

The Similarities of the Fertilization Envelope and Moats

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Rule to Build By

“To defend a complex, create barriers of entry.”

What

To illustrate this rule-to-build-by, the fertilization envelope of the original vitelline envelope of an egg with one bound sperm supports this principle. Similarly, moats are an architectural form that supports this principle. Examples of defensive moats are at the Bodiam Castle (Figure 1) and Caerphilly Castle (Figure 2).

How

In order for an egg to be fertilized, one sperm is mandatory (Figure 3). Polyspermy is when more than one sperm fuses with an egg. There are two ways to prevent polyspermy: the fast block and the slow block. The fertilization envelope plays a major role in slow block, because it serves as a defensive barrier against polyspermy. The fertilization envelope is a tough, thick membrane that is a combination of constituents of the cortical granules and the original vitelline envelope. Before the sperm binds to the egg's species specific sperm receptor, the egg's vitelline envelope is tethered to the tips of microvilli on the egg's plasma membrane (Figure 4). Once the sperm fuses with the egg, the fast block and slow block are triggered. During fast block, there is a spread of positive charge in the egg's cytoplasm that creates an electrochemical gradient. When the sperm binds to the egg's receptor, positively charged sodium ions rush into the egg, giving the egg a positively charged cytoplasm. The egg cell changes its ability to bind sperm because the sperm have receptors that are positively charged, and can only bind to an egg with a negatively charged cytoplasm. Once one sperm binds to the egg, the fast block occurs with the help of voltage gated sodium channels that allow for sodium ions to rush in and change the egg cell's cytoplasm charge in milliseconds. The rapid change in membrane potential of the egg after the fusion of gametes prevents polyspermy (Morris, 2009) and (Wilt, 2004).

Even though the egg's fast block helps prevent polyspermy, the slow block, which involves the fertilization envelope, allows for the egg cell to develop a physical barrier against the surrounding sperm (Figure 5). Like the fast block, the slow block begins once the sperm fuses with the egg. The cortical granules closest to where the sperm fuses with the egg undergo exocytosis first, and they trigger surrounding cortical granules to exocytose. The cortical granules play a major role in the slow block process. They are located in the peripheral plasmic area (also known as the cortex) of the egg. They are loaded with proteases, hardening enzymes, and glycoproteins that attract water. Once the sperm fuses with the egg, the cortical granules undergo exocytosis and release contents into the vitelline envelope. This raises osmotic pressure and also causes swelling. The vesicle membrane of the cortical granules is physically restraint, but when the cortical granules release, there is an osmotic swelling force. The contents within the cortical granules cleave the vitelline envelope off the plasma membrane (proteolytic cleavage), and water comes in (osmotic swelling) to help lift off the vitelline envelope to form the fertilization envelope (Morris, 2009) and (Wilt, 2004).

The cortical granules are triggered to exocytose through a series of intracellular signals, collectively known as the IP3 pathway. When the sperm binds to the G-protein coupled receptor on the egg it loses GDP and gains GTP. The activation of G-protein receptors is the beginning of the IP3 pathway. This exchange occurs on the alpha subunit of the G-protein. The beta and gamma molecules stay together and fuse away, and the alpha and GTP molecules stay together. Tethered to the plasma membrane is phospholipase C, which is an enzyme that is activated by the interaction of the sperm with the G-protein coupled receptor (Morris, 2009). PIP2, Phosphatidylinositol 4, 5- bisphosphate, is an inositol that has been phosphorylated twice (bis-phosphate), and acts as an intermediate in the IP3 pathway. PIP2 is a substrate for hydrolysis by phospholipase C, which cuts the PIP2. Two second messengers are the product of this reaction: IP3, inositol 1, 4, 5- triphosphate along with DAG, diacylglycerol. IP3 snips all of the PIP2 to create more IP3. IP3 carries six negative charges so it changes the conformation of anything it binds to. DAG remains on the cell membrane and

activates protein kinase C, which activates the signal cascade. Cytosolic proteins are activated by the protein kinase C that phosphorylates them. The IP3 binds to the ligand-gated ion channel located on the endoplasmic reticulum. Calcium channels on the endoplasmic reticulum open, and this allows calcium ions to be released from the endoplasmic reticulum and flow into the cytosol through Ca^{2+} channels. This triggers the exocytosis of the cortical granules, which initiate the formation of the fertilization envelope. Hyaline is also created as a result of the exocytosis of the cortical granules. Hyaline is very sticky and tough and wraps the plasma membrane in the new extracellular layer that wraps the cell. The fertilization envelope is a defensive barrier to prevent polyspermy (Morris, 2009).

Moats have a similar defensive purpose as the fertilization envelope. Moats are typically man made, physical barriers that were created as a preliminary line of defense to prevent the architectural form they surrounded from being besieged. Moats are most commonly known for being defensive barriers for castles, but they also surrounded buildings and towns. Additionally, moats do not always completely surround an architectural form. There are two types of moats, dry moats and moats with water. Both types of moats were created for the same purpose. Moats can range from being 3 feet deep to 30 feet deep, and have a width over 12 feet long (Marvin Hull, 2008).

Both the fertilization envelope and moats are physical barriers that separate what they are protecting from potentially harmful outside environments. They both help the structure they are protecting remain safe so that they can thrive.

Why

The fertilization envelope upholds the rule-to-build-by because without it, an egg cell would undergo polyspermy because it would not be as well protected. Polyspermy leads to more than one sperm entry per egg, which causes abnormal development and eventual death of the embryo (Carroll, 2003). The fusion of egg and sperm create a zygote (Morris, 2009). Both the egg and sperm are haploid, which means that they carry only one of each chromosome type in their pronucleus. During the S period, the two germ cells fuse their nuclear membranes and reestablish diploidy, followed by DNA synthesis. Once the sperm nucleus (that is in the cytoplasm of the egg) fuses with the egg's nucleus it becomes diploid. A diploid cell is a cell that has two haploid nuclei fuse to form two sets of chromosomes per nucleus. It is important to prevent polyspermy because if two sperm fused with an egg, a polynucleus would form. Multi-polar mitotic divisions would occur because there would be additional centrioles that would cause these divisions. Multi-polar mitotic divisions would lead chromosomes being unequally distributed to progeny cells and would also distribute patterns of cytokinesis. Polyspermy is fatal because the zygote is normally diploid (2N), but with two sperm is a triploid with 3N (Wilt, 2004) (Figure 6). All organs in polyploids have defects, and most embryos spontaneously abort in the uterus (Gregory, 2006). Without the fertilization envelope polyspermy would be a lot more common, and the rate of an embryo's survival would be lowered. The formation of the fertilization envelope is one of three major cellular mechanisms that prevent polyspermy. It serves as a barrier to entry for the egg cell, and without it, the zygote would not thrive and live long.

Moats uphold the rule-to-build-by because without them, the architectural form that they surrounded would not be as well defended against outside threats. Without moats, the architectural form they were protecting would have been more accessible and vulnerable to invaders. Water moats were especially beneficial to castles/ towns, because the water moats were sometimes too deep for unwanted invaders to wade through. Moats reduced the risk of tunneling, because invaders were fearful of the unsteady grounds the water moats created. Additionally, any invader in a moat was seen as an easy target for castle guards (Hull, 2008). Without the presence of a moat to act as a physical primary line of defense, many castles would be vulnerable to attack.

Figures

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Figure 1: Bodiam Castle has a large moat that surrounds it in order to defend the castle. It was built in 1385 by Sir Edward Dalyngrigge, who was a war veteran. This castle is located in East Sussex, Britain (Jackman, 2008).



Figure 2: This is an aerial view of Caerphilly Castle. Its moat is nicely shown from this angle. It was built for a powerful nobleman from 1268- 1271 as a response to a dispute, and is located in Caerphilly, Wales (Pritchard, 2010).



Figure 3: Shown here is an egg with human sperm interacting with its surface. This image was taken by a scanning electron micrograph. Many sperm interact with the egg, but only one fertilizes it (Alberts, 2010).

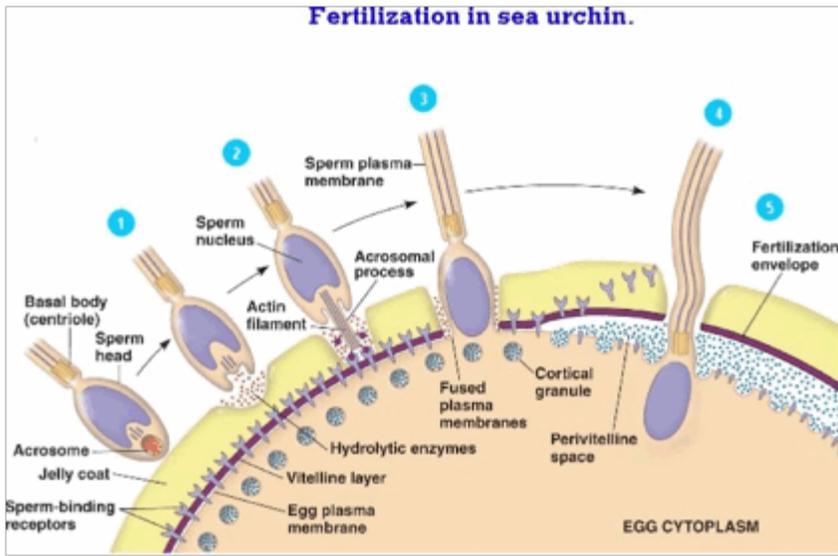


Figure 4: Shown in this image is the step by step process of a sea urchin's sperm fusing with an egg. It also displays where the vitelline envelope, plasma membrane, cortical granules, and fertilization envelope are located in an egg cell. (Chen, 2009)

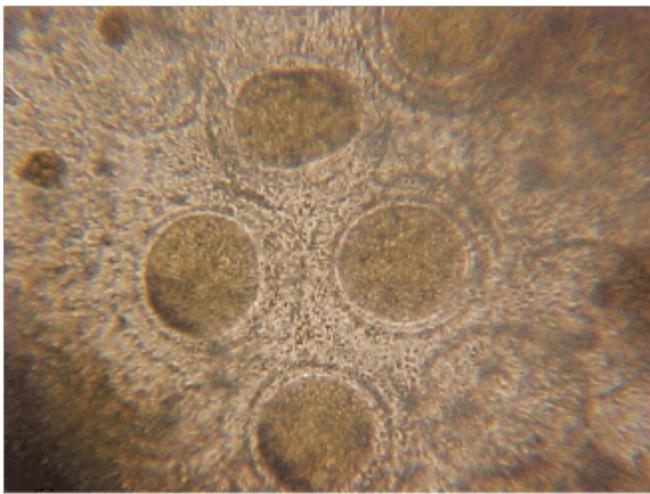


Figure 5: Visible in this image of fertilized sea urchin eggs is their fertilization envelope formed around the cell. This image is of a live specimen. The formation of the fertilization envelope can take anywhere from a half minute to five minutes (Barta, 2003).



Figure 6: This image displays what happens to a sea urchin's development when it undergoes polyspermy. Here you can see defects at the first cleavage division. Chromosomes are segregated randomly between different spindles (Cebra, 2001).

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