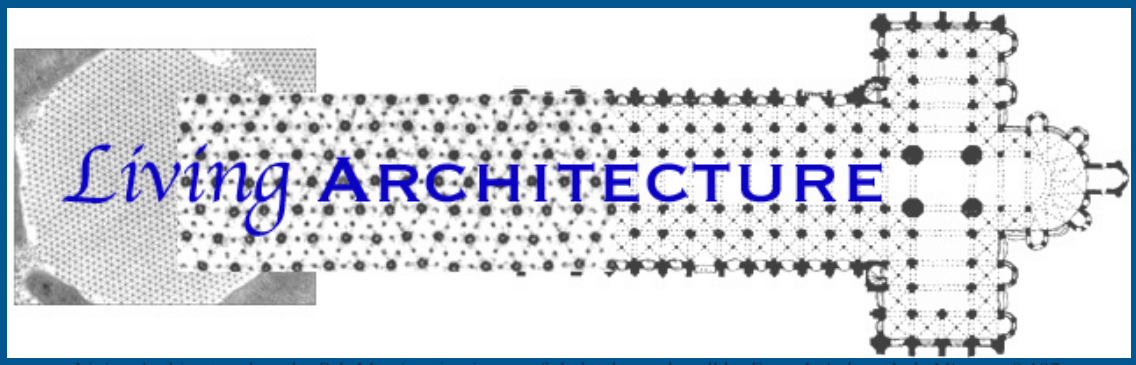
Wheaton Journal of
Cell Biology Research

Issue 6, Spring 2016:

"Living Architecture"

R.L. Morris, Editor. Wheaton College, Norton Massachusetts.



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The Golgi Apparatus as an Analogy to Hershey's Chocolate Factory

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BIO 219 / Cell Biology
Final Research Paper
3 May 2016

The Three Subdivisions of the Golgi Apparatus as an Analogy to Hershey's Chocolate Factory

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Living Architecture Research Report written for
Wheaton Journal of Cell Biology Research
BIO 219 / Cell Biology
Wheaton College, Norton Massachusetts
3 May 2016

Rule-to-Build-By:

"To conduct multiple activities simultaneously, subdivide spaces and assign different functions to each space." (Morris & Lane, 2012).

What:

The Golgi apparatus has three distinct membranous zones for processing cell material: the trans face, the medial zone, and the cis face. This illustrates the principle of distinct, simultaneously active but subdivided spaces demonstrated in the third rule-to-build-by.

The Hershey's Chocolate factory in Hershey, PA produces chocolate through the acquisition of raw ingredients, separate processes, and packaging for export. This upholds the rule-to-build-by as there are separate areas for different processing in order to export the finished chocolate product at the end.

How:

The Golgi apparatus has at least three distinct regions in its cisternae that make up the organelle. These zones are designated by the order in which a vesicle travels to the organelle. The cis face of the Golgi is where the vesicle, sent from the endoplasmic reticulum, first merges with the Golgi. The medial zone of the Golgi is the home to further vesicle content modification in the center of the organelle. The trans face of the Golgi is responsible for final vesicle content modification and budding off for transport to the plasma membrane and elsewhere in the cell. (Plopper, 2014). These processes occur simultaneously as visible in figure 1.While this concept is simple enough, the method by which post-translational modification in a system of moving vesicles fusing with and budding from a membrane maintains cisterna-specific function continues to be the topic of new research.

Since the Golgi is responsible for the processing of an array of proteins and lipids, the cisternae-specific enzymes and other components are numerous. Biochemical analysis studies, such as the one on a cis-Golgi matrix protein GM130 by Nakamura et. al. (1995) indicate that while there may be some overlap in proteins between the cisternae of the Golgi, many proteins are highly localized. The localization of these proteins allows for a stepwise modification, as illustrated with the example of a glycan in figure 2, of the incoming contents of a vesicle in which the target

for modification (often a protein produced in the endoplasmic reticulum) can be modified effectively. A mixture of Golgi proteins in different areas of the Golgi may not be able to efficiently and accurately modify a specialized protein as needed.

How these proteins stay together in their cisternae with such large vesicle turnover is still somewhat of a mystery. Explanations include the kin recognition model, in which proteins such as has been observed in enzyme N-acetylglucosaminyltransferase I bind membrane domains and create oligomers large enough to prevent their movement into vesicles for transport throughout the Golgi. They instead remain in their cisterna (Nilsson, 1994). Another model, the bilayer thickness model, discusses how thickness of the Golgi cisternae are different at different locations within the Golgi and the intermembrane domains of the proteins that localize in these areas are shaped to match that thickness. These proteins are often dependent on factors like cholesterol for proper formation (Nezil & Bloom 1992).

Proteins destined for Golgi processing are produced predominantly in the endoplasmic reticulum. Vesicles that bud from the endoplasmic reticulum destined for the Golgi are associated with proteins such as COPI (which promotes budding) and COPII on the surface of the vesicles (Barlowe, et. al. 1994) which, when present, signal for the vesicle to be transported towards the Golgi. Once arriving at the Golgi, there are a plethora of signals and proteins that work to move targets through the Golgi, one of them being rab6p a GTP-binding protein, which regulates membrane traffic from the medial Golgi to the trans face of the Golgi and possibly beyond (Antony et. al. 1992). The trans face of the Golgi is a wide array of vesicles and cisternae that allow for the transport of various components throughout the rest of the cell (Plopper, 2014).

In the Hershey's factory, raw cocoa enters, chocolate bars leave. This is analogous to the Golgi's function as raw materials enter, they are modified, and finish product is exported. At Hershey's factory, the internal processes are also segregated in a similar stepwise, orderly fashion.

After the entrance of the raw materials, the cocoa beans are "screened" to weed out the unsuitable ones, and then mixed. Afterwards, they are roasted. Following a roast, they are broken and smashed, then "milled" to form liquid chocolate, then into cocoa butter. This cocoa butter will be processed further to produce a nice chocolate texture. Afterwards, the milk is added and the material is further processed and sugar is added. Finally, they are molded, perhaps some nuts are thrown in depending on what they are making, and then are packaged and sent off to locations all around the country (Inside the Magic, 2010). This is analogous to the Golgi in the sense that unmodified materials enter, undergo several steps of processing in delineated areas, and eventually are packaged (shown in figure 3) and sent to destinations away from the organelle.

Why:

In the theoretical scenario of a disordered Golgi without specialized compartments and organized construction, a protein requiring a specific sequence of molecules in order to function properly, a protein signal for example, would unlikely result in the necessary sequence for full functionality.

Rabouille et. al. (1995) states that "complex, bi-antennary, N-linked oligosaccharides" could not be created without the sequential action of the Golgi apparatus. These molecules are heavily

modified from the raw material produced in the endoplasmic reticulum and certainly would not be able to function without their dependence on the Golgi.

Stepwise modification in separate cisternae in the Golgi illustrate the principle of simultaneous, differing function across subdivisions. The trans, medial, and cis cisternae are subdivisions of the Golgi and they contain different factors that alter targets differently. Since the Golgi is an evolving, ever-twisting network of membranes, and a cell's need for protein and lipid modifications is frequent, the Golgi apparatus is always processing material simultaneously (Plopper 2014).

The evolution of the Golgi as a stepwise process was probably to increase the molecular possibilities of the products produced by the endoplasmic reticulum as well as increase the amount of possible modification for molecular diversification.

The Hershey's factory segregating different chocolate-making steps into different rooms makes logical sense for a number of reasons. One example is the step in which the cocoa enters the roasting room. In this room, the temperature is extremely high in order to roast the cocoa. It makes no sense to have other processes that might not need high heat, let alone workers or milk that needs to be stored in a cold place in the roasting room. Another step features lines of open troughs of liquid chocolate. It makes sense that they would separate the cracking step (which may or may not exude small cocoa particles in cracking events) in order to protect the open trays of chocolate. Hershey's needs to make a consistent product. Placing environments of different temperatures, human workers intermingled with machines and other changing factors would make the chocolate an inconsistent taste and texture (Inside the Magic, 2010).

If the chocolate was not produced in the exact order that it is made, it does not become typical Hershey's chocolate, and perhaps not even chocolate at all. Imagine just switching the "weeding" step with the packaging step and leaving rocks and other nasty tidbits to be sold to companies without the candy having ever been wrapped. Stepwise and in order is a must for both the Golgi and the Hershey's factory. The subdivision of the factory into differing steps all processing chocolate simultaneously is the epitome of the third rule-to-build-by.

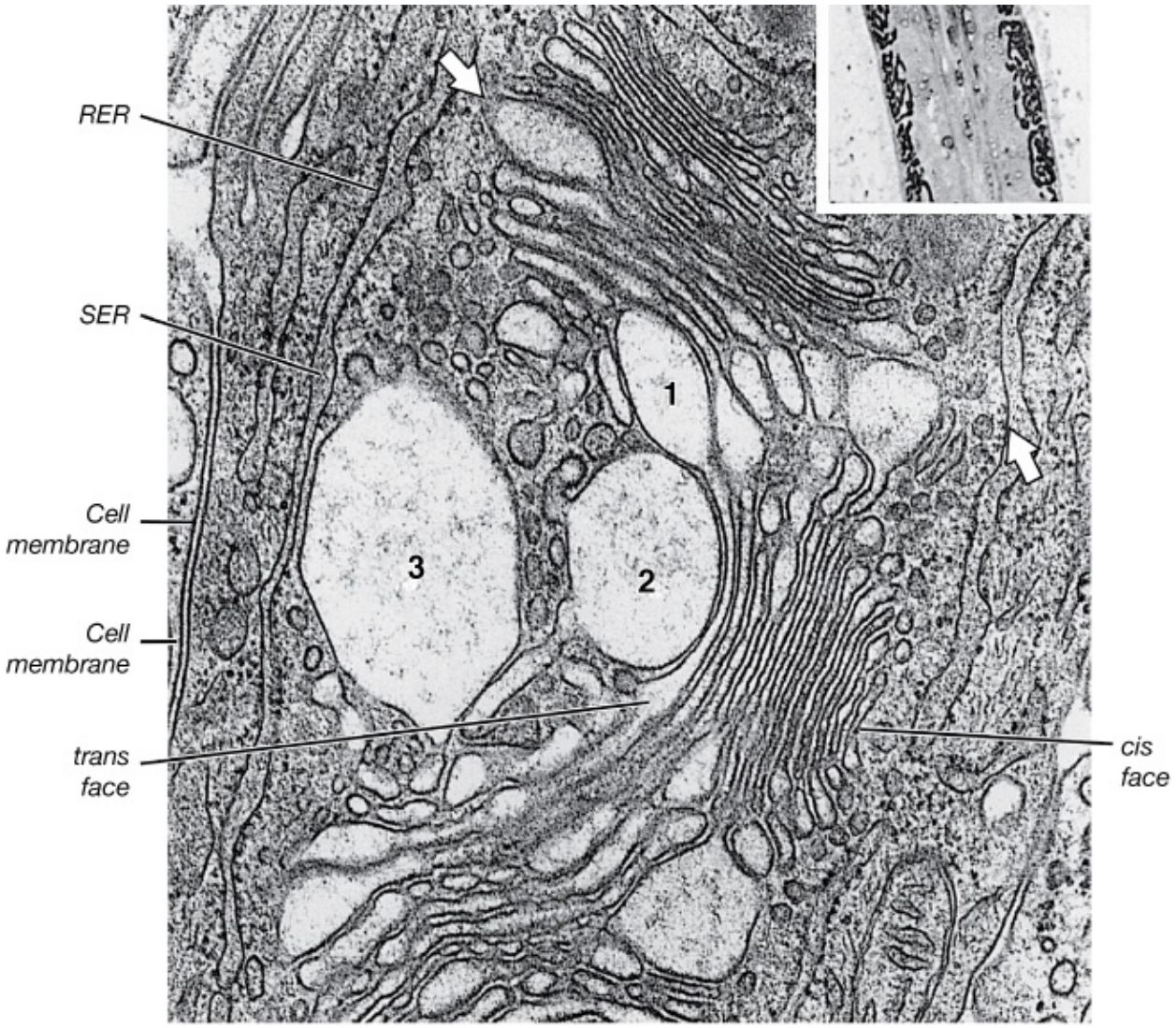

Figure 1: The three main Golgi zones, the cis cisternae, shown by electron microscopy. Vesicles are entering from the right of the Golgi cross section, the central section illustrates the medial zone and finally on the right is the trans Golgi, showing the mass numbers of budding vesicles (Mescher, A. L., 2013).

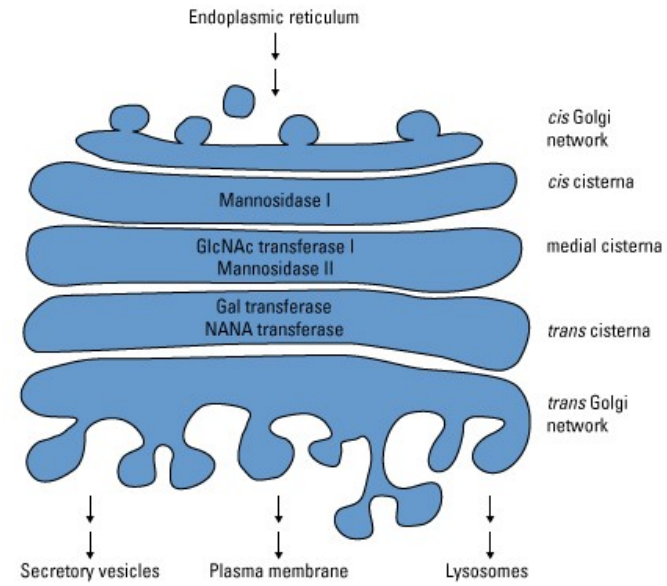

Figure 2: A process of glycosylation of a protein in a stepwise fashion through the Golgi apparatus. Demonstrates how the Golgi can change a glycan in this fashion (Thermo Fisher, Retrieved 26 April, 2016 from https://www.thermofisher.com/us/en/home/life-science/protein-biology/protein-biology-learning-center/protein-biology-resource-library/pierce-protein-methods/protein-glycosylation.html)

Figure 3: Chocolate kisses leave the factory floor, fully packaged, ready to be pushed out to stores in a separate shipping area. (Melby, 2012).

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