Biophysical Mechanisms Underlying Microtubule Electrical Oscillation and Amplification

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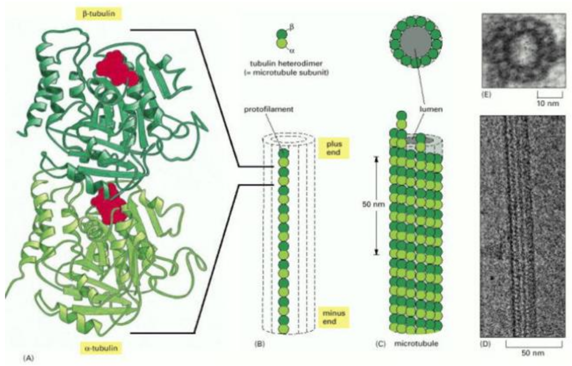
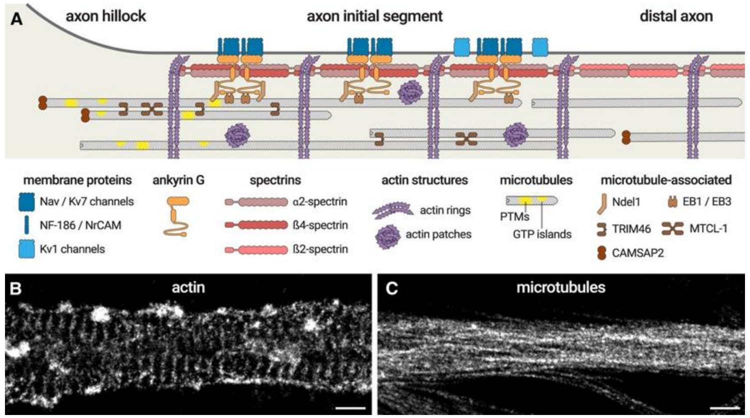
- α-tubulin and β-tubulin form a dimer
- Dimers produce protofilaments
- 13 protofilaments form the MT sheet
- MT sheet folds into a hollow cylinder
- MT has pores in the wall, and C-terminals ("tails")



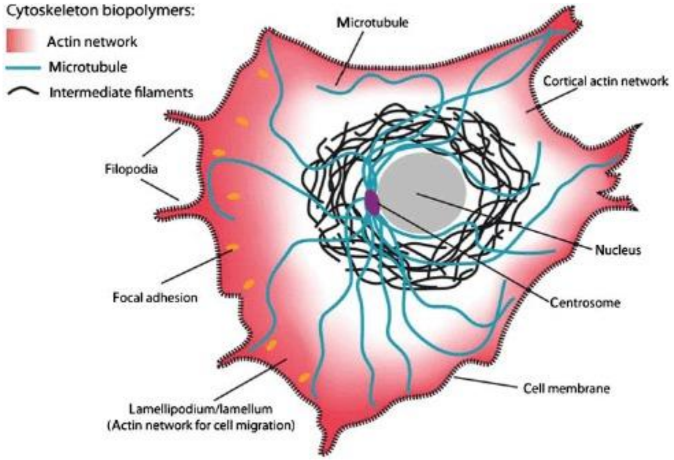
Alberts, Bruce, et al. (2002)

- In neuronal axons and dendrites MTs are in parallel bundles



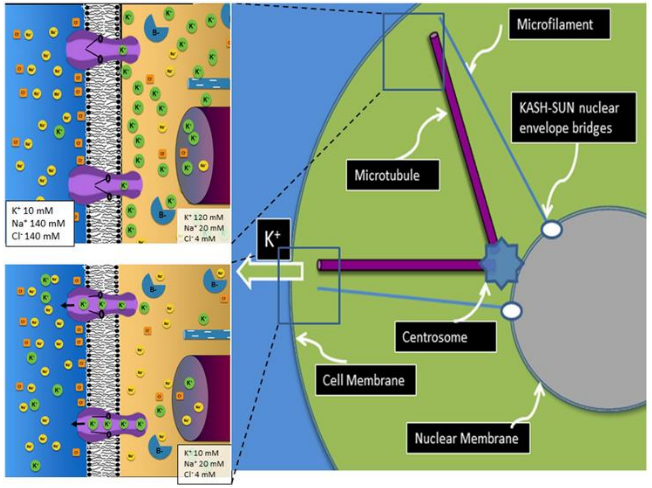
Rasband and Elior Peles. (2021)

- MT grows radially outward from the centrosome



Huber, Florian, et al. (2013)

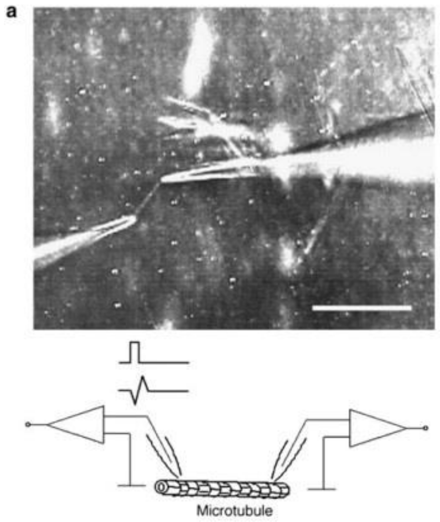
- MTs can transmit signals between different cell compartments, e.g., to and from membrane channel to centrosome.

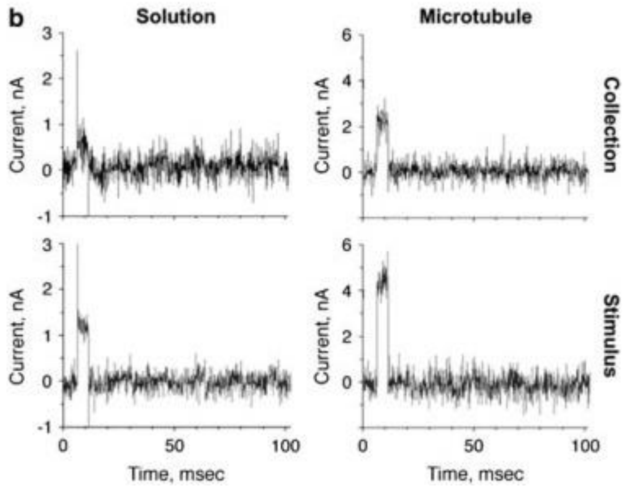


Frieden and Gatenby (2019)

Electrical properties of MT

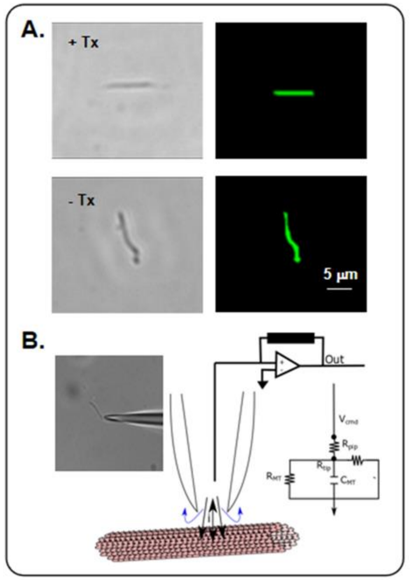
- Microtubules transmit and amplify electric signals.

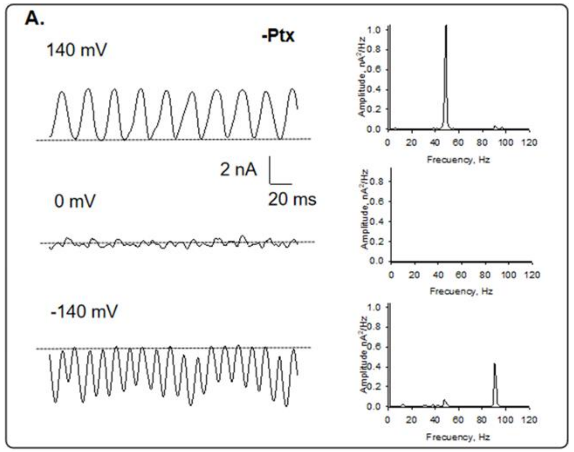


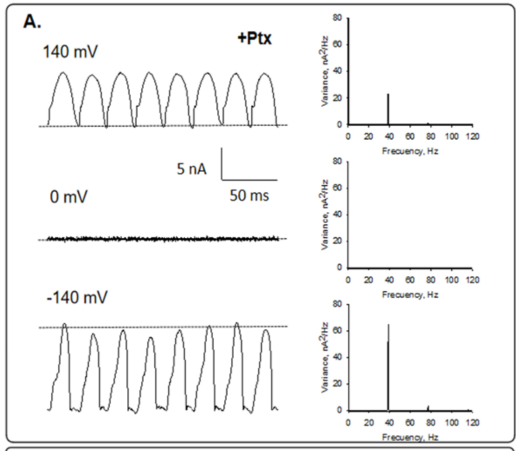


Priel, Avner, et al. (2006)

- Microtubules produce electrical oscillations.







Gutierrez, Brenda C., et al. (2023)

A novel coupled transmission lines model for MT

- Existing MT models cannot explain the electrical oscillation
- Transmission line models for MT did not include the lumen.

Outer transmission line

Capacitive and/or resistive coupling

Inner transmission line

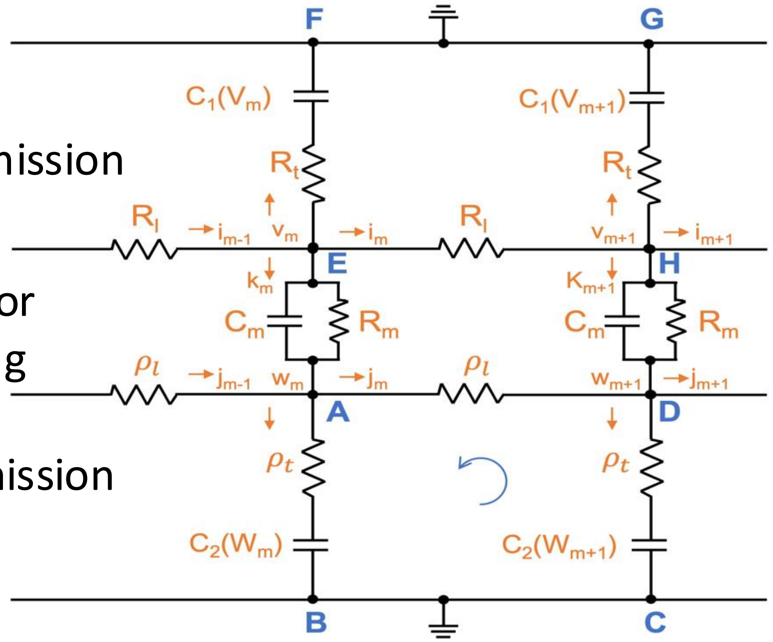


Fig: Two coupled transmission line model for microtubule. Condensed ions on outer and inner walls of microtubules form transmission lines. The transmission lines are connected by conductance representing pores connecting two surfaces of microtubule.

$$\frac{\partial \Psi}{\partial \tau} - 6\Psi\frac{\partial \Psi}{\partial \xi} + \frac{\partial^3 \Psi}{\partial \xi^3} = -M_1\frac{\partial \Psi}{\partial \xi} + M_2\frac{\partial \Phi}{\partial \xi} - N_1\Psi - N_2\Phi + \nu_1\frac{\partial^2 \Psi}{\partial \xi^2} - F_1\frac{\partial^3 \Psi}{\partial \xi^3}$$

$$\frac{\partial \Phi}{\partial \tau} - 6\Phi\frac{\partial \Phi}{\partial \xi} + \frac{\partial^3 \Phi}{\partial \xi^3} = -M_3\frac{\partial \Phi}{\partial \xi} + M_4\frac{\partial \Psi}{\partial \xi} - N_3\Phi - N_4\Psi + \nu_2\frac{\partial^2 \Phi}{\partial \xi^2} - F_2\frac{\partial^3 \Phi}{\partial \xi^3}$$

- The transmission line equations are coupled perturbed KdV equations.
- The coefficients (M1, M2, N1, etc.) are related with the circuit components which themselves depend on MT structure and biological environment.

A novel coupled transmission lines model for MT

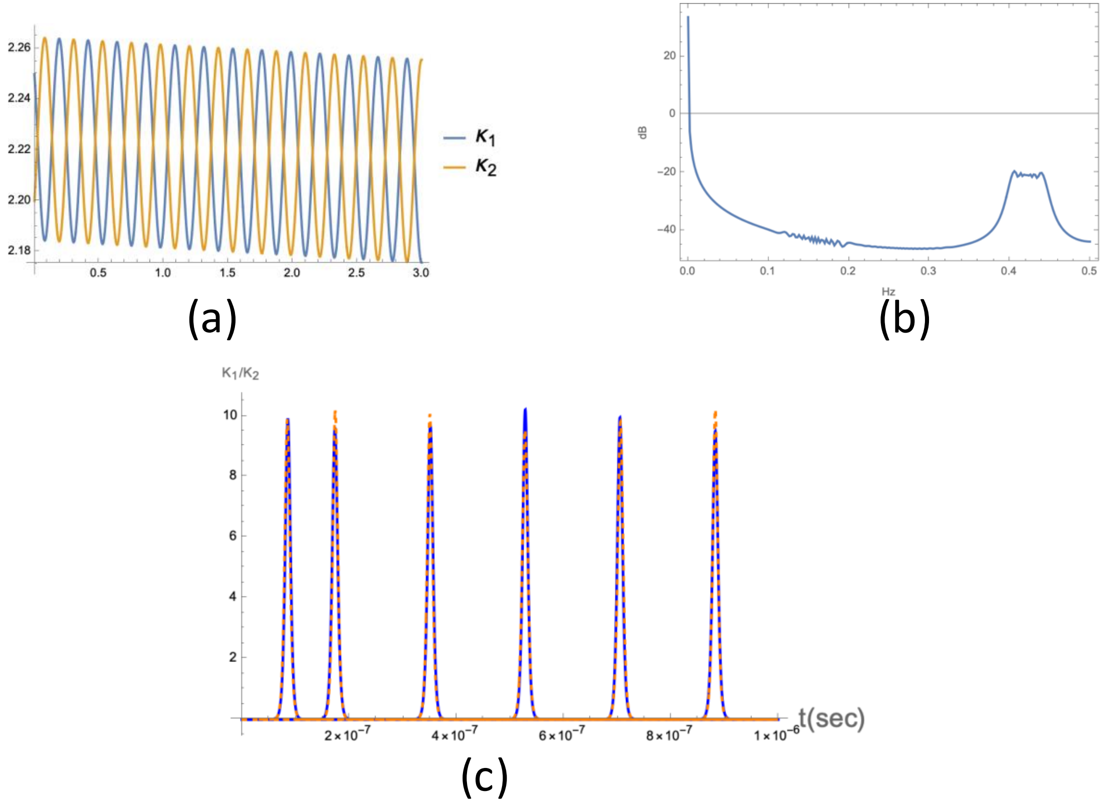


Fig: For symmetric lines conditions, amplitude oscillations (a), periodogram (b), and solitons solutions (c) [M1 = 3, M2 = 3, M3 = 3, M4 = 3, N1 = 0.001, N2 = 0.001, N3 = 0.001, N4 = 0.001, ν1 = 0, ν2 = 0, F1 = 0, F2 = 0].

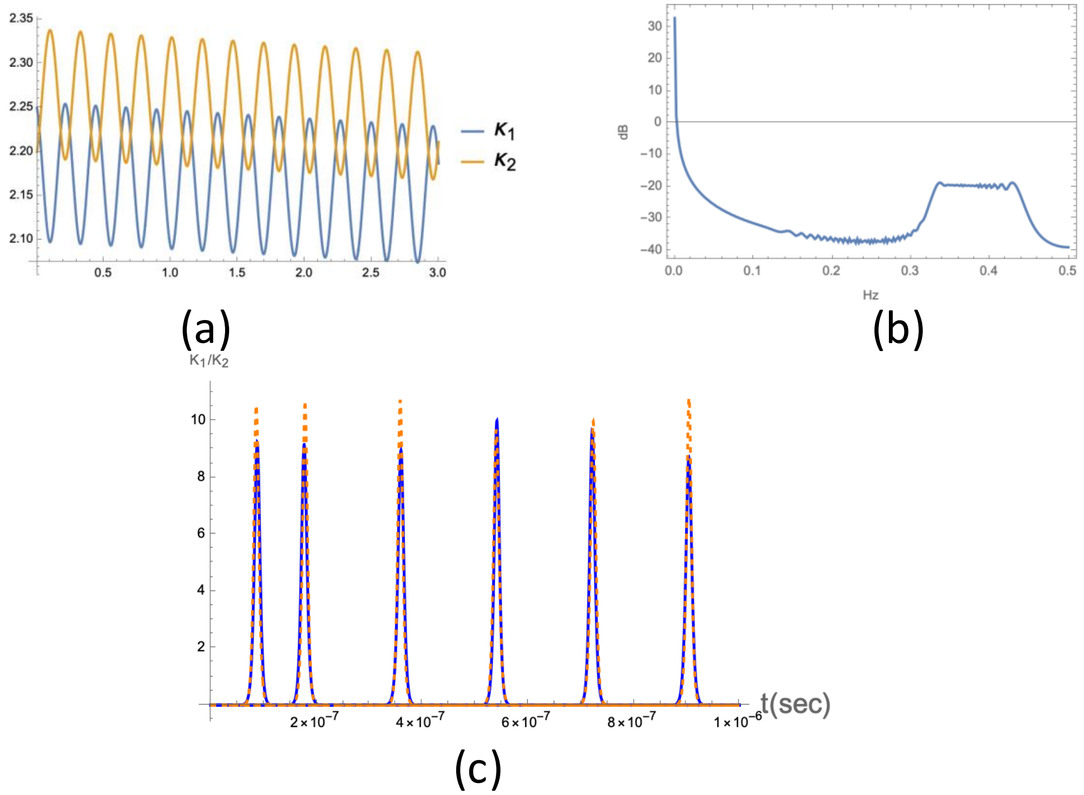


Fig: For asymmetric lines conditions, amplitude oscillations (a), periodogram (b), and solitons solutions (c) [M1 = 3, M2 = 3, M3 = 1, M4 = 3, N1 = 0.001, N2 = 0.001, N3 = 0.001, N4 = 0.001, ν1 = 0.001, ν2 = 0.001, F1 = 0.002, F2 = 0.001].

- Theoretically, for the first time, the model predicts electrical oscillations in microtubule with frequency of the order of experimental measurements.
- We are now calculating model parameters based on microtubule structure and biological environment.