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Some Factors That May Determine the Frequency Response of Cells and Tissue to Applied Electrical and Mechanical Forces

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A variety of experiments has shown that the response of cells and tissue to electric fields and mechanical shear stresses of physiological strength decreases with frequency. I have proposeda that a common transduction mechanism may exist for both types of physical signalling - the generation of a mechanical torque which is transmitted across the cell membrane to the cytoskeleton by integrins or similar molecules. In that case common mechanisms may act to determine the frequency response of cells and tissue to both electrical and mechanical forces. There are several candidates for such mechanisms. In cartilage these forces produce oscillating torques on the aggrecans which may be communicated via hyaluronan chains to the cell surface. I model the aggrecan as a damped, driven, rigid body coupled to the hyaluronan by a harmonic-type force exerted by the link proteins. The damping is produced by the surrounding fluid. With reasonable guesstimates for the various parameters of the model the frequency response falls off rapidly above 10 to 100 Hz and is relatively constant below about 0.1 Hz. At the cell surface a similar model is applied to an integrin subjected to an oscillating electric field or a mechanical shear stress. In this case the harmonic restoring force is provided by the membrane and the damping by the extracellular fluid. With reasonable guesstimates for the various parameters of the model the frequency response falls off rapidly above 100 to 1000 Hz and is relatively constant below about 10 Hz. A third mechanism for the reduction of response at higher frequencies is the lossy mechanical response of the cytoplasm itself. Fabry et al. have shown" that factional stresses in the cytoskeleton become significant for frequencies above about 10 Hz. Some combination of these three processes may be responsible for the observed decrease with frequency of the response to these forces.

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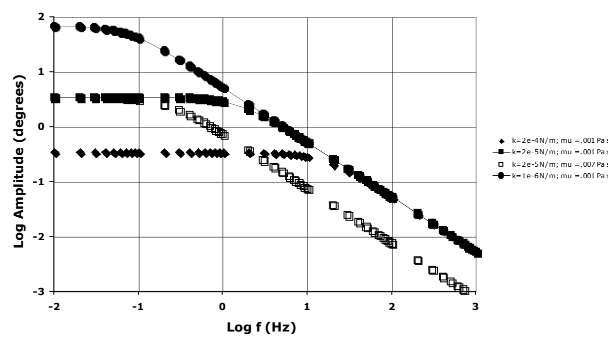

Figure 1 : Amplitude of rotational displacement of the aggrecan for an applied electric field of 1 V/m. Solid circles, force constant k = 1 □N/m and viscosity m = 0.001 Pa s; solid squares, k = 20 □N/m and m = 0.001 Pa s; open squares, k = 20 □N/m and m = 0.007 Pa s; solid diamonds, k = 200 □N/m and m = 0.001 Pa s.

References

1. Hart, F. X. (2006) Bioelectromagnetics 27, 505-508.

2. Fabry, B., et al. (2003) Phys. Rev. E 68, 041914.