MODELING THE TETHER PULLING EXPERIENT TO PROBE THE MECHANICAL AND ELECTROMECHANICAL PROPERTIES OF CELLULAR MEMBRANES

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INTRODUCTION

The experiment with pulling tethers from cellular membranes is commonly used to analyze the membrane mechanical (bending stiffness, viscosity, tension) and electromechanical (forces generated by applied electric fields) properties. In this experiment, a bead originally attached to the cellular membrane is pulled away by optical or magnetic forces. After reaching a critical distance, the bead-membrane connection reduces to a thin tube (tether). The dynamic (pulling) or static (holding) tether force is measured as a function of time and tether length. The membrane characteristics can be estimated by using a model that relates the measured force to the membrane mechanical and electromechanical properties.

MODEL AND COMPUTATIONAL METHOD

The cellular membrane is modeled as an axisymmetric elastic shell with finite bending stiffness and negligible shear modulus [1, 2]. We consider three regions of the membrane, the body of the tether, attachment region, and transition region between the two (Figure 1). We assume that in the attachment region the membrane is connected to the underlying cytoskeleton by a system of bonds with prescribed geometry. We also assume that the top part of the bond associated with the membrane deforms as an elastic spring. The bond is intact if its vertical displacement does not reach a threshold, upon which the bond breaks. We numerically integrate the equations of membrane equilibrium, including the adjustment of the number of the intact bonds and the corresponding detachment radius.

RESULTS AND DISCUSSION

We apply our model to two cells, cochlear outer hair cell (OHC) and human embryonic kidney (HEK) cell. In OHC, the membrane is connected to the cytoskeleton by a system of cylindrical bonds (pillars) with a typical diameter of 10 nm and typical spacing of 30 nm. The HEK cell has a dense system of bonds that we model as a continuous spring layer. Both cells are important to human active hearing: the OHC membrane possesses the motor generating electromechanical forces, and the HEK cell is used for transfection of the membrane protein prestin which is a critical part of the OHC motor. By using our model, we compute the membrane profile in the attachment and detachment regions in both cells as a function of the membrane bending modulus, bond geometry, and holding force. We also compute the distributions of the resultants, bending moments, and adhesion/bending energy density The proposed model allows a point-wise computation of the membrane deformation in the tether pulling experiment, and it can be used in the design and interpretation of this experiment. The model can also be extended to include electromechanical coupling if the membrane (cell) is under the action of an electric field. Finally, the obtained results can be useful for the general modeling of cellular membranes.

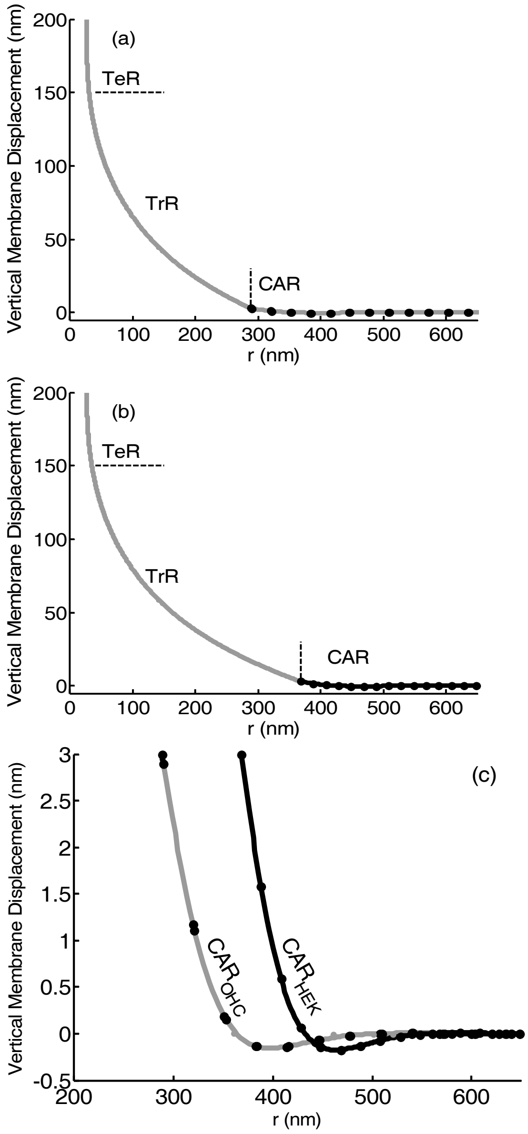

Figure 1: Computed membrane profiles for two cells. Three specific regions are considered, TER (body of the tether), CAR (region of membrane adhesion to the cytoskeleton), and TrR (transition region) between them. (A) and (b) present all three regions for the OHC and HEK cell, respectively; (c) presents the attachment regions for two cells (dark dots represent bonds connecting the cellular membrane and the cytoskeleton).

REFERENCES

[1] Schumacher K et al., *J. Biomech,. Eng.* **130**: 31007, 2008
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