5.5: Evolution of Eukaryotes

Why can this fish live in these tentacles, but other fish cannot?

Anemones and Clown Fish have a well-known symbiotic relationship. In the ocean, the Clown Fish are protected from predator fish by the stinging tentacles of the anemone, and the anemone receives protection from polyp-eating fish, which the Clown Fish chases away. But what about symbiotic relationships at a much smaller scale? Is it possible for two single-celled organisms to have a symbiotic relationship? As you will find out, yes it is!

Evolution of Eukaryotes

Our own eukaryotic cells protect DNA in chromosomes with a nuclear membrane, make ATP with mitochondria, move with flagella (in the case of sperm cells), and feed on cells which make our food with chloroplasts. All multicellular
organisms and the unicellular Protists share this cellular intricacy. Bacterial (prokaryotic) cells are orders of magnitude smaller and have none of this complexity. What quantum leap in evolution created this vast chasm of difference?

The first **eukaryotic cells** - cells with a **nucleus** an internal membrane-bound **organelles** - probably evolved about 2 billion years ago. This is explained by the **endosymbiotic theory**. As shown in the Figure below, **endosymbiosis** came about when large cells engulfed small cells. The small cells were not digested by the large cells. Instead, they lived within the large cells and evolved into organelles.

From Independent Cell to Organelle. The endosymbiotic theory explains how eukaryotic cells evolved.

The large and small cells formed a **symbiotic relationship** in which both cells benefited. Some of the small cells were able to break down the large cell’s wastes for energy. They supplied energy not only to themselves but also to the large cell. They became the **mitochondria** of eukaryotic cells. Other small cells were able to use sunlight to make food. They shared the food with the large cell. They became the **chloroplasts** of eukaryotic cells.

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**Mitochondria and Chloroplasts**

What is the evidence for this evolutionary pathway? Biochemistry and electron microscopy provide convincing support. The **mitochondria** and chloroplasts within our eukaryotic cells share the following features with prokaryotic cells:

- Their organelle DNA is short and circular, and the DNA sequences do not match DNA sequences found in the nucleus.
- Molecules that make up organelle membranes resemble those in prokaryotic membranes – and differ from those in eukaryotic membranes.
- Ribosomes in these organelles are similar to those of bacterial **ribosomes**, and different from eukaryotic ribosomes.
- Reproduction is by binary fission, not by mitosis.
- Biochemical pathways and structures show closer relationships to prokaryotes.
- Two or more membranes surround these organelles.

The "host" **cell membrane** and biochemistry are more similar to those of Archaebacteria, so scientists believe eukaryotes descened more directly from that major group (Figure below). The timing of this dramatic evolutionary event (more likely a series of events) is not clear. The oldest fossil clearly related to modern eukaryotes is a red alga dating back to 1.2 billion years ago. However, many scientists place the appearance of eukaryotic cells at about 2 billion
years. Some time within Proterozoic Eon, then, all three major groups of life – Bacteria, Archaea, and Eukaryotes – became well established.

What Does it all Mean?

Eukaryotic cells, made possible by endosymbiosis, were powerful and efficient. That power and efficiency gave them the potential to evolve new characteristics: multicellularity, cell specialization, and large size. They were the key to the spectacular diversity of animals, plants, and fungi that populate our world today. Nevertheless, as we close the history of early life, reflect once more on the remarkable but often unsung patterns and processes of early evolution. Often, as humans, we focus our attention on plants and animals, and ignore bacteria. Our human senses cannot directly perceive the unimaginable variety of single cells, the architecture of organic molecules, or the intricacy of biochemical pathways. Let your study of early evolution give you a new perspective – a window into the beauty and diversity of unseen worlds, now and throughout Earth’s history. In addition to the mitochondria that call your 100 trillion cells home, your body contains more bacterial cells than human cells. You, mitochondria, and your resident bacteria share common ancestry – a continuous history of the gift of life.

The three major domains of life had evolved by 1.5 billion years ago. Biochemical similarities show that eukaryotes share more recent common ancestors with the Archaea, but our organelles probably descended from bacteria by endosymbiosis.

Summary

• Eukaryotic cells probably evolved about 2 billion years ago. Their evolution is explained by endosymbiotic theory.
• Mitochondria and chloroplasts evolved from prokaryotic organisms.
• Eukaryotic cells would go on to evolve into the diversity of eukaryotes we know today.

Explore More

Use the time slider in this resource to answer the questions that follow.

• Evolution at http://johnkyrk.com/evolution.swf.
1. When did cells begin to "swallow" other cells?
2. When did respiration develop?
3. The rapid rise in atmospheric oxygen favored which cells?
4. When did eukaryotic cells first form? What distinguished these cells from their predecessors?

**Review**

1. When did the first eukaryotic cells evolve?
2. Describe the endosymbiotic theory.
3. Discuss the evidence for the evolution of mitochondria and chloroplasts.