Cell Membranes Under Hydrostatic Pressure Subjected to Micro-Injection

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Abstract. The work is concerned with the determination of the mechanical behaviour of cell membranes under uniform hydrostatic pressure subject to micro-injections. For that purpose, assuming that the shape of the deformed cell membrane is axisymmetric a variational statement of the problem is developed on the ground of the so-called spontaneous curvature model. In this setting, the cell membrane is regarded as an axisymmetric surface in the three-dimensional Euclidean space providing a stationary value of the shape energy functional under the constraint of fixed total area and fixed enclosed volume. The corresponding Euler-Lagrange equations and natural boundary conditions are derived, analyzed and used to express the forces and moments in the membrane. Several examples of such surfaces representing possible shapes of cell membranes under pressure subjected to micro injection are determined numerically.

Keywords: Cell membrane, micro-injection, spontaneous-curvature model, axisymmetric shapes, forces and moments, bending energy, variational statement, Euler-Lagrange equations, natural boundary conditions, jump conditions
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INTRODUCTION

The 2010 Nobel Prize in Physiology or Medicine was awarded to Robert Edwards for the development of human in-vitro fertilization in 1977 (Louise Brown, the world's first "test tube baby", was born on 25 July, 1978). On the other side, genetic engineering is a rapidly developing area of biology in the past 30 years aimed in creation of transgenic organisms with desired properties. Recently, the controlled delivery of diamond and gold nanoparticles within a single cell has being developed (see, e.g. [7]), and is expected to become a broadly applicable tool for therapy, since these nanoparticles being not toxic can be used as carriers for therapeutics, proteins, antibodies, DNA and other biological agents. Presently, these three fields of the human activity involve the intracellular delivery of substances by micro-injection. During the process of a micro-injection, a micro pipette pierces the cell membrane and releases substances within the cell interior. The success of a micro-injection depends mainly on the mechanical properties of the injected cell membrane and on the specific way of interaction between the membrane and the holding and injection pipettes.

Observing the literature on micro-injections of cells one realizes that large cells are the most often studied, typical examples being the zebrafish and mouse embryos. The

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