The Strength and Flexibility of the Plasma Membrane Compared to Chainmail Armor

Lucas Yoder
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Rule-To-Build By:
To build a structure that is flexible but strong, use small repeating subunits that can move individually with respect to their neighbors.

What:
The plasma membrane is strong and flexible because of its phospholipid structure that keeps them together while allowing the membrane to be fluid. Chainmail armor is strong and flexible because of its many chain links that allow it to bend without weakening it.

How:
The plasma membrane is essential to the longevity and functionality of every cell. Cells need their phospholipid bilayers to act as selective barriers designating different compartments of cell function and to contain these subunits and keep them in close proximity of each other. Membranes are made up of phospholipids, which form membranes due to the many hydrophobic interactions of each of these phospholipids. A lipid bilayer is a two dimensional fluid. The hydrophobic tails of the lipids point inward, while their hydrophilic heads interact with the intra and extracellular H2O (Morris, 2012). (See Figure 1). This allows the membrane to bend, within the limitations of the cytoskeleton, and not rupture due to water’s excluding property. This in turn forces them together. The individual phospholipid subunits can move between each other, allowing the membrane to be flexible. When a membrane is more fluid, it contains a lot of unsaturated lipid tails. Unsaturated lipids can move more freely past each other because the interactions between the phospholipids are less complementary. This allows for more space in the membrane. This fluidity is made possible by the “kinks” in one of the tails of a phospholipid that is created by the carbon-to-carbon double bond in the fatty acid tail. A tail with a kink is less likely to associate with the neighboring lipids with straight tails. The more unsaturated fatty acids in the plasma membrane the more fluid it becomes, due to the less interacting lipid tails (Catalá, 2012). When the lipid molecules move more freely past each other the membrane is more flexible. The membrane is still strong though, because of the hydrophobic interactions of the phospholipids and the exclusion properties of water. By themselves phospholipids are not strong, but in the membrane, where they are side by side, and can interact, they create a structure that holds the cell together. The membrane can stand up to pressures on the inside and outside of the cell (Alberts, et al. 2010).

Chainmail is a type of armor that has been used throughout history in many cultures in Asia and Europe (See Figure 2). Each piece of armor consists of thousands of small round chain link subunits that are linked together to minimize the holes and other weaknesses (such as weight), while also maximizing the strength and flexibility. The most common metal used to make these rings was iron. The most common pattern is the 4-1 where each ring is link to 4 others (left, right, above, and below). This made each ring tilt to a certain degree, which allowed them to move and rotate with the person wearing them to maximize flexibility (See Figure 3). The rings were riveted closed to ensure they wouldn’t bust if the wearer got thrashed with mighty blow. If a person wearing chainmail received a slashing attack, the rings would shed the blow simply by being so close together. If a stabbing attack were to take place, the chainmail would contort around the stabbing object, the links would shift, and the armor would prevent the stabbing object from entering the skin (as long as the rivets held up and the rings didn’t break).
Why:

It is advantageous for the plasma membrane to be fluid for several reasons. First, it allows resident proteins to float on top and inside the membrane so that they can start signaling pathways, or any other function (Alberts, et al. 2010). Second, fluidity allows the membrane to not burst apart when compressed between other cells, or when migrating to another part of the organism. Consider the plant cell wall. This rigid structure keeps the plant plasma membrane from bursting by keeping it safe inside the wall, however, if the plant is to bend or the cell is to receive pressure, the cell wall is likely to take damage. A fluid human plasma membrane can take the stress of being compressed or contorted because the phospholipids can shift as they are needed. Thirdly, a simultaneous increase in stiffness, or a decrease in the ratio of unsaturated to saturated lipids, of both plasma and red blood cell membranes may decrease the microcirculatory flow of the blood, which can ultimately lead to tissue hypoxia, insufficient tissue nutrition, and diabetes-specific micro vascular pathology (Weijers, 2012).

It is advantageous for soldiers to protect themselves in battle, while also maintaining maximum mobility. Chainmail weighs far less than a full suit of armor, and is most effective against slashing attacks. While stabbing is it’s weakness, chainmail was still considered sufficient to the skilled warrior, and was often worn underneath some sort of plate armor that protected the chest and back from stabbing thrusts (Larson, 1940). The advantage here for the wearer is that the chainmail will offer protection by placing metal in between the skin and the sword, while also fitting the wearer more like clothing than armor.

Figures:

Figure 1: The lipid bilayer (plasma membrane). Note the hydrophilic heads and hydrophobic tails (pointing inward) of the lipids. Also note the kinked tails on many of the lipids that makes them less complementary to each other (Alberts, et al. 2010).
Figure 2: A chainmail jacket. Note the pattern of linkage and the seams of the sleeves. Also note the extraordinary number of links used. (Chainmail, http://lmc.gatech.edu)

Figure 3: Close-up of chainmail pattern. Notice the way the rings are connected – each to 4 other rings. Also notice the tilt of each ring relative to the one’s it’s linked to. The mail is designed to be flexible. (Roman Chainmail Detail, http://fr.wikipedia.org)

References:

Catalá, A. (2012). Lipid peroxidation modifies the picture of membranes from the "fluid mosaic model" to the "lipid

Images: