The Self Organisation of Plant Microtubules inside the Cell Volume Yields their Cortical Localisation, Stable Alignment and Sensitivity to External Cues

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Abstract.

Old Model : MTs confined to cell surface

Paper Model : MTs confined to 3D volume.
They naturally localise to cortex, ∴ directional persistence.

Find some MT parameters indep to cell shape:
- Length
- Number,

The geometry of wall can be overcome with directional cues.

Introduction:

protein.
Tubulin → Proto Filaments (≈13) → 25nm tubes
"microtubules"

The network of MTs changes in minutes

The MTs form superstructures at all stages of cell division:
- Before : "Preprophase band"
- During : "The spindle"
- After : "Phragmoplast"

During interphase the MTs form a dense array
Call them CMTs (Cortical microtubules)
↑ we know a lot about these.

A manifestation:
When tubc is mutation affecting tubulin / etc we see morphological defects.

What do CMTs do?
- Influence orientation of cellulose in cell walls (via some biochem mechanism...)
- This affects mechanical anisotropy of cell wall and controls growth direction.

i.e. We understand how

MTs ⇒ Cell shape.

But we don't know how

Cell Shape ⇒ MTs well.

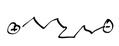
We have evidence that:
- MTs transverse to longest axis

- Mechanical stress orients MTs to area of max stress

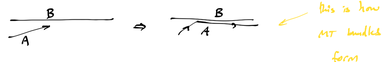
- Cortical MT orientation affected by
  - → blue light
  - → hormones.

How do MTs evolve in time?

- MTs form shift polar structures.



- At + end : growth / pause / shrink
  At − end : pause / shrink
- Together this leads to movement of MT
  "hybrid treadmilling"
- When MT A encounters MT B:
  - → At shallow angle, "Zippering"



this is how MT bundles form

i.e. grows along B
  - → At steep angle either:
    - ↳ "Crossover" (they ignore eachother)
    - ↳ "Catastrophe" (kill self by shrinking from + end)

Results

(1) Model for Interphase MTs growing in cytoplasm / at membrane

- MTs are line segments that:
  - ↳ nucleate (appear randomly)
  - ↳ Grow / Shrink
  - ↳ Interact with eachother
- Cell surface is triangular mesh

- Considered 3 base shapes:
  - ↳ cube 
  - ↳ square 
  - ↳ long 

dim on order 10 μm

Smoothed : max curv. ~ 5 μm
Sharp : max curv. ~ 1 μm

(2) MTs become cortical due to directional persistence

- Tied weak anchoring to membrane
- This induced cortical microtubules.

So 2D model showed CMTs do not prove strong anchoring.

(3) Strong Anchoring Decreases MT number and length; increases bundling (less room)

(4) Number / Length of MTs and prop in bundles unaffected by Cell Shape

(5) MT array anisotropy affected by local curvature, not global shape.

In square shapes MTs align to diag.
↑ this is diff. in reality, see Spelman paper.

(6) Avg orientation affected by Shape

(7) Small External Directional Bias Affects Network Orientation.

"directional cue" = biased to grow in specific direction each time step.

- A very weak cue (~ 1%) causes massive realignment
- This is despite robust organisation.
- The MT-MT interaction reinforces these cues so they cause realignment, preventing ⊥ growth.