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Actin Bundling Proteins and Rebar Structuring

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Rule-to-Build-By:

“To construct self-supporting structures, balance forces of tension and compression”
(Morris & Staudinger 2016).

What:

Actin bundling proteins interact with actin to construct self-supporting structures that balance the forces of tension and compression and reinforcing steel (known as rebar), is placed within concrete during construction in order to balance the forces of tension and compression within a self-supporting, human-built structure.

How:

The cellular structure of actin filaments held together by actin bundling proteins can be explained through an understanding of actin itself. Actin is a globular protein found in almost all eukaryotic cells that forms microfilaments (Plopper 166). Although the protein itself has a variety of uses within multiple processes of a cell, including cell motility, muscle contraction, cell division, and cytokinesis, this investigation will be focusing on its ability to maintain cellular tension and retain cell shape. There are multiple different types of actin within a cell and each type has specific proteins that bind to it in order to carry out cellular functions. The specific actin binding proteins that will be addressed are the bundlers and crosslinkers. These types of binding proteins use ATP-actin to form microvilli, filopodia, and stress fibers (Wynder et al., 2005).

Microvilli are cellular membrane protrusions that are involved in absorption, secretion, and cell adhesion. Each microvillus is filled with dense bundles of cross-linked actin filaments held together by the bundling proteins fimbrin, villin, and espin, that serve as the structural and foundational core for the villi (Kraus, 2005). The inside of a microvilli can be seen in Figure 1. The way that these actin filaments are constructed with the bundling proteins that hold them together, they must anchor themselves within the actin cortex and retain tensional strength in order to prevent the microvilli from being pulled off of the cell. The actin cores also retain the shape of microvilli by continuing the uniform shape of one another after coming in contact with whatever the cell may move up against (Kraus, 2005).

Filopodia are small, slender projections that extend past the cytoplasm used for cell movement. Just as the microvilli do, these small “foot-like” protrusions use actin as their structural core (Plopper 175). An extending filopodium contains polar actin filaments that are bundled by the binding proteins fascin and fimbrin. At the tip of a filopodium, there are actin polymerizing modules that continue the constant polymerization of actin in order to support the extending cell structure as it moves (Faix, 2006). This is visibly demonstrated in Figure 2. The physical act of pulling the cell forward would not be possible without these actin filaments bundled together to support the filopodia.

Stress fibers are thick bundles of actin filaments, cross-linking proteins, and myosin II motors (Plopper 176-177). These bundles are parallel to the actin filaments that are constructing the filopodia of a cell but actually grow inward into the cytosol for support. These filaments contain polar ends that signify which way they are extending. In terms of stress fibers, the plus end is growing inward, as stated above, and the filaments themselves continue this way due to the cross-linking protein α -actinin. The bundles themselves are then crosslinked by the non-muscle myosin II (NMMII) to form the actual stress fibers (Tojkander et al., 2012). As the name indicates, stress fibers deal directly with balancing the forces of tension when adhering to another cell or when a cell is carrying out basic migration.

Each one of these cellular structures can be broken down into actin filaments that contain actin bundling proteins. The bundlers and crosslinkers themselves are what truly hold the actin in place in a uniform pattern that makes cell tension spread evenly throughout. Any sort of cellular movement forces compression onto these structures and they are specifically built to withstand as much force and pressure as needed to retain shape and form for the cell (Plopper 173).

Rebar is a steel bar used specifically to reinforce and deal with tension within concrete. Rebar is used because although concrete is great at handling compression from a given load, it is terrible at dealing with tension (Merritt et al., 1995). The reinforced concrete can handle bending and outside forces that would cause layers of just poured concrete to collapse. The rebar is laid down in a uniform pattern before the pouring of the concrete. The pattern is used to form a better bond with the concrete and is almost always in a “cross stitched” arrangement to provide the most evenly spread out support. The basic and widely accepted pattern of rebar can be found by examining Figure 3. The individual steel bars are actually ribbed like screws in order to mechanically bind it to the concrete and maximize adhesion to one another (Merritt et al., 1995). Rebar can be traced back to as early as the 15th century during the construction of the Château de Vincennes and the 18th century for the building of the Leaning Tower of Nevyansk. Both of these structures had thousands of meters of rebar visibly stretching through the buildings to help support the internal structures (Krivosheev, 2002). This technique has now been refined into the present use of rebar.

Why:

Each one of the previous explained cell structures follows the aforementioned Rule-to-Build-By in order to basically provide structural support for the cell. Microvilli use their actin cores to hold themselves together and retain overall shape while constantly moving. The bundling proteins within the cores are essential to this function as they are the actual tension carriers and hold the actin together. The filopodia contain actin filaments that are constantly “growing” and extending themselves out into the extracellular space. The actin-filled filopodium is able to extend in a given direction due to the structural support that the actin provides. The actin would not be able to help in this process at all if it didn’t have both of the bundling proteins that it uses to continue its structural shape and provide thorough support of the extending protrusion (Plopper 175). Stress fibers are actual actin filaments that are held together by cross linking, bundling proteins that serve as a balancing force of tension during cell movement. The fibers are synthesized parallel to the filopodia and build themselves directly opposite into the cytosol to provide support for the cell as it moves (Plopper 177). The advantage of having these bundling proteins is that they have taken on the entire job of balancing both the forces of tension and compression when it comes to extending cellular structures and cell movement. The bundling and crosslinking proteins have evolved to uniformly position the actin so that all forces are evenly spread out among the actin filaments.

Rebar is an effective tool in any form of concrete construction as its sole purpose in the self-supporting structure is to balance the forces of tension and compression. The evolutionary advantage of this principle, “to construct self-supporting structures, balance forces of tension and compression”, is that the more stable and evenly distributed the pressure is on a structure, the larger and more stable it can become. If there is an even spread of weight amongst bound proteins or bars when building, you can continue to expand the structure in multiple ways with low risks of damage or structural failure.

Figures:

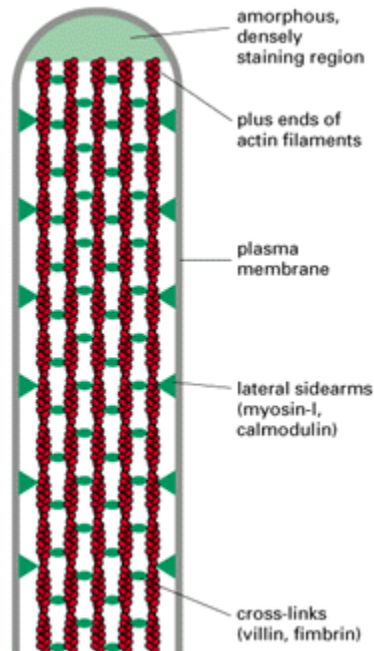


Figure 1. The internal structure of microvilli shows how binding proteins such as villin and fimbrin hold the actin filaments together in order to support the structure. Note the long, red actin filaments held together by the small, green bundling proteins. (This image was retrieved from *The Molecular Biology of a Cell* by Bruce Alberts et al. <http://www.bion.com/book/biology/mvoc/mvoc.cgi?action=figure&fig=16-76.htm>)

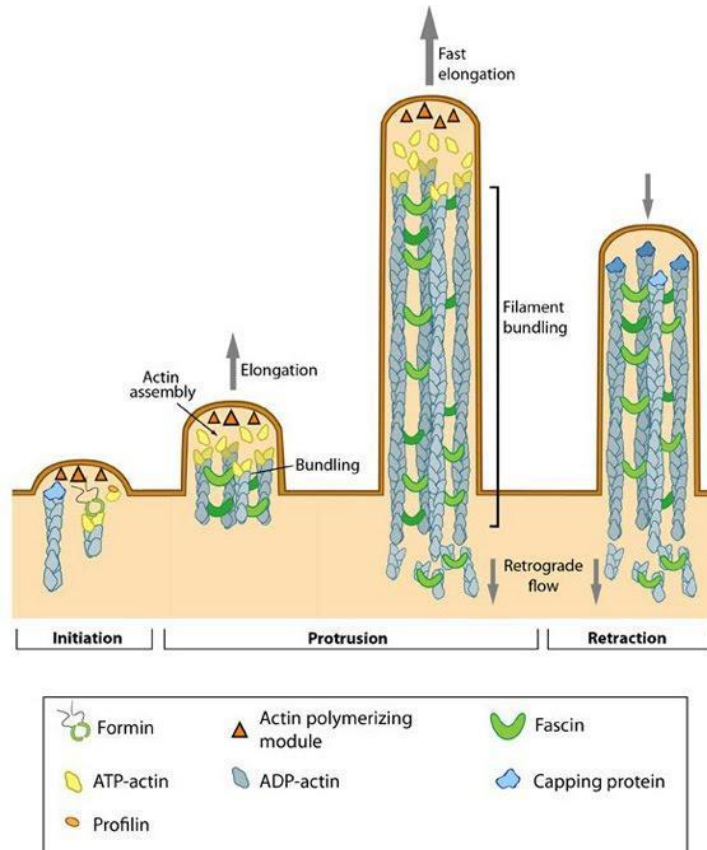


Figure 2. The Actin filaments are constantly polymerizing inside of the extending filopodia. These actin filaments are bound to one another in self-supporting structures through the use of actin bundling proteins. The bundles provide the support needed to continue actin extension. (This image was retrieved from The National Center for Biotechnology Information. <http://www.ncbi.nlm.nih.gov/pubmed/16337369>)



Figure 3. Rebar is laid down systematically to provide tension support for the concrete that will be poured over it. Once the concrete is poured, the rebar will take on most of the weight and ensure that the concrete will be a reliable, structural base. (This image was retrieved from Medford Concrete Contractors.

http://www.myconcreteconcepts.com/wp-content/uploads/2013/12/IMG_0298.jpg

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