Plant Cell Biology

Ram Dixit
Washington University in St. Louis

July 10, 2017
Lecture Goals

1. Introduction to the major components of plant cells and how they differ from animal cells
2. Understand the basics of plant cell expansion and morphogenesis
3. Understand current ideas for how mechanical forces affect the cytoskeleton and cell wall biology
Components of a Higher Plant Cell

- Chloroplasts → fix C via photosynthesis
- A rigid polysaccharide-based cell wall → no cell motility
- Large central vacuole → turgor pressure and cortical cytoplasm
- Dispersed Golgi bodies → trafficking of proteins and cell wall components
- Lack centrosomes and dynein → microtubule arrays are linearly arranged
The interior of plant cells is very dynamic!

Cytoplasmic streaming

Mitosis

From: Microscopic world
Morphogenetic mechanisms of plants and animals

**Animals**
- 100s of different cell types
- Cell migration and apoptosis are important

**Plants**
- 30-40 different cell types
- Cell migration and apoptosis are not involved/important

Animal shape is a history of cell division, migration and apoptosis
Plant shape is a history of cell division and expansion (direction and degree)

*Animals respond behaviorally, plants respond developmentally*  
—Ian Sussex
Modes of plant cell expansion

Diffuse growth

Tip growth

Root hairs

Pollen tubes

Hypocotyl cells

Trichomes

Pavement cells
How the axis of diffuse growth is determined

Turgor pressure drives plant cell expansion (turgor pressure in growing cells is 0.6-2.0 Mpa or 3-10x car tire pressure! Blood pressure is around 0.002 MPa)

Isotropic cell expansion

Anisotropic cell expansion

Tatyana Svitkina lab, UPenn
Turgor pressure is critical to cell growth, function and the way plants interact with their environment.

Cell elongation $\rightarrow$ leads to organ elongation.

Guard cell turgor pressure controls stomatal pore size $\rightarrow$ regulates gas ($O_2$, $CO_2$, $H_2O$) exchange.
The cortical microtubule (CMT) scaffold

• The arrangement of cellulose microfibrils mirrors that of the underlying CMTs
• CMTs are thought to guide the directional deposition of cell wall material, thus controlling plant morphogenesis
• Disruption of CMT arrays causes morphological and developmental defects

Ledbetter and Porter
J Cell Biol (1963)
The cortical microtubule array is dynamic

Green = tubulin
Red = EB1 (plus-end tracking protein)
• Cortical MTs form different structures in different cell types
• Change configuration depending on developmental and environmental inputs
How plant cell morphogenesis works

The plant "cytoskeleton" does not function as a skeleton (supporting structure), but rather as a scaffold for guiding cell wall deposition (organizing framework).
Microtubule function depends on their spatial organization

Plant Microtubule Arrays

Function:
- Specify cell growth axis
- Define cell division site
- Chromosome segregation
- Cytokinesis

Orientation of plant cell division

Periclinal divisions create new cell layers (increase girth)

Anticlinal divisions add more cells to a layer (increase surface area)

Figure 1. Formation of a new lateral root from the pericycle of a pre-existing primary root. Initiation starts with anticlinal divisions of contiguous pericycle cells in the primary root (stage I). Then anticlinal and periclinal cell divisions progressively generate an organised lateral root primordium (stages II–VI). Eventually expansion of the basal cells leads to the emergence of the lateral root (stage VII).
Tip growth

Pollen tube: a model for tip growth

Picture: Anja Geitman lab
A pollen tubes journey

• Pollen grains carry the plant sperm cells
• After pollination, pollen germinates to produce a pollen tube
• Pollen tubes grow quite rapidly (2.8 μm s⁻¹ in maize and 0.2-0.3 μm s⁻¹ in lily) and in a guided manner within the female tissue to reach the ovule
• Release sperm cells for fertilization of the egg
Cytoplasmic streaming: powered by Myosins!

Plant Myosin XI: the fastest known processive motor protein (Chara Myo XI velocity = 70um/sec)
Cell wall assembly and function

The cell wall is very important for plant physiology and for commercial use (paper, fiber, wood, fuel...)
Cell wall serves numerous functions

• Act as an “exoskeleton” providing rigidity and allowing positive turgor pressure to develop.

• Also provide the rigidity required to withstand negative pressure (tension) in xylem.

• Determine the mechanical strength of plants.

• Glue cells together to form tissues and organs, preventing movement of cells relative to one another

• Act as diffusion barriers, thus limiting the movement of large molecules from the environment toward the plasma membrane.

• Determine cell shape and constrain expansion.
**Cell wall types**

- **Primary walls:**
  - Formed by growing cells
  - Relatively thin and simple
  - Flexible enough to allow cell expansion

- **Secondary walls:**
  - Formed after cells finish expanding (and have differentiated)
  - Additional strengthening added interior to the primary wall
  - Highly specialized

Kretschmann (2003), Nature materials, 2: 775-776
Major cell wall components

- **Cellulose**: linear polymers of glucose molecules in (1-> 4)β linkages that contribute to the strength and structural bias of the cell wall. The most abundant biopolymer on the planet!
- **Hemicellulose(s)**: a wide variety of branched-chain polysaccharides such as xyloglucan and arabinoxylan. They typically cross-link cellulose microfibrils by binding to their surface via hydrogen bonds.
- **Pectins**: Also a heterogeneous group of polysaccharides containing acidic sugars (e.g., galacturonic acid). Pectins form a hydrated gel-like filler in wall. The pectin network determines the porosity of the cell wall.
- **Lignin**: aromatic, phenolic macromolecules linked in a complex polymeric network; involved in cell wall reinforcement and thickening (secondary walls), especially of woody tissues (~25-33% of dry weight in wood).
- **Proteins**: **Structural proteins**: HRGP (hydroxyproline-rich glycoprotein), GRP (glycine-rich protein) and PRP (proline-rich protein); **Enzymes for wall assembly**: peroxidase (lignin), XET (xyloglucan endotransglucosylase); **Enzymes for cell expansion**: Expansins.
- **Lipids**: Cutin on epidermal surface; suberin of Casparian strip
Major cell wall components

Cellulose

Xyloglucan (hemicellulose)

Rhamnogalacturonan II (pectin)

Lignin
The plant cell wall is a heterogeneous structure. Its composition and mechanics changes dynamically over the course of growth and development (not “dead” material!)
Cell wall synthesis

Building blocks delivered in secretory vesicles or synthesized at PM

These spatially separated activities need to be coordinated for proper cell wall assembly
Cell wall loosenining

Hemicellulose and pectin link cellulose microfibrils via non-covalent interactions → CW loosening is thought to break these linkages.

Cell wall enzymes are most active in acidic environment.

Cell wall enzymes induces cell wall extension.

Cell wall enzyme activity correlates to cell/tissue growth rate.
Plant Cell Mechanobiology
Plant cells are literally cemented together
Mechanical force (endogenous and exogenous) affect microtubule orientation and auxin distribution

Predicted (A) and observed reorientation of cortical microtubules is response to changing mechanical stress by cell ablation.

Microtubule and PIN1 (a key transporter of the plant hormone auxin, in red) orientations correlate to the direction of mechanical stress.
Compressive forces and lacerations affect microtubule orientation

Laceration (*) of leaf leads to microtubule re-orientation over time.

This response depends on the microtubule severing protein, katanin.

- What are the mechanisms that sense mechanical forces?
- How is this information transduced to alter microtubule organization?
- How does this affect cell growth?