

Microtubules in Cilia and Flagella and the Burj Khalifa: Balancing tension and compression

Living Architecture Research Project Report

Bio219: Cell Biology

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Rule To Build By: The second rule of the Rules to Build By that in order to construct self-supporting structures, you must balance forces of tension and compression.

What: Both the microtubules of cilia and flagella and the Burj Khalifa demonstrate this rule.

How: The main structure of cilia and flagella are composed of microtubules and cross-linking proteins. Microtubules are a long, stiff, hollow tubes of protein built by small subunits known as tubulin. In most microtubules, these tubulin molecules are highly unstable, causing microtubules to polymerize and depolymerize due to dynamic instability. These sorts of microtubules are effective in cellular transport. However, in microtubules, these tubulin molecules are far more stable due to their association with other proteins that cause cross-linkage within a system of microtubules (Alberts et al. 2010). Microtubules grow by adding more tubulin molecules to the apical tip, in essence, building up (Lodish et al. 2000)

Microtubules are organized in an interesting array to maintain their structural integrity. They are arranged in a structure called an axoneme, where nine microtubule doublets surround a central two microtubules. The total structure is referred to as a “9 + 2 arrangement”. The doublets are composed of an A tubule and a B tubule. The outer ring of microtubule doublets are held together by a protein called dynein, which are attached to the inner and outer sides of the A tubule. The outer dynein reaches out towards the B tubule of the adjacent microtubule while the inner dynein reaches towards the inner microtubules. The inner microtubules are surrounded by a structure known as the inner sheath. The outer doublets are permanently linked by a protein called nexin. Radial spokes also constitute another cross linking system, that increases tensile strength (Lodish et al. 2000).

In order to maintain it's upright posture, it obviously must be attached to a larger object (in this case, the cell). The axoneme connects to a cylindrical structure known as a basal body, which is composed of nine triplet microtubules (Lodish et al. 2000). The structure of this basal body is identical to that of the centrioles (Anonymous 2012).

Cilia and flagella are cellular bodies that are distinguished by their ability to move. They move by bending their core and allowing the microtubules to slide past each other. Dynein is especially concerned in this bending process. The outer head of dynein interacts with other microtubules, creating the sliding motion that occurs during a bend. The cross links allow the entire body of microtubules to bend instead of just sliding one microtubule past the others. (Alberts et al. 2010)

Within these structures, the ability to balance tension and compression are clearly exhibited. Microtubules are known for their ability to maintain the structure of the object they are supporting. Microtubules are especially effective in guarding against compressive forces, allowing the structures they reinforce to remain erect, like cilia and flagella. Having the ability to move without disassembling also denotes the ability to resist tension. Cross-linking proteins are especially responsible for this. By maintaining links between the microtubules, dynein and nexin allow the flagella or cilia to bend and then revert back to their original shape. These cross-linking proteins allow for the resistance of internal and external tensions (Alberts et al. 2010).

The structure of the Burj Khalifa is very important to maintaining it's astounding height of 828 meters. The foundation of the Burj Khalifa is made with a reinforced concrete mat that is supported by reinforced concrete piles. This base is made in a “Y” shape to ensure great wind resistance of the entire building (Anonymous 2009).

The upper structure is composed of a buttressed core in which six high performance concrete walls buttress each other in order to protect against twisting forces. Corridors also connect the perimeter columns to the interior columns, allowing for all of the structures, inside and out, to aid in the load of compressive forces such as gravity (Anonymous

2009).

Why: The microtubule skeleton upholds this principle because it is evolutionarily sound. These forms of permanent structures in biology must be able to resist multiple kinds of intercellular and intracellular forces. If a biological structure can do this, it is able to remain permanent like in the form of the microtubule skeleton of cilia or flagella. In other cases, microtubules are not as sturdy, and this fact is advantageous in those cases because cellular transport does not occur in only one part of the cell; microtubules need to be polymerized everywhere.

Cilia and flagella are both able to resist tension and compression because they use both forces to their advantage. Both structures use tension and compression in order to move themselves and perform their function of either moving the entire cell (in the case of a sperm cell) or moving other things along or passed the cell they are attached to (in the case of a cell in the lining of the gut). The sliding of microtubules in the act of bending causes tension on the structure as a whole. Therefore, cilia and flagella don't just survive under tension and pressure; they need these forces in order to carry out their basic functions and they have mechanisms that cause tension within themselves.

In short, microtubules don't just endure tension and compression; they thrive within those forces to meet their goals of movement. Without these forces and the capability to create these forces within a structure, the structure itself would not be as effective.

The Burj Khalifa must uphold these principles in order to stay erect. Compression in the form of gravity and tension in the form of wind resistance are the two main forces a building must contend with. By having a stable reinforced concrete base and highly buttressed floors to spread compression forces throughout the building, the building can contend with compression. By using the hexagonal core and a "Y" shaped structure, the building can resist wind and other forces that cause tension.

Figures

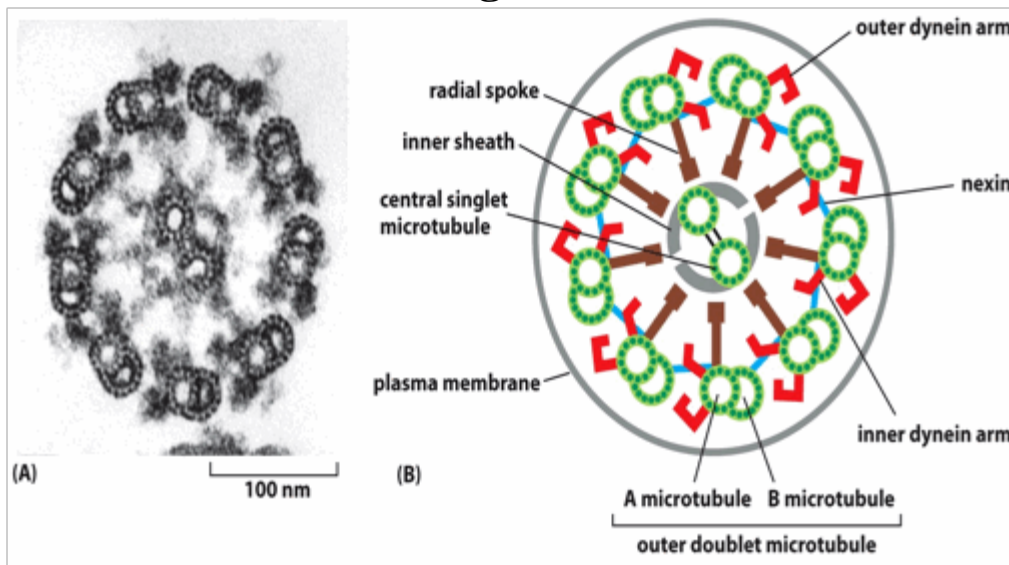


Figure 1A shows the “9+2” structure and the configuration of the different cross-linking proteins in an actual electron micrograph of a flagella. Figure 1B shows the same configuration, but in a diagram (Alberts et al. 2010).

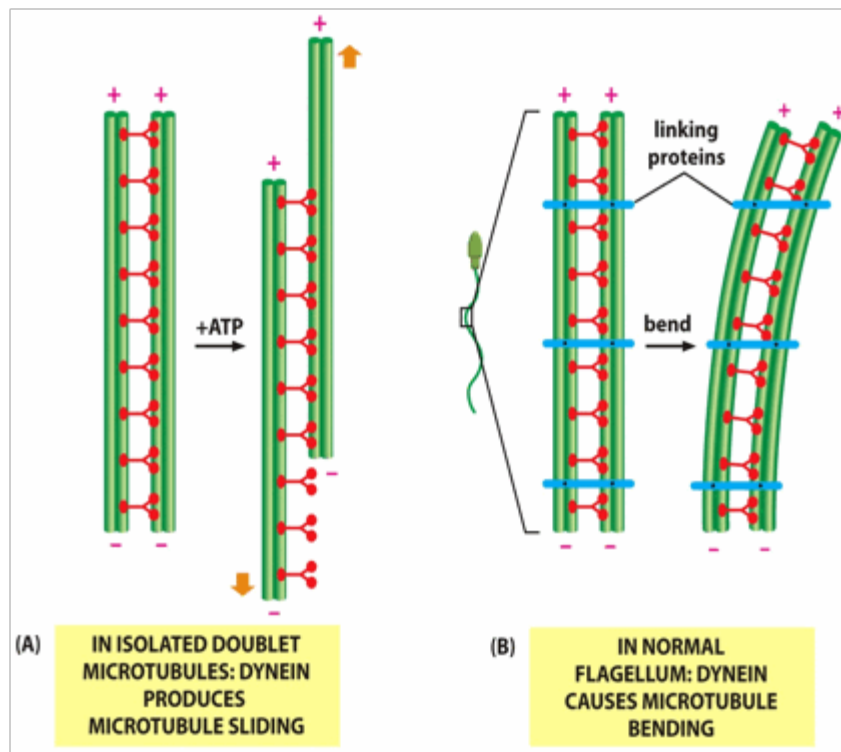


Figure 2A shows how dynein causes microtubule sliding in a regular microtubule doublet. Figure 2B shows how flagella bend instead of slide due to their linking proteins. (Alberts et al. 2010)



Figure 3 shows the Burj Khalifa and its scale to its surrounding area. The world's tallest free standing building must contend with gravity and a huge amount of wind resistance (Anonymous 2009).

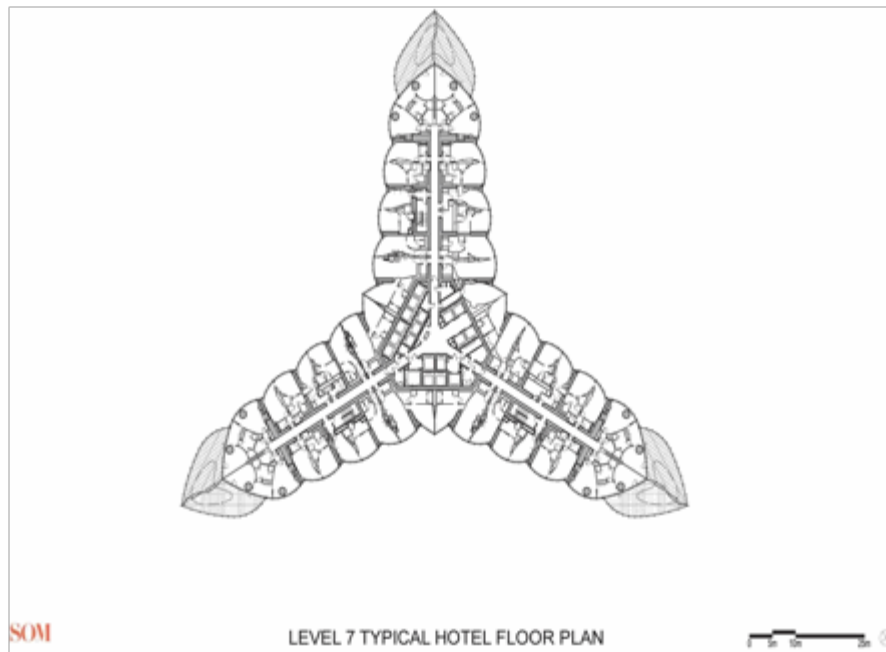


Figure 4 shows the “Y” shaped configuration of the building that aids in not only fighting the compression of gravity, but also is able to combat wind and still be standing (Buttressed Core 2012)

References

- Alberts, B., Bray, Dennis, B., Hopkin, K., Johnson, A., Lewis, J., Raff, M., Roberts, K., Walter, P. Essential Cell Biology. 3rd ed. New York, New York: Garland Science. 2010.
- [Anonymous] 2009. Burj Khalifa. Online. <http://www.burjkhalifa.ae/language/en-us/home.aspx> on 1 December 2012
- [Anonymous] 2012. Microtubules. Online. Available from <http://en.wikipedia.org/wiki/Microtubule> on 1 December 2012
- [Anonymous] 2012. Buttressed Core Structural System for Burj Khalifa. Online. Available from <http://openbuildings.com/buildings/buttressed-core-structural-system-for-burj-khalifa-profile-5429> on 1 December 2012
- Lodish H, Berk A, Zipursky SL, et al. Molecular Cell Biology. 4th edition. New York: W. H. Freeman; 2000. Available from: <http://www.ncbi.nlm.nih.gov/books/NBK21698/> on 1 December 2012