading waveforms are explored to investigate the viscoelastic response of cells and to validate the mathematical simulations with the results characterized experimentally. The results show the nonlinear elastic moduli of cell membranes identified as a function of extension ratio, rather than the lumped-parameter models as reported in the literature. Effects of loading configurations on the cellular fatigue behavior of RBCs is further studied by subjecting cells to static loads for prolonged periods of time or to large numbers of controlled mechanical fatigue cycles. The results indicate that loss of deformability of RBCs during cyclic deformation is much faster than that under static deformation at same maximum load over same accumulated loading time. Such fatigue-induced deformability loss is more pronounced at higher amplitudes of cyclic deformation. These results uniquely establish the important role of mechanical fatigue in influencing physical properties of biological cells. They further provide insights into the accumulated membrane damage during blood circulation, paving the way for further investigations of the eventual failure of RBCs causing hemolysis in various hemolytic pathologies.

BIOGRAPHICAL SKETCH
Born in Nantong, Jiangsu, China
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CONCERNING PERIOD OF PREPARATION
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Time in Preparation: 2015 - 2019

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Published Papers:

Qiang Y, Liu J, Du E. Dynamic fatigue measurement of human erythrocytes using dielectrophoresis[J]. Acta biomaterialia, 2017, 57: 352-362.

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