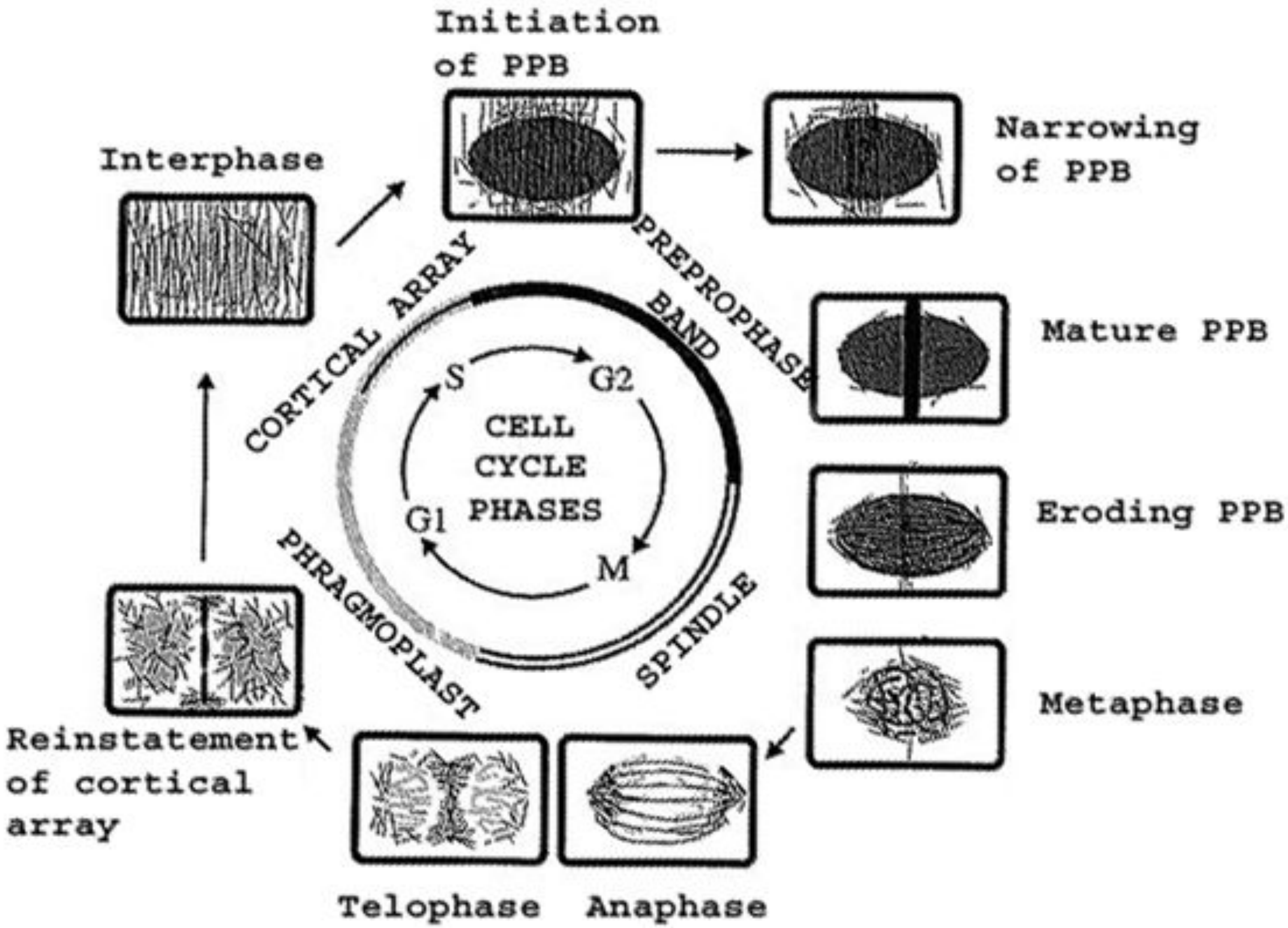
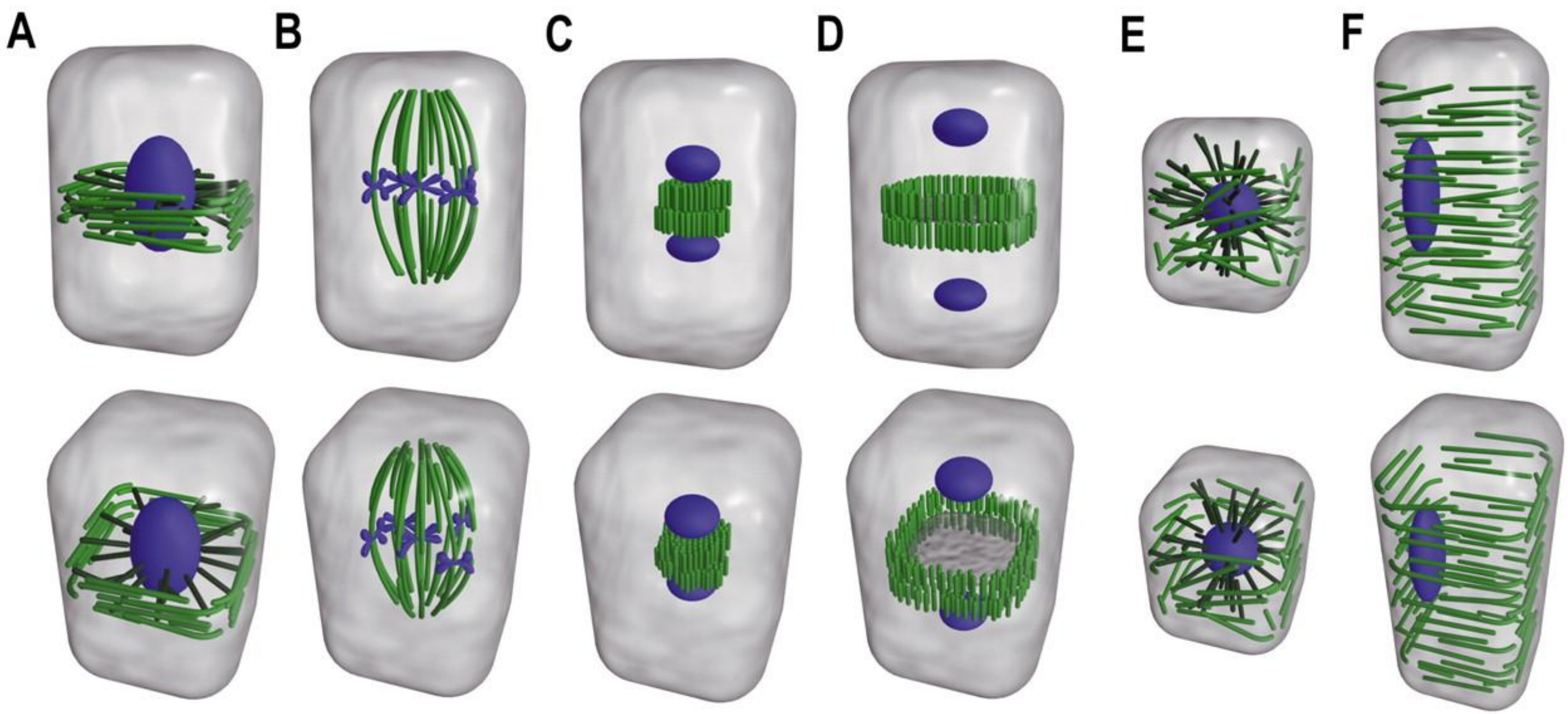
ЛЕКЦИЯ 1

СИСТЕМА МИКРОТРУБОЧЕК ВЫСШИХ РАСТЕНИЙ

СИСТЕМА МИКРОТРУБОЧЕК В КЛЕТОЧНОМ ЦИКЛЕ ВЕГЕТАТИВНЫХ КЛЕТОК РАСТЕНИЙ



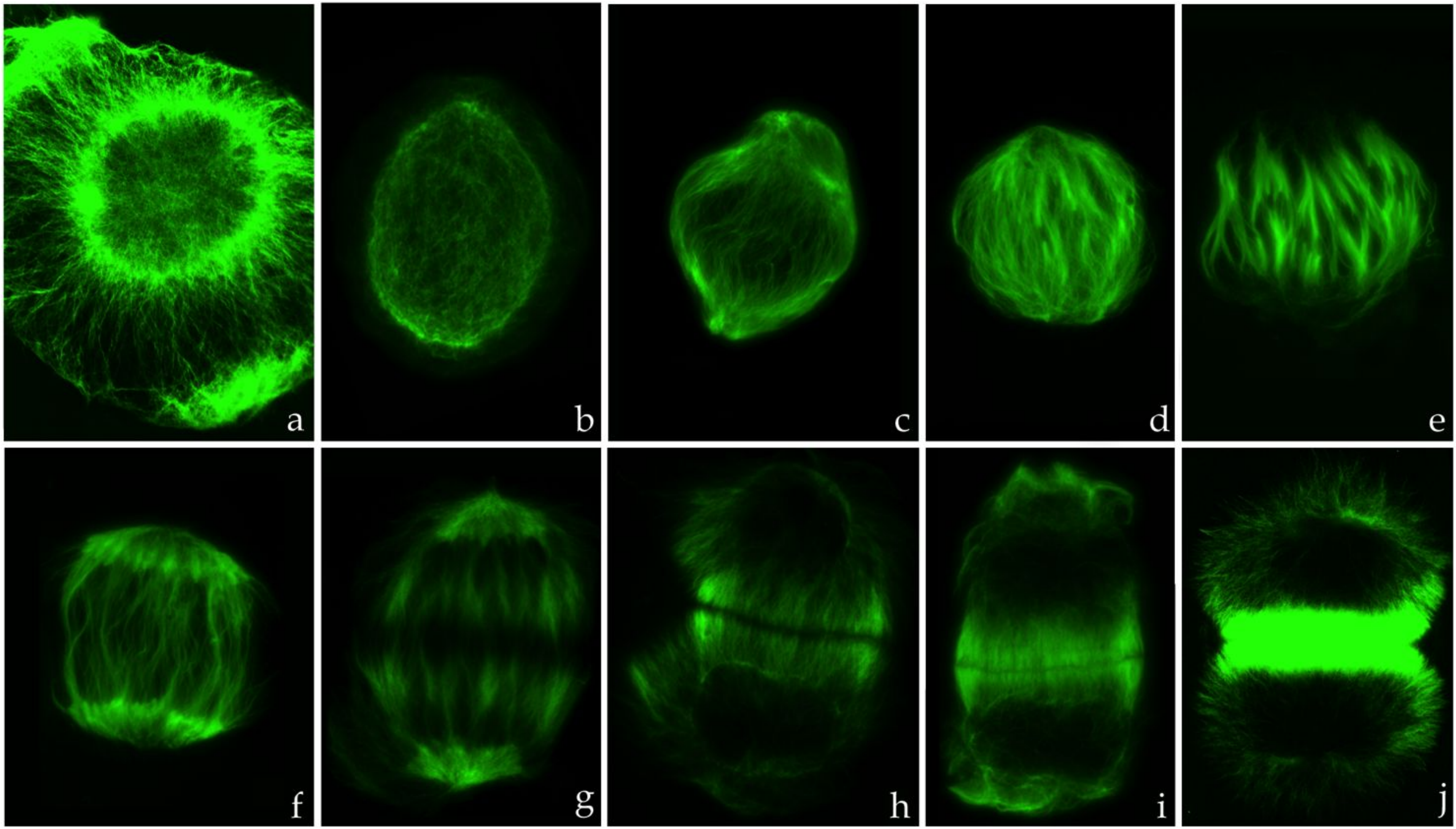
These schematic illustrations, rendered in 3D at two aspects, show microtubule arrays through the plant cell cycle.



Geoffrey O. Wasteneys J Cell Sci 2002;115:1345-1354

Journal of Cell Science
jcs.biologists.org

МИКРОТРУБОЧКИ В КЛЕТОЧНОМ ЦИКЛЕ



СИСТЕМЫ МИКРОТРУБОЧЕК В КЛЕТКАХ ВЫСШИХ РАСТЕНИЙ

ИНТЕРФАЗА

КОРТИКАЛЬНЫЕ ПУЧКИ

РАДИАЛЬНАЯ СИСТЕМА

G2 фаза

ПРЕПРОФАЗНОЕ КОЛЬЦО МИКРОТРУБОЧЕК

МИТОЗ

МИТОТИЧЕСКОЕ ВЕРЕТЕНО и ФРАГМОПЛАСТ

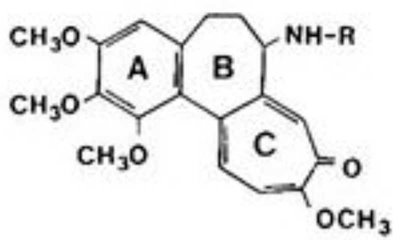
ИНГИБИТОРЫ ПОЛИМЕРИЗАЦИИ МИКРОТРУБОЧЕК (I)

ЖИВОТНЫЕ КЛЕТКИ РАСТИТЕЛЬНЫЕ КЛЕТКИ

РАСТИТЕЛЬНЫЕ ГЕРБИЦИДЫ
АЛКАЛОИДЫ 1) ДИНИТРОАНИЛИНОВЫЕ
КОЛХИЦИН (ОРИЗАЛИН,
ТРИФЛУРАЛИН)
ВИНБЛАСТИН 2)
ФОСФОРООРГАНИЧЕСКИЕ
ВИНКРИСТИН (АМИПРОФОСМЕТИЛ –
АРМ)
СИНТЕТИЧЕСКИЕ 3) ФЕНИЛКАРБАМАТЫ
(CIPC)
СОЕДИНЕНИЯ 4) БЕНЗАМИДЫ
(ПРОПИЗАМИД)

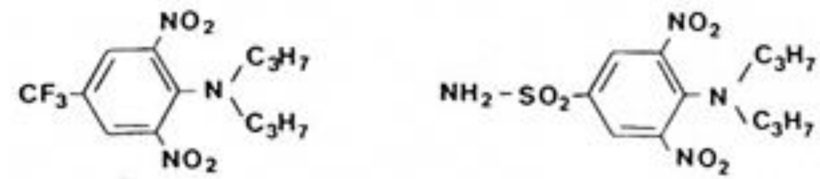
ИНГИБИТОРЫ ПОЛИМЕРИЗАЦИИ МИКРОТРУБОЧЕК (II)

ЖИВОТНЫЕ КЛЕТКИ

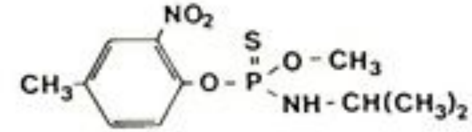


Chemical structure of colchicine and colcemid: R = $COCH_3$ for colchicine, R = CH_3 for colcemid.

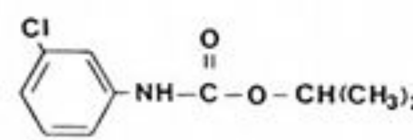
РАСТИТЕЛЬНЫЕ КЛЕТКИ



Chemical structures of trifluralin (left) and oryzalin (right).



Chemical structure of APM.



Chemical structure of CIPC.

TABLE 1 | List of MAPs described in plants.

MAP	Characterized in	References	Notes
MAP65			
MAP65-1	*Arabidopsis thaliana*	Jiang and Sonobe, 1993; Smertenko et al., 2004; Van Damme et al., 2004	
MAP65-2	*Arabidopsis thaliana*	Li et al., 2009	
MAP65-3/PLEIADE	*Arabidopsis thaliana*	Muller et al., 2004	
MAP65-4	*Arabidopsis thaliana*	Van Damme et al., 2004	
MAP65-5		Gaillard et al., 2008; Smertenko et al., 2008	
MAP65-6		Mao et al., 2005	
MAP65-7		Theologis et al., 2000	Found *in silico* in *Arabidopsis*
MAP65-8	*Arabidopsis thaliana*	Smertenko et al., 2008	Does not associate with MT
MAP65-9	*Arabidopsis thaliana*	Smertenko et al., 2008	Pollen, does not associate with MT
OTHER PROTEINS			
TANGLED 1	*Zea mays*	Smith et al., 2001	
p60 katanin subunit (AtKSS, AtKN1)	*Arabidopsis thaliana*	Burk et al., 2001	
p80 katanin subunit	*Arabidopsis thaliana*	Bouquin et al., 2003	
RUNKEL (RUK)	*Arabidopsis thaliana*	Krupnova et al., 2009	
Spc98p	*Arabidopsis thaliana*	Erhardt et al., 2002	
BPP1	*Arabidopsis thaliana*	Hamada et al., 2013	
NEDD1	*Arabidopsis thaliana*	Zeng et al., 2009	Acts as an anchoring factor of γ-tubulin complex, decorates spindle MTs preferentially toward theirs minus ends
PLANT SPECIFIC MAPS			
MAP190	*Nicotiana tabacum* (BY-2)	Igarashi et al., 2000	
MAP70 -1	*Arabidopsis thaliana*	Korolev et al., 2005; Pesquet et al., 2010	
MAP70 -2	*Arabidopsis thaliana*	Korolev et al., 2005	
MAP70 -3	*Arabidopsis thaliana*	Korolev et al., 2005	
MAP70 -4	*Arabidopsis thaliana*	Korolev et al., 2005	

(Continued)

TABLE 1 | Continued

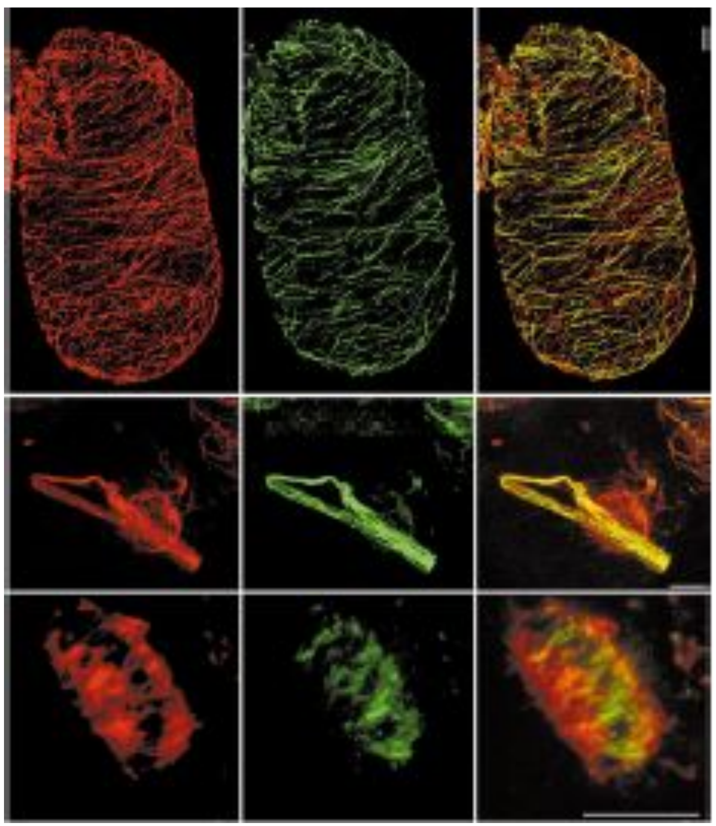
MAP	Characterized in	References	Notes
MAP70 -5	*Arabidopsis thaliana*	Korolev et al., 2005, 2007	
SPR1	*Arabidopsis thaliana*	Nakajima et al., 2004; Sedbrook, 2004	
SPR2	*Arabidopsis thaliana*	Furutani et al., 2000	
SB401	*Solanum berthaultii*	Huang et al., 2007	
SBgLR	*Nicotiana tabacum*	Liu et al., 2013	Potato pollen-specific protein
Atg8	*Arabidopsis thaliana*	Ketelaar et al., 2004	Homolog of autophagy protein
AtMPB2C	*Arabidopsis thaliana*	Ruggenthaler et al., 2009	Homolog of MPB2C, involved in the alignment of cortical MT
MDP40	*Arabidopsis thaliana*	Wang et al., 2012	Regulator of hypocotyl cell elongation
WVD/WDL family	*Arabidopsis thaliana*	Perrin et al., 2007	
AIR9	*Arabidopsis thaliana*	Buschmann et al., 2006	

TABLE 2 | List of multifunctional MAPs described in plants.

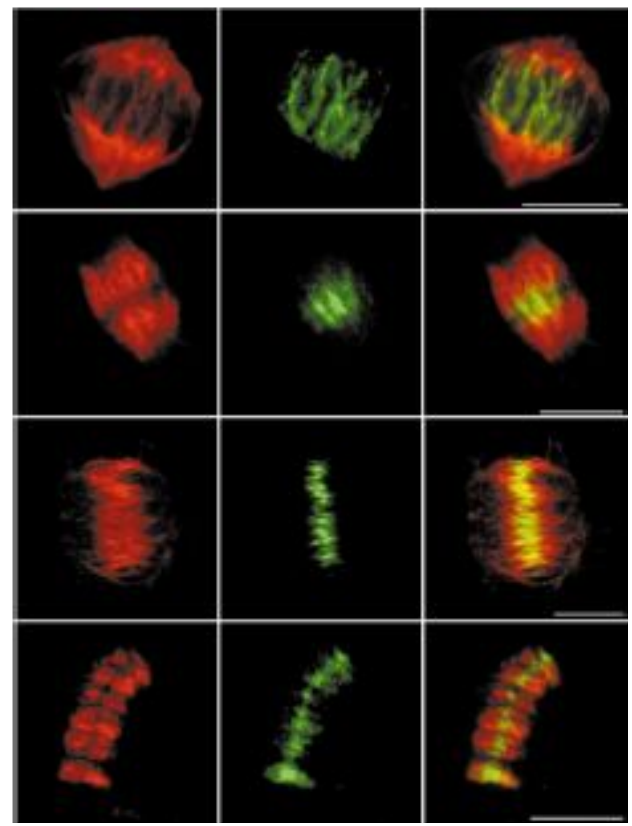
MAP	Characterized in	References	Notes
ENZYMES OR CHAPERONS			
GAPDH	Mammalian cells	Sirover, 1999; Tisdale et al., 2009	
Glycolytic enzymes: lactate-dehydrogenase, pyruvate kinase, aldolase and during specific conditions also for glucose-6-phosphate isomerase and phosphoglycerate-kinase		Walsh et al., 1989	
Hsp70	*Arabidopsis thaliana*	Ho et al., 2009	Also involved in signaling
Hsp90		Koyasu et al., 1986; Sanchez et al., 1988; Williams and Nelsen, 1997; Freudenreich and Nick, 1998; Petrasek et al., 1998; Pratt et al., 1999; Lange et al., 2000; de Carcer et al., 2001; Harrell et al., 2002; Wegele et al., 2004; Glover, 2005; Basto et al., 2007; Weis et al., 2010; Krtkova et al., 2012	Also involved in signaling
Plant chaperone CCT	*Nicotiana tabacum*	Nick et al., 2000	
EF1α	*Daucus carota*	Durso and Cyr, 1994	
EF-2	*Arabidopsis thaliana*, suspension cells	Chuong et al., 2004	
PLDδ	*Nicotiana tabacum*	Gardiner et al., 2001	Also involved in signaling
THO2	*Nicotiana tabacum*	Hamada et al., 2009	Putative RNA-processing THO2 relative protein
PROTEINS INTERACTING WITH OTHER CELL STRUCTURES			
Actin Binding Proteins			
FH4	*Arabidopsis thaliana*	Deeks et al., 2010	Also involved in signaling
FH14	*Arabidopsis thaliana*	Li et al., 2010	aLso involved in signaling
FH1	*Arabidopsis thaliana*	Rosero et al., 2013	Also involved in signaling
ARPC2	*Nicotiana tabacum*	Havelková et al., 2015	
Proteins Involved in Signaling			
PCaP2 (MAP18)	*Arabidopsis thaliana*	Wang et al., 2007; Kato et al., 2010	
MDP25 (PCaP1)	*Arabidopsis thaliana*	Li et al., 2011	PCAP1, MT destabilizing protein
MIDD1	*Arabidopsis thaliana*	Oda et al., 2010	MT-end tracking protein

NTMAP65-1 DIFFERENTIALLY DECORATES MICROTUBULE ARRAYS THROUGHOUT THE CELL CYCLE OF BY-2 TOBACCO CELLS (SMERTENKO ET AL., 2000)

tubulin NtMAP65-1 merge

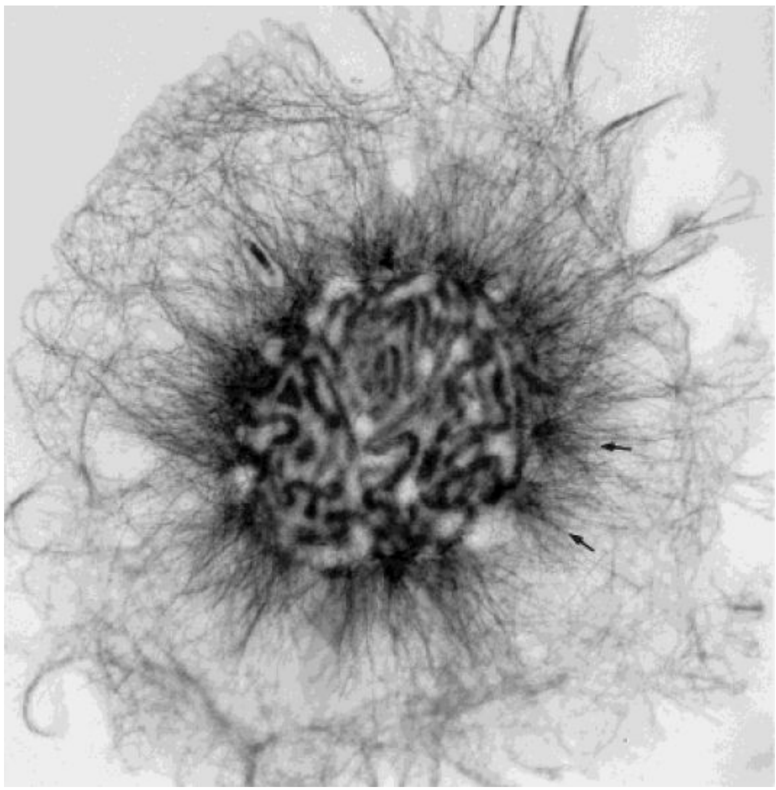


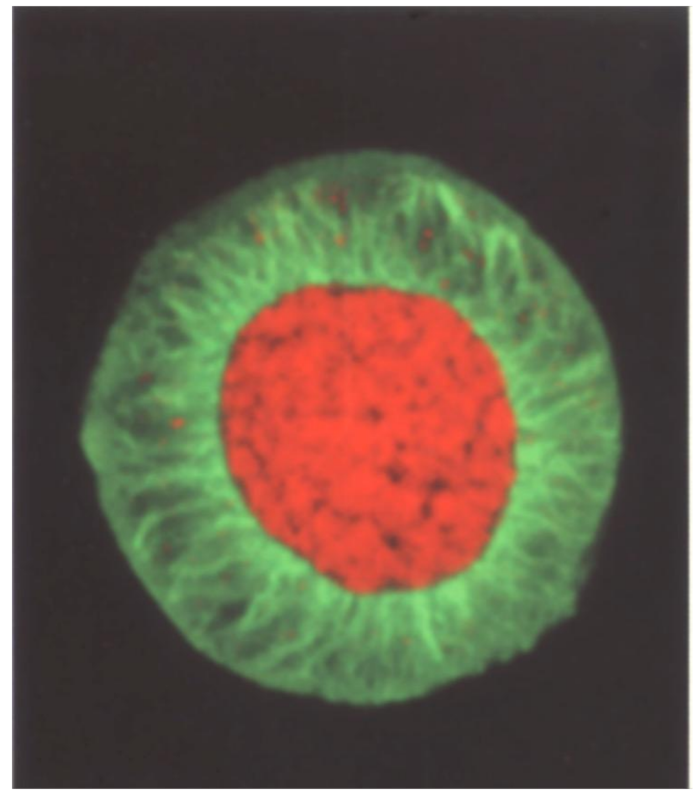
tubulin NtMAP65-1 merge



МИКРОТРУБОЧКИ ИНТЕРФАЗНЫХ КЛЕТОК

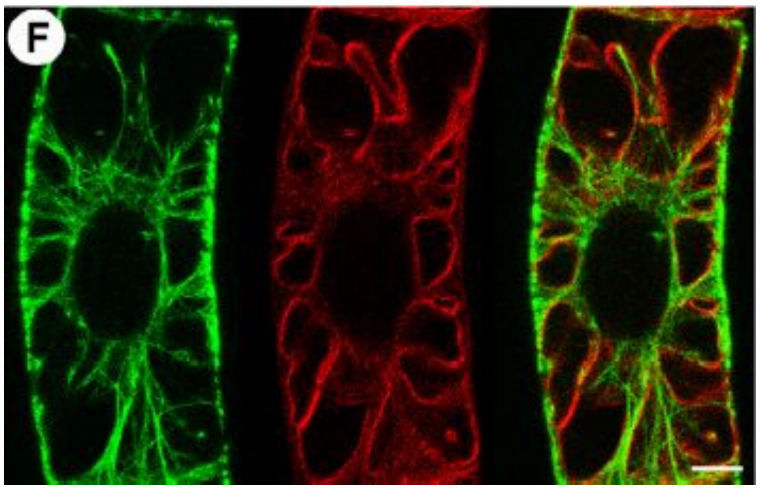
РАДИАЛЬНАЯ СИСТЕМА МИКРОТРУБОЧЕК В ИЗОЛИРОВАННЫХ КЛЕТКАХ ЭНДОСПЕРМА SCADOXUS И МИКРОСПОРОЦИТАХ ОРХИДНЫХ





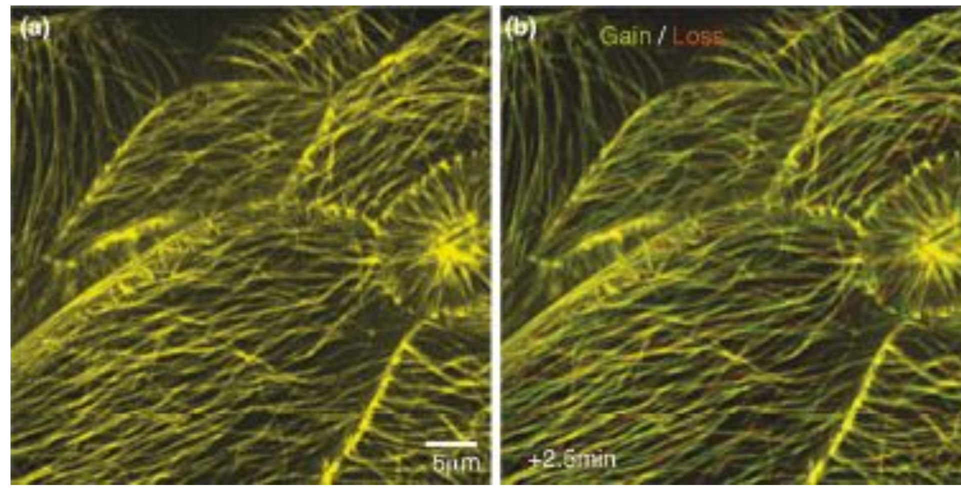
МИКРОТРУБОЧКИ НА СТАДИИ ИНТЕРФАЗЫ

РАДИАЛЬНАЯ СИСТЕМА в вакуолизированных



Микротрубочки в клетках культуры табака BY-2 выявляются с помощью GFP-MAP4 и вакуолярная система – с помощью FM4-64

КОРТИКАЛЬНЫЕ ПУЧКИ в клетках гипокотиля

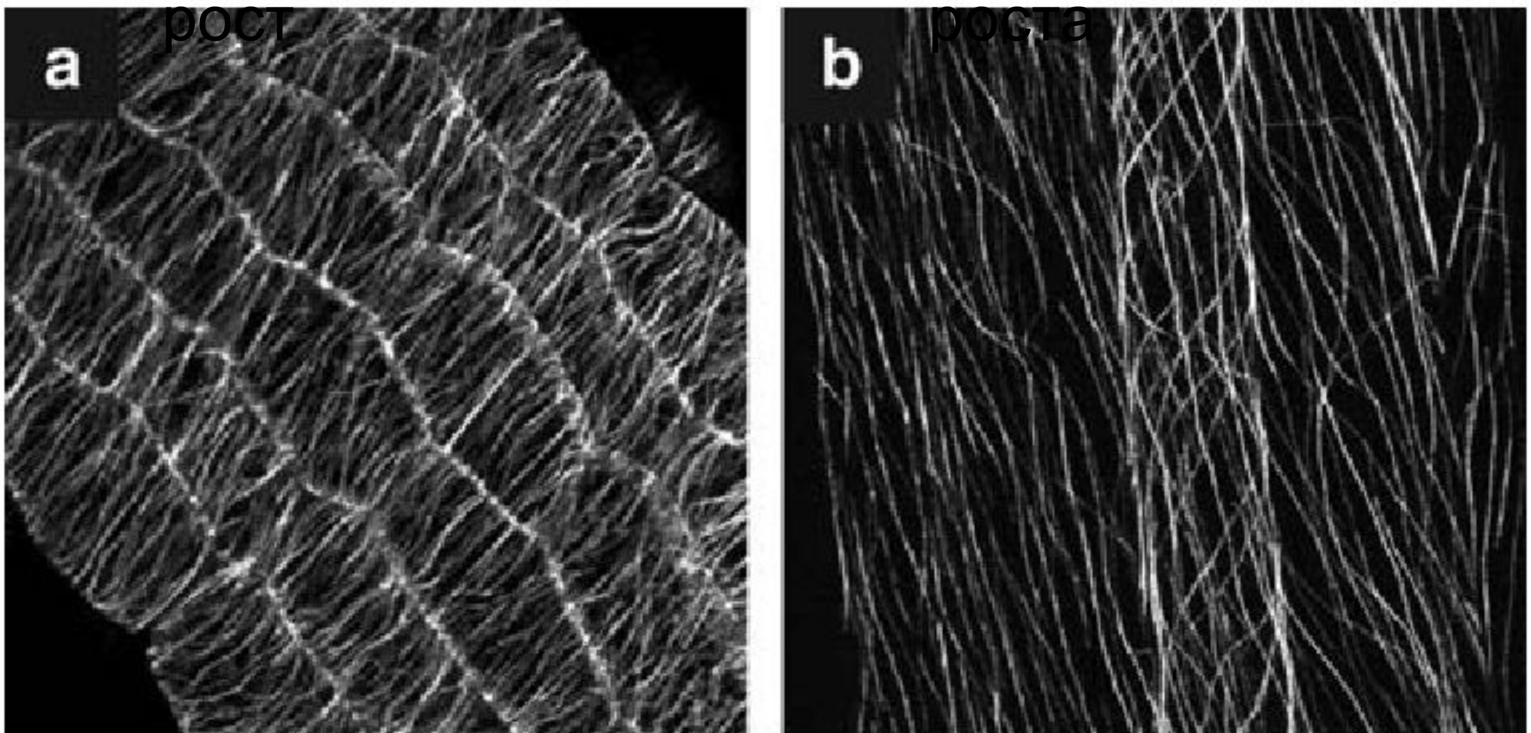


Проростки Arabidopsis (клетки эпидермиса листа экспрессирующие меченый тубулин).

КОРТИКАЛЬНЫЕ ПУЧКИ МИКРОТРУБОЧЕК В КЛЕТКАХ ЭПИДЕРМИСА *ARABIDOPSIS THALIANA*

Активный рост

Остановка роста

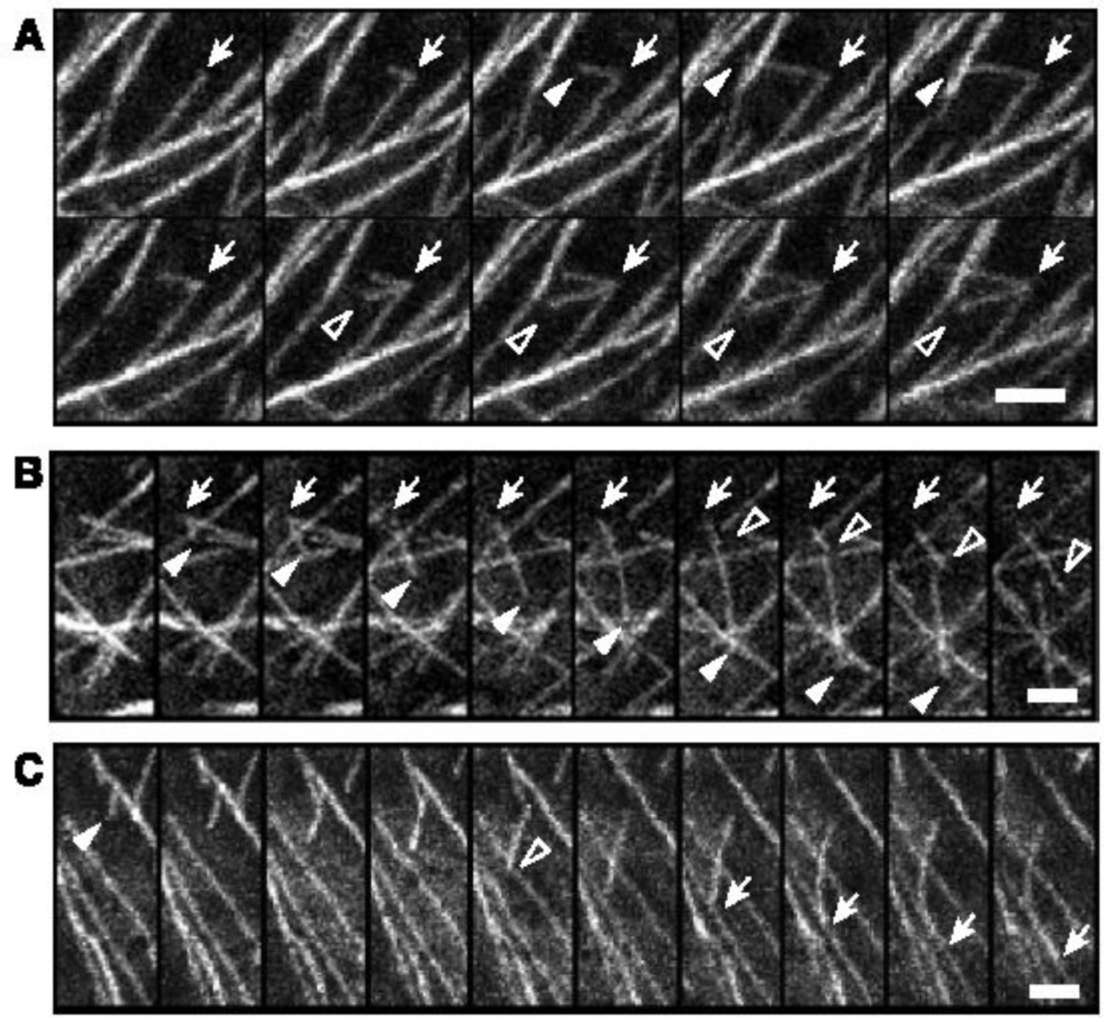


КОРТИКАЛЬНЫЕ МИКРОТРУБОЧКИ В КЛЕТКАХ РАЗНЫХ ОРГАНОВ РАСТЕНИЙ (from Fishel and Dixit, 2013)

Figure 1. Examples of CMT array patterns in an Arabidopsis seedling. At the zone of rapid cell elongation, near the apex of the hypocotyl, CMT arrays in epidermal cells show net transverse orientation (top left). As the cells stop elongating and mature, towards the base of the hypocotyl, CMT arrays in epidermal cells show net longitudinal orientation (bottom left). In cotyledons and leaves, CMT arrays show a complex, net-like pattern in pavement cells and a radial pattern in guard cells (right).

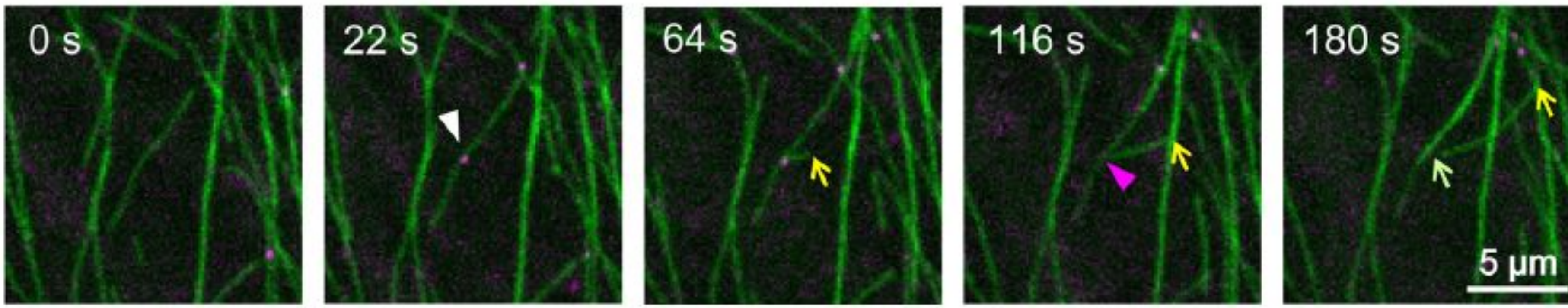
SUSTAINED MICROTUBULE TREADMILLING IN *ARABIDOPSIS* CORTICAL ARRAY (Shaw et al., 2003)

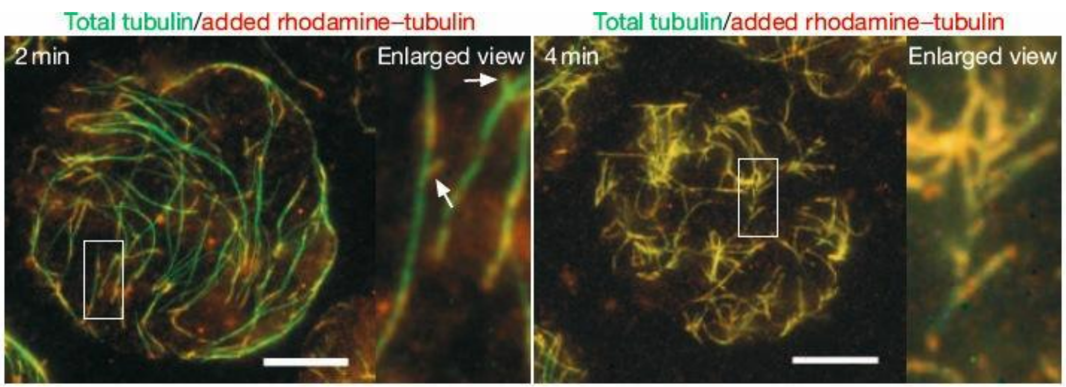
(**A)** Time series (left to right) of two new microtubules (solid and open arrowheads) polymerizing from a site at the cell cortex (arrow) and diverging from this origin at different angles.
(**B)** A newly polymerized microtubule (solid arrowhead) detaching from a cortical site of origin (arrow). After detachment, a second microtubule (open arrowhead) is initiated at the same location.
(**C)** Motile microtubule (solid arrowhead) crossing one microtubule (open arrowhead) before encountering a second polymer and bundling (arrows).

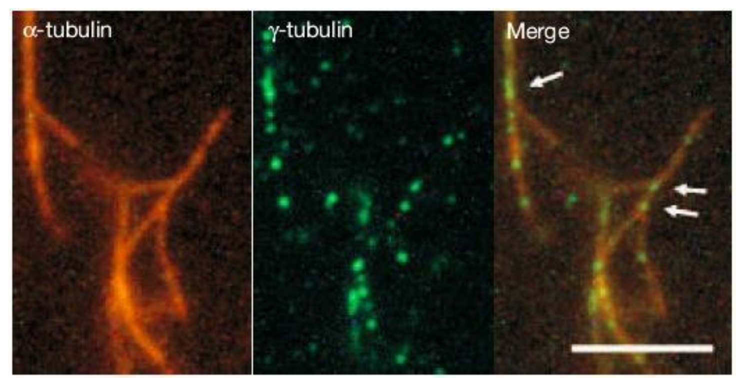


MICROTUBULE-DEPENDENT MICROTUBULE NUCLEATION BASED ON RECRUITMENT OF γ–TUBULIN IN HIGHER PLANTS (Murata et al., 2005)

Инициация новых микротрубочек в кортексе



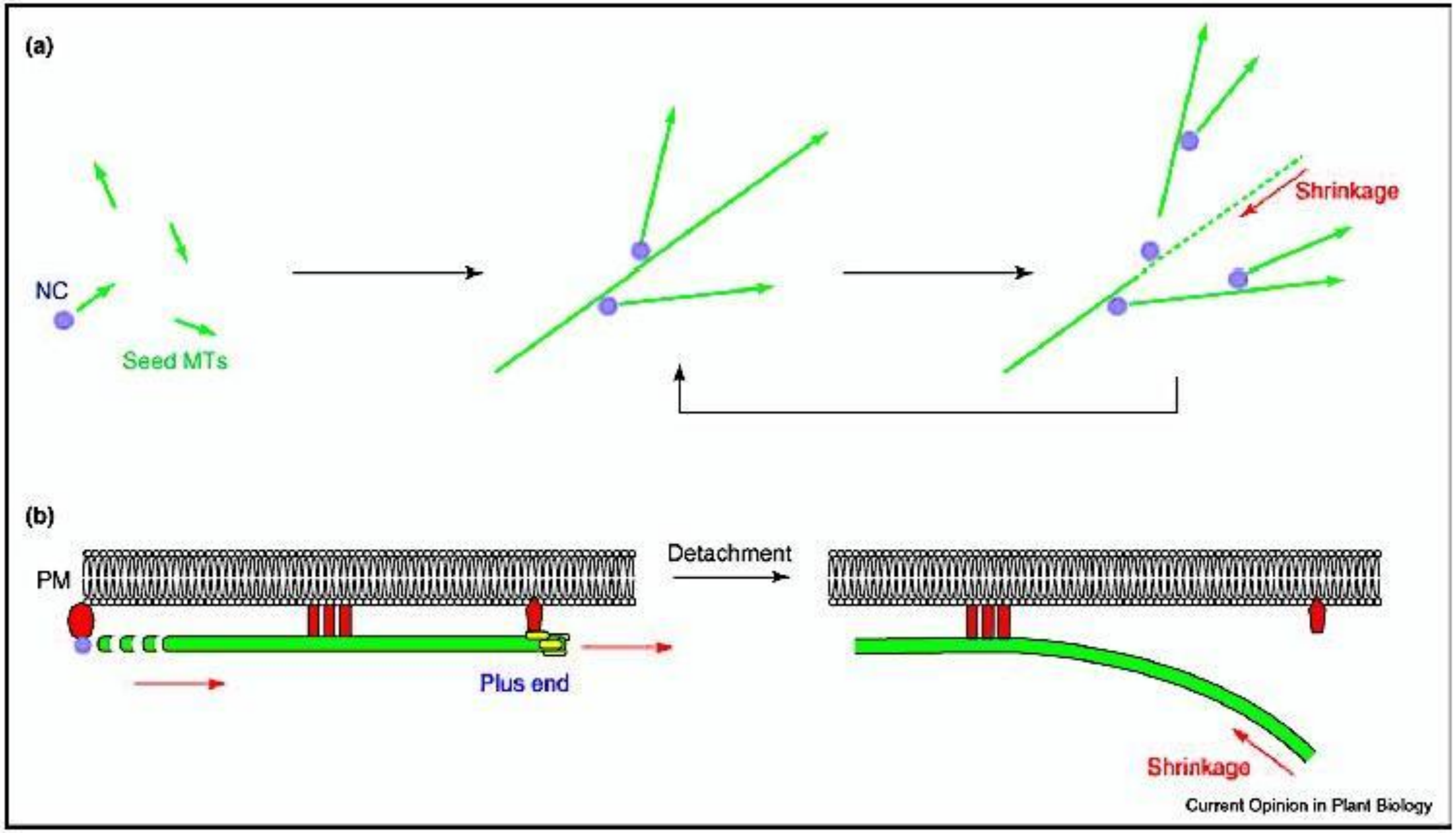




Сборка микротрубочек *in vitro*

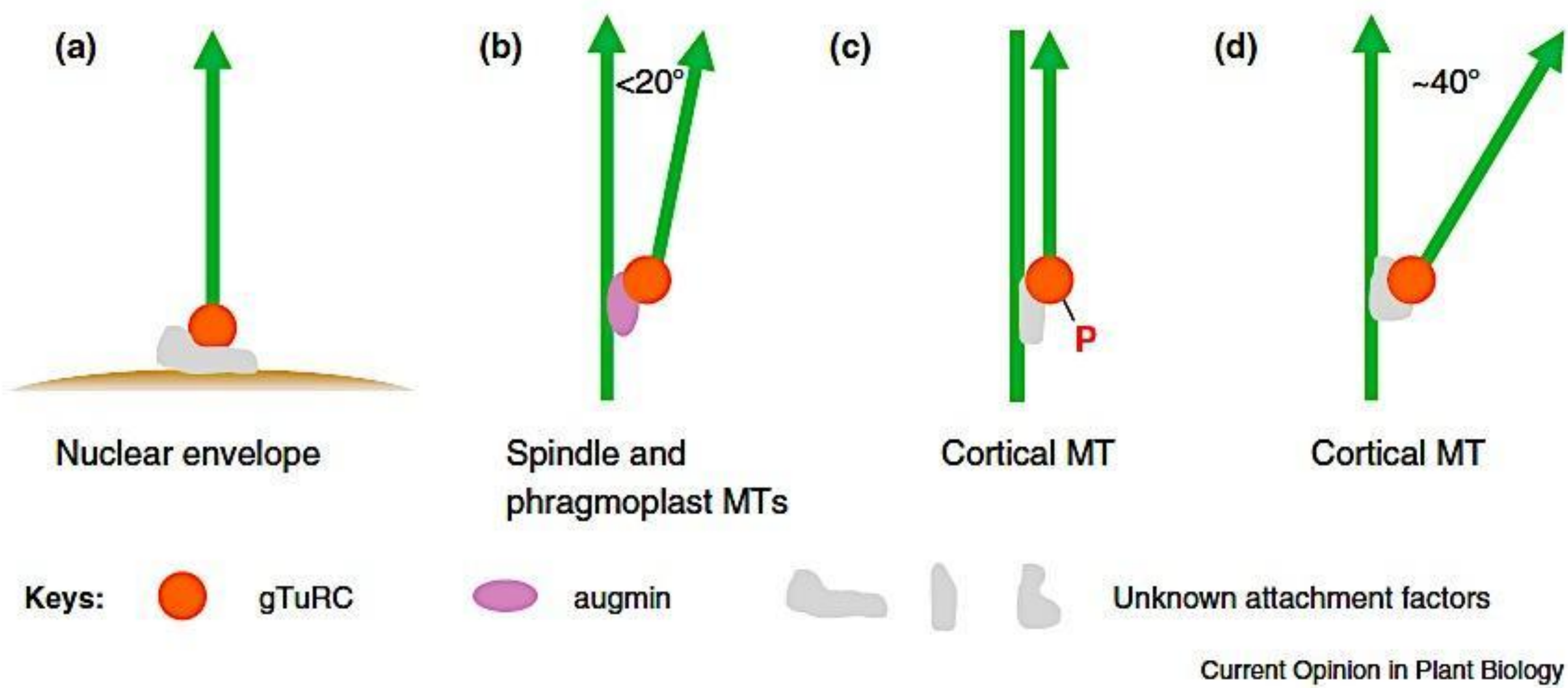
Микротрубочки в клеточных экстрактах

МОДЕЛЬ НУКЛЕАЦИИ МИКРОТРУБОЧЕК В КОРТЕКСЕ

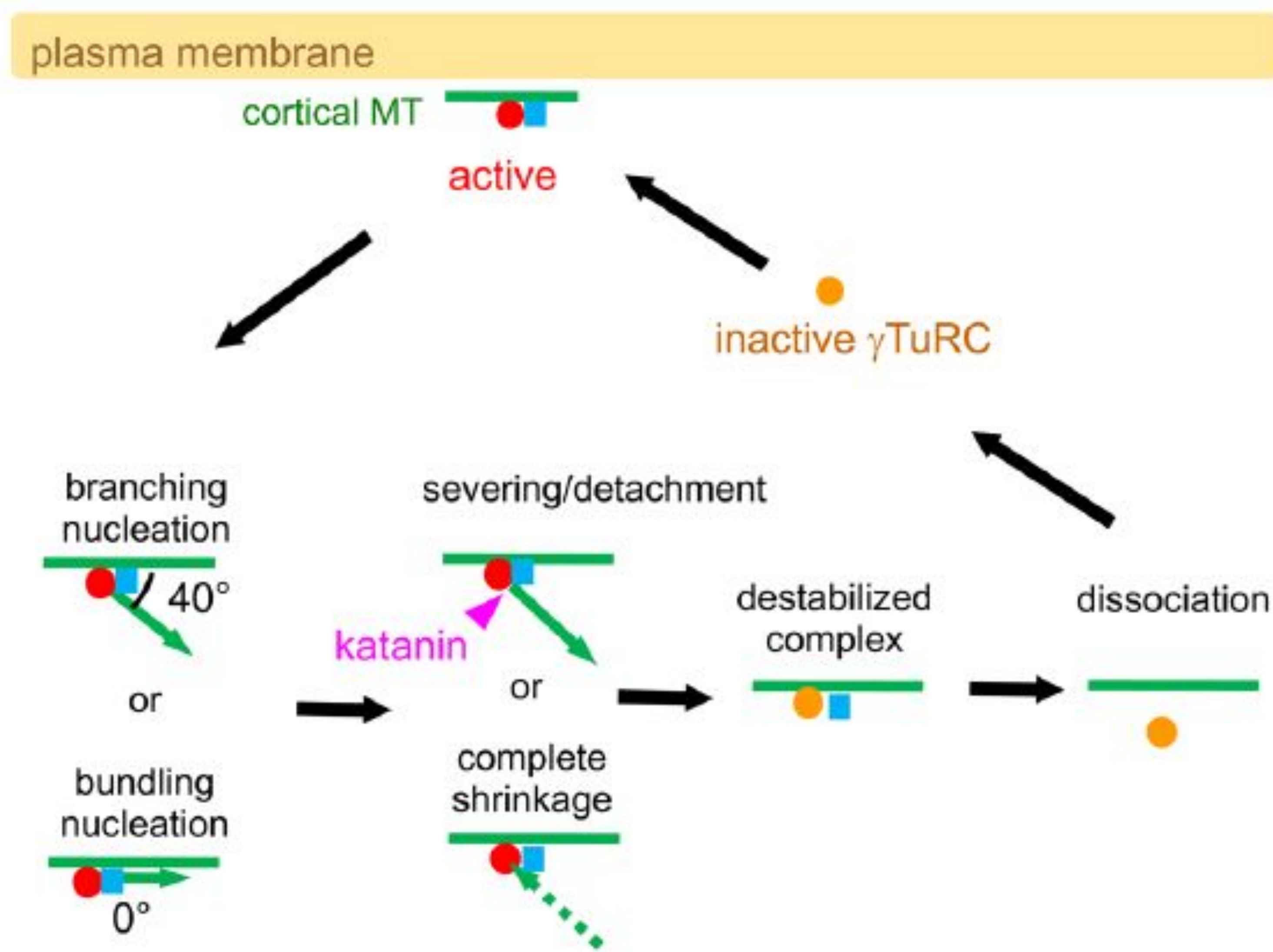


Interphase MTs are nucleated at and anchored to the cell cortex. **(a)** A small number of seed MTs are thought to appear at the cortex of early interphase cells, although it is not clear whether they are nucleated *de novo* at the cortex or transported from the cytoplasm by endoplasmic MTs. New cortical MTs form on the pre-existing MTs as branches with a defined angle. Nascent MTs detach from the nucleation sites and migrate to the cortex. The presumed nucleation complex (NC) appears to remain at the original cortical site after depolymerization of its resident MT, and is functional for some time. The arrowheads indicate the direction of the MT plus ends. **(b)** After the minus end detaches from the cortical nucleation site, a MT associates with the inner surface of the plasma membrane (PM), possibly at the length of the MT wall or at the growing plus end, by way of putative MT–membrane linker proteins (red). Accidental loss of the cortical contact, possibly at the plus end, might dissociate a plus-end region of the MT into the cytoplasm, resulting in rapid shrinkage or re-association with the cortex.

ВОЗМОЖНЫЕ МЕХАНИЗМЫ НУКЛЕАЦИИ МИКРОТРУБОЧЕК С ПОМОЩЬЮ γTURC В КЛЕТКАХ РАСТЕНИЙ (HASHIMOTO, 2013)



МОДЕЛЬ АКТИВАЦИИ НУКЛЕИРУЮЩИХ КОМПЛЕКСОВ В КОРТЕКСЕ РАСТИТЕЛЬНЫХ КЛЕТОК



ПОСЛЕДСТВИЯ РАЗНЫХ ВАРИАНТОВ ВЗАИМОДЕЙСТВИЯ СВОБОДНЫХ МИКРОТРУБОЧЕК В КОРТИКАЛЬНОЙ ЦИТОПЛАЗМЕ (HASHIMOTO, 2016)

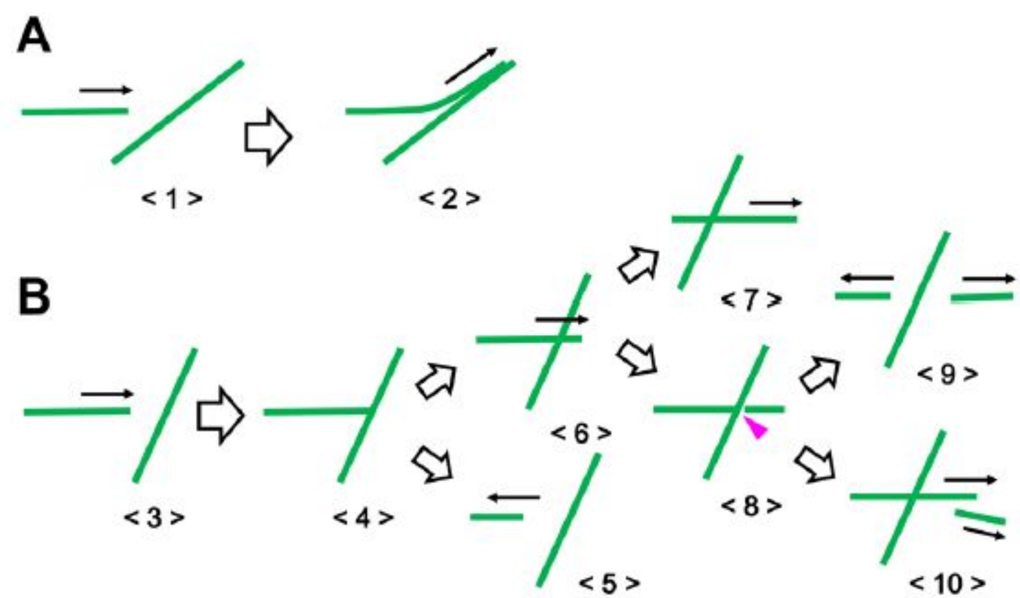
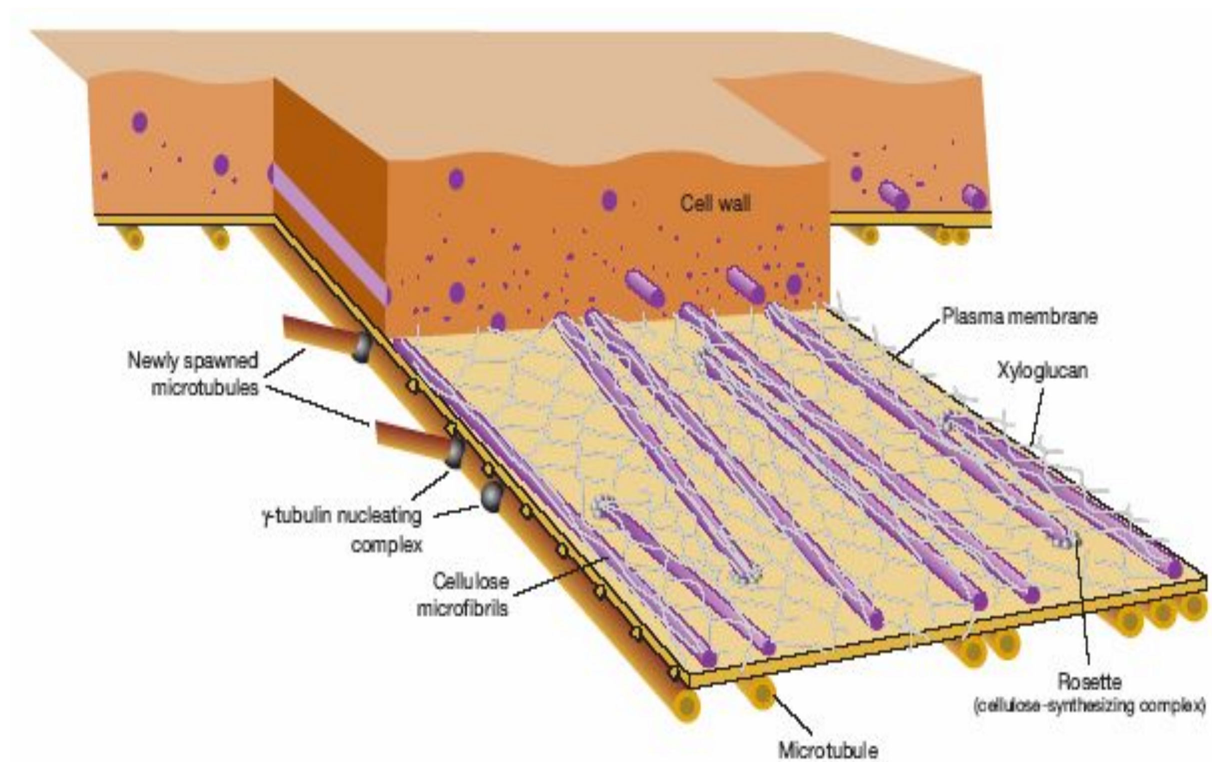


Figure 7. Schematic representation of MT-MT interactions and their outcomes.

(A) A growing plus end (arrow) approaches another MT that lies ahead of it at a relatively shallow angle **<1>**, and the end of the colliding MT changes its trajectory to align with the impeding MT, and forms a bundle **<2>**. **(B)** When a growing plus end (arrow) approaches another MT at a wide angle **<3>** and the two MTs meet **<4>**, the plus end of the colliding MT may start to depolymerize **<5>**. In other cases, the plus end crosses over the interacting MT lattice **<6>** and continues to grow **<7>**. The crossing MT may be severed at the junction point (magenta arrowhead) **<8>**. The exposed plus end of the rear MT frequently depolymerizes **<9>**, but sometimes starts to grow, generating two growing MT ends **<10>**.

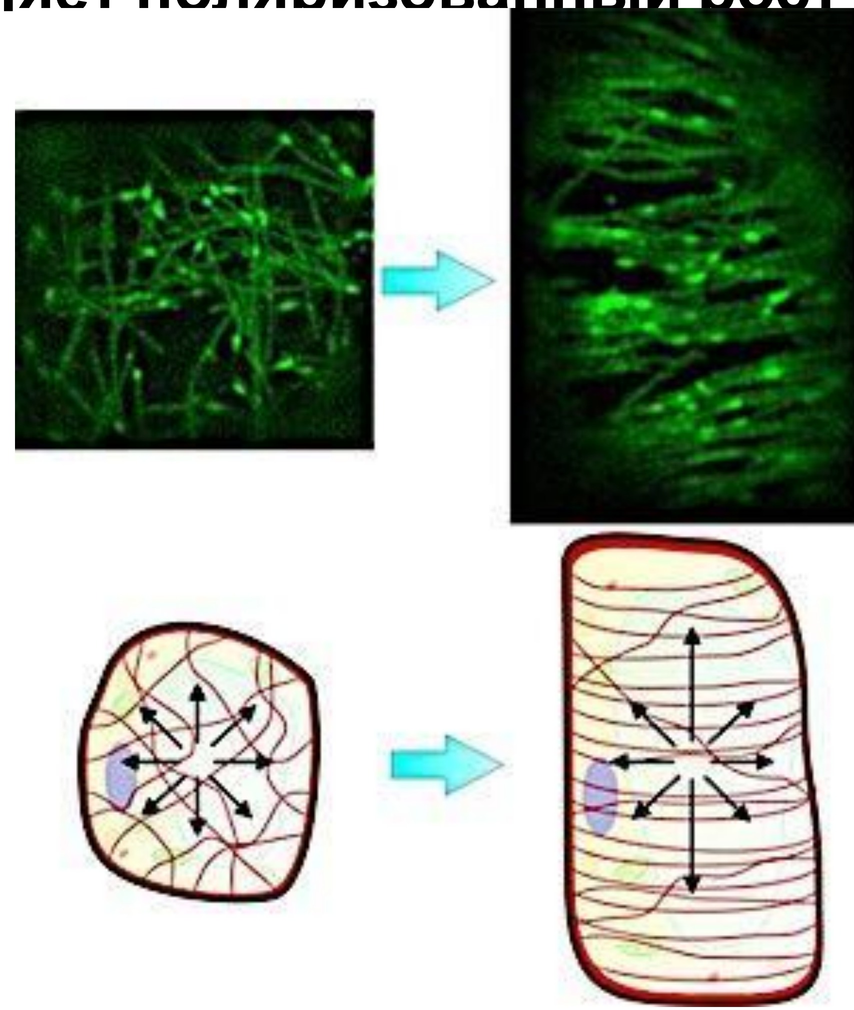
КОРТИКАЛЬНЫЕ МИКРОТРУБОЧКИ И ФОРМИРОВАНИЕ ЦЕЛЛЮЛОЗНОЙ КЛЕТОЧНОЙ СТЕНКИ

Ориентация кортикальных микротрубочек в растущих клетках

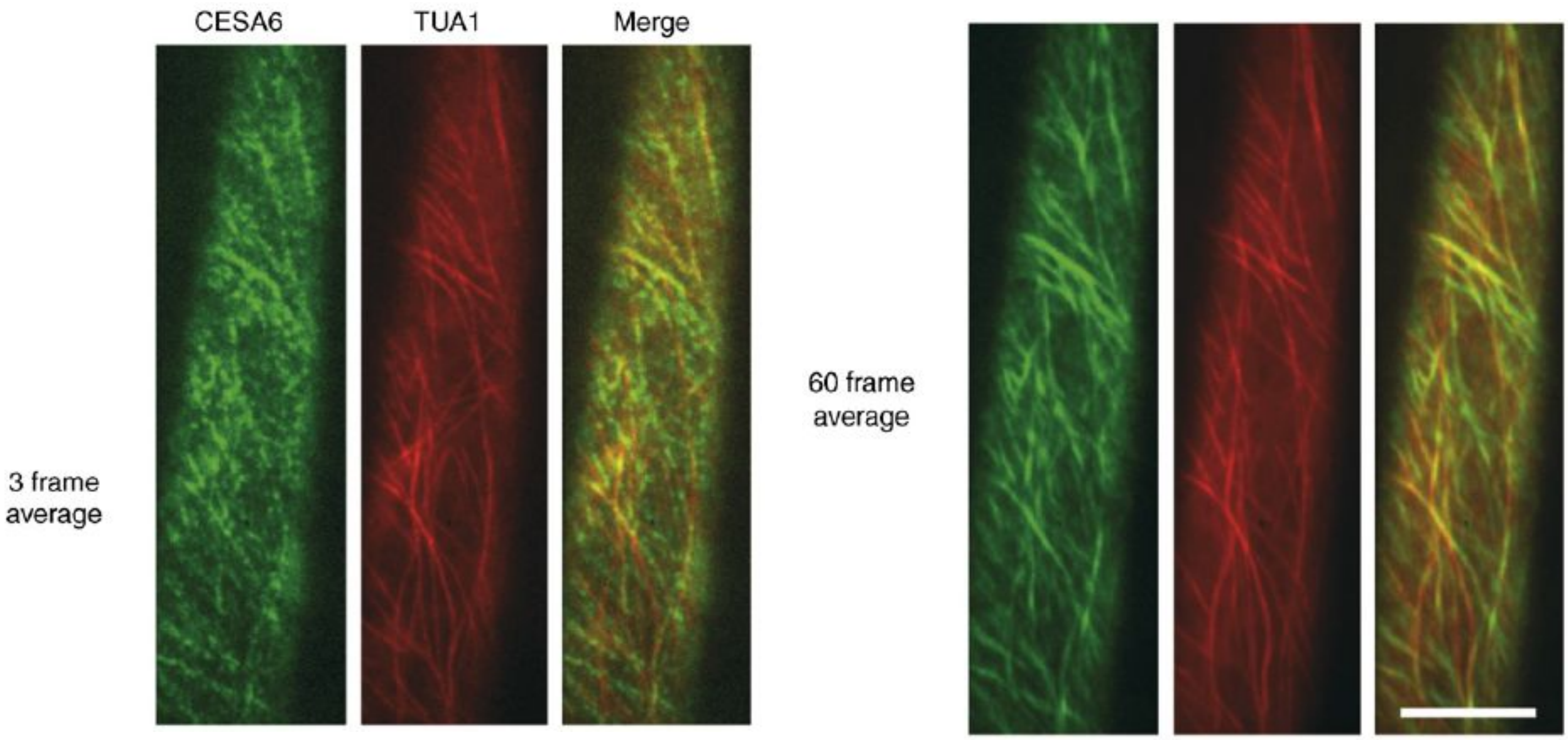


Кортикальные микротрубочки и микрофибриллы целлюлозы в клеточной стенке

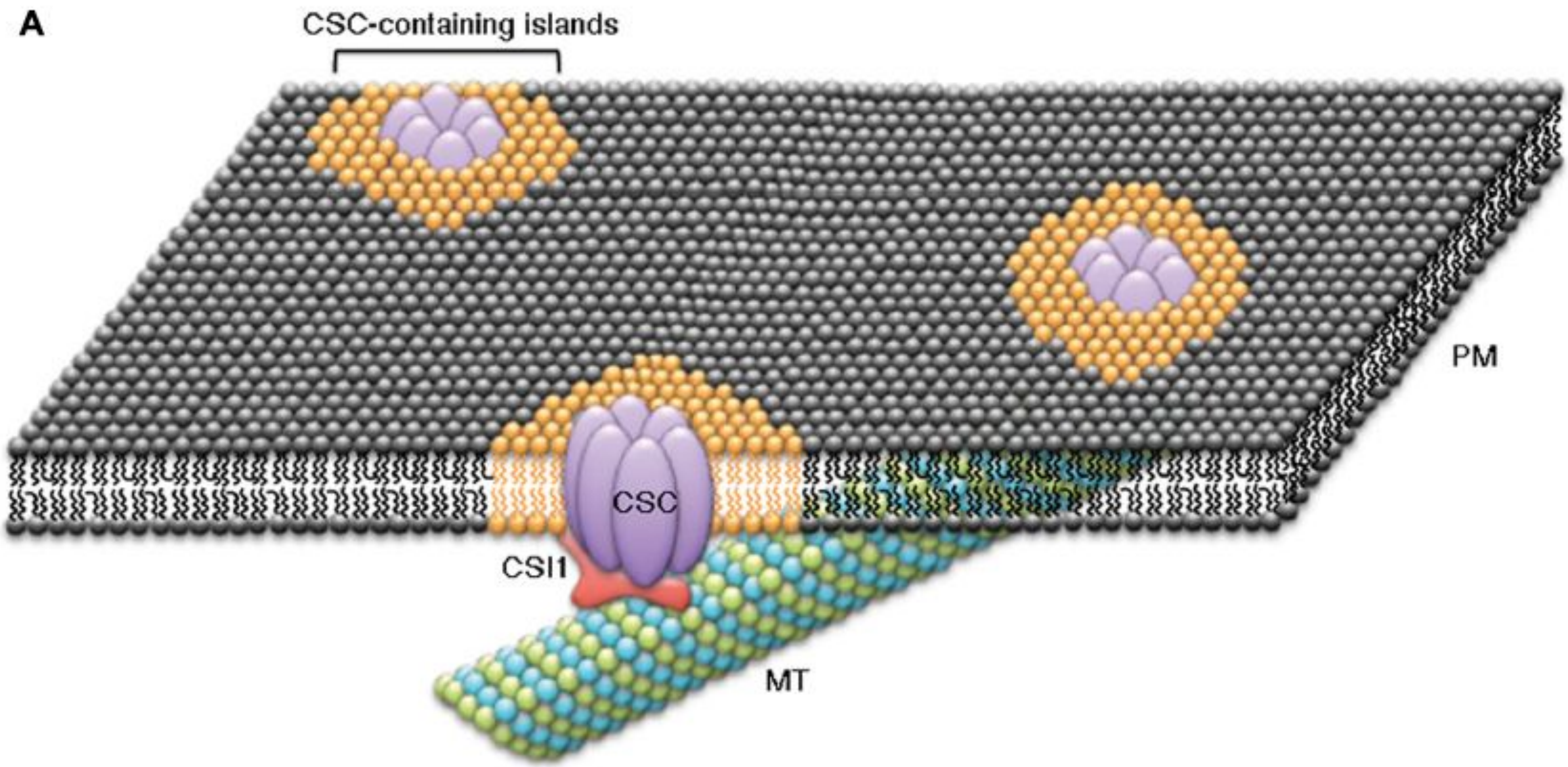
ОРГАНИЗАЦИЯ КОРТИКАЛЬНЫХ МИКРОТРУБОЧЕК (ЗЕЛЕНЫЕ) ОТРАЖАЕТ РАСПОЛОЖЕНИЕ МИКРОФИБРИЛЛ ЦЕЛЛЮЛОЗЫ (РОЗОВЫЕ). Переход от хаотической организации к упорядоченной направляет поляризованный рост клеток



THE FUNCTIONAL ASSOCIATION OF MICROTUBULES WITH THE CELLULOSE SYNTHETASE COMPLEX (Paredez et al., 2006)



Schematic representation of the cellulose biosynthesis machinery displays a continuum between cellulose synthase complexes (CSCs), CSC-associated proteins (e.g., CSI1), cortical microtubules (MT), and the plasma membrane (Lei et al., 2014)



An overview of the localization, trafficking pathways and proposed trafficking mechanisms of CSCs (from Bashline et al., 2014)