Self-Organization of Microtubules in Plant Cells

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Self-Organization of Microtubules

Microtubules are polar rod-like polymers that play a key role in many cellular processes, such as cell division, protein and organelles transport, cell organization etc. They are ubiquitous in eukaryotic cells and can form different arrays, parallel and anti-parallel bundles and radial spindles. Structure unit of a microtubule is tubulin dimer, which consists of two subunits: α-tubulin and β-tubulin. Tubulins can be bound with either GTP or GDP. Tubulin dimers form 13 protofilaments in a special way (see figure below). The polarity of their constitution leads to different behavior of their ends: while one of them (it is called plus-end) can actually switch from growing to shrinking and back, the other one, called minus-end, tend to shrink or to be stable. Behavior of the plus-end is called dynamic instability and is caused by the degradation of GTP bound with tubulin dimers, what modifies the equilibrium conformation of the dimer, making microtubule unstable.

In plant cells microtubules are organized in parallel arrays which are adjacent to the cell’s membrane. This arrays are sensitive to gravitation through the mechanism that is still unknown. In vivo this arrays are perpendicular to the growth axis of the plant.

Mechanisms of Self-Orientation

We propose that microtubules are affected by some hormones. One of these hormones may be auxin, though now there are not enough reliable proofs that it actually affect microtubules in plant cells. Nevertheless, we assume that the gradient of concentration of some media modify the growth rate of the microtubules, making it faster. It doesn’t affect any other parameters of microtubules. However, it’s still not known how strong this gradient affect the growth rate, so we take this number arbitrary.

Microtubules are modeled as rigid rods that lay on a plain, therefore interacting in two-dimensional space. For all of them growth and shrinkage rates, as well as rates of switching between growth to shrinking and back, are defined. They are impenetrable by other microtubules, so in case of collision between them one of them stop growing. The gradient of the hormone’s concentration affects the growth rate: it becomes maximal in the direction where this gradient equals zero. This leads to the reorientation of microtubules. They tend to orientate to the isocentration lines. To analyze the alignment of the array we use anisotropy parameter S and Sl, which are described in VA Baulin, CM Marques, F Thallman, Biophys. Chem., 2007.

Parameters used for simulations:

<table>
<thead>
<tr>
<th>MT growth rate (nm/s)</th>
<th>MT shrinkage rate (nm/s)</th>
<th>Minus-end shrinkage rate (nm/s)</th>
<th>Number of MT added each second</th>
<th>Growth-shrinkage transitions per ms</th>
<th>Shrinkage-growth transitions per ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0.85</td>
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<tr>
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</tr>
</tbody>
</table>

Conclusions and plans:

Microtubules can self-organize themselves in different arrays if they feel the changes in concentration of some hormone. It is only enough for them to modify their growth rate for that, there is no need to modify any other parameter.

Still, the exact numbers how does the gradient affect the growth rate are unknown and are to be clarified. Another thing concern the exact agent that modify the alignment. This agent is also unknown and is to be figured out.