The Endosymbiotic Theory

Cleodie Swire

The King's School, Canterbury, E-mail: 07ccs@kings-school.co.uk

DOI: 10.4103/0974-6102.92200

Definitions

Prokaryote – Organism with cells without a true nucleus or other membrane-bound organelles

Eukaryote – Organism whose cell(s) contain(s) a distinct, membrane-bound nucleus

Autotroph – An organism that can make its own food

Heterotroph – An organism that must obtain ready-made food

Endocytosis – A process in which a cell takes in materials by engulfing them and fusing them with its membrane, as shown in Figure 1

Aerobic – Organism that requires oxygen for survival

Anaerobic – Organism that can function without oxygen

Symbiosis – Two different organisms benefit from living and working together

Endosymbiosis – One organism lives inside another

Mitochondrion – Organelle where aerobic respiration occurs within the cell

Carbohydrate + Oxygen → Carbon dioxide + Water + Energy

Chloroplast – Organelle where photosynthesis occurs in plant cells

Carbon dioxide + Water (with sunlight and chlorophyll) → Carbohydrate + Oxygen

Figure 2 shows that mitochondria and chloroplasts are very similar to prokaryotic cells; these observations lead to The Endosymbiotic Theory.

Theory

Researchers comparing the structures of prokaryotes and cell organelles, as shown in Figure 2, came to the conclusion that organelles such as mitochondria and chloroplasts had originally been bacteria that were taken into larger bacteria by endocytosis and not digested. The cells would have had a mutually beneficial (symbiotic) relationship. The ingested cells developed

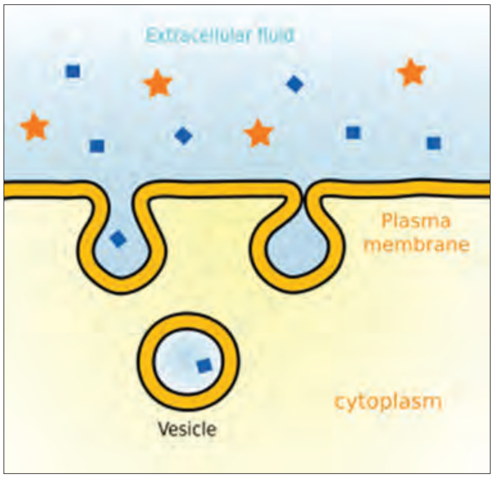


Figure 1: A diagram showing endocytosis [available from http://en.wikipedia.org/wiki/File: Average_prokaryote_cell-_en.svg]

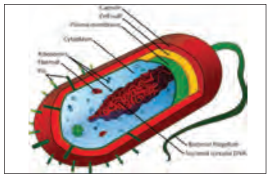
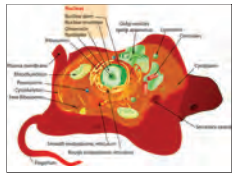
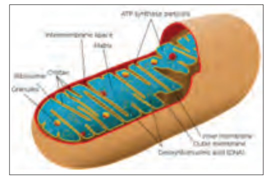
Cell type	Eukaryote	Prokaryote	Mitochondria	Chloroplasts
DNA	Organized into chromosomes	Single loop	Single loop	Single loop
Ribosomes	80S	70S	70S	70S
Size/microns	50-500	1-10	1-10	1-10
Cell nucleus?	Yes	No	No	No
Membrane-bound organelles?	Yes	No	No	No
Replication	Mitosis	Binary fission	Binary fission	Binary fission
Number of cells	One or more	Usually one		
Example/image	Animal cell	Bacteria		
	 [available from http://en.wikipedia.org/wiki/File:Pinocytosis.svg]	 [available from http://en.wikipedia.org/wiki/File:Animal_cell_structure_en.svg]	 [available from http://en.wikipedia.org/wiki/File:Animal_mitochondrion_diagram_en_(edit).svg]	 [available from http://en.wikipedia.org/wiki/File:Animal_cell_structure_en.svg]

Figure 2: A table comparing various characteristics of different cells and cell types

into organelles, such as mitochondria and chloroplasts, which now cannot live outside the host cell.

Mitochondria

Aerobic bacteria were taken in by anaerobic bacteria. The enveloped bacteria would have used the oxygen from the air (which was useless to its host) to provide far more adenosine triphosphate (ATP) (useful energy) than the host could produce on its own, while the host cell would provide materials to respire, protection, and a steady environment.

Chloroplasts

Autotrophic photosynthetic bacteria cells were taken in by the heterotrophic prokaryote cells. The ingested cell would continue to provide glucose and oxygen (which could be used by the mitochondria as endocytosis of the photosynthetic prokaryote occurred after the endocytosis of aerobic cells) by photosynthesis. The host cell would provide carbon dioxide and nitrogen for the engulfed cell, as well as protecting it.

Over time, both cells lost their ability to survive without each other.

Proof

Similarities to bacteria

Figure 2 shows that mitochondria and chloroplasts have many similarities to prokaryotic bacteria. They are of a similar size and have 70S ribosomes, as opposed to the 80S ribosomes found in eukaryotic cells.

These cells all divide by binary fission, as shown in Figure 3.

DNA

The organelles have their own DNA, separate to the DNA found in the nucleus of the cell, which they use to produce enzymes and proteins to aid their function. This was predicted by the researchers, and was later proved to be true for mitochondria and chloroplasts.

All of these likenesses suggest that mitochondria and chloroplasts developed from prokaryotes.

Double outer membranes

Mitochondrion and chloroplasts have double outer membranes – the inner layer came from the engulfed cell and the outer membrane from the host cell during endocytosis.

Replication

Mitochondrion and chloroplasts can only arise from pre-existing organelles – the DNA that codes for them is not found in the nucleus of the cell, but in naked loops of DNA within the organelles themselves. This suggests that these organelles were originally separate cells that needed to replicate themselves.

Fossil record [Figure 4]

Fossil evidence shows that bacteria were present 3.8 billion years ago, when there was no oxygen in the atmosphere and all organisms were anaerobic.

Photosynthetic bacteria appeared about 3.2 billion years ago, producing oxygen. As the oxygen levels increased, the anaerobic organisms began to die out as oxygen is toxic to most cells (even ours!).

Organisms that could respire aerobically developed about 2.5 billion years ago.

This evidence suggests that the ‘ancestors’ to the mitochondria and chloroplasts developed outside the cell, and later merged with other larger prokaryotes, leading to the development of eukaryotes.

Uses

The discoveries regarding the origins of the mitochondria and chloroplasts have led to several scientific applications.

History of Evolution

The DNA found in mitochondria (mtDNA) is passed

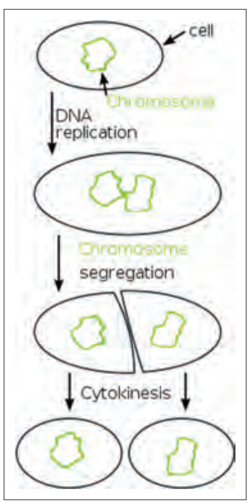


Figure 3: A diagram showing binary fission of a prokaryotic cell [available from http://en.wikipedia.org/wiki/File: Binary_fission.svg]

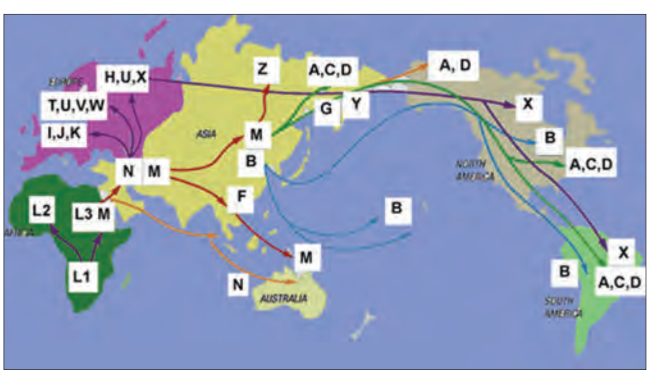


Figure 5: A graph showing human migration patterns, created by studying mtDNA. The letters denote the different groups of mtDNA [available from http://en.wikipedia.org/wiki/File: Migration_map4.png]

directly from mother to child, and changes much more slowly than other types of DNA, providing information about evolutionary history. This can be used to determine how closely related two species are to one another and migration patterns as shown in Figure 5.

Astrobiology

Organisms called archaebacteria, which live in the most extreme habitats on Earth, have been studied as they are the organism believed to be most like the bacteria that inhabited the Earth billions of years ago.

They now inhabit salt ponds and boiling hot springs. As they live in places previously assumed to be unsuitable for life, they are being studied as they may provide clues about extra-terrestrial life. There has been some research done suggesting that the archaebacteria could survive space travel by meteorite, so there is potential for life on other planets.

Researcher

The Endosymbiotic Theory of eukaryote evolution was first suggested by Dr. Lynn Margulis [Figure 6] in the 1960s, and officially in her book, ‘Symbiosis in Cell Evolution' in 1981. Her ideas were initially ridiculed by her fellow biologists, but through research and persistence her theory was eventually accepted and is now regarded as the most credible explanation of eukaryote evolution.

She is best known for her theory of symbiogenesis,

Event	Years ago
Origin of the Earth	4.5 billion
Prokaryote bacteria dominate	3.5 billion
Oxygen starts to accumulate in the atmosphere	2.5 billion
Eukaryotes appear	1.5 billion
Cambrian explosion of multicellular eukaryote organisms	0.5 billion

Figure 4: Timeline of events affecting The Endosymbiotic Theory

Figure 6: Dr. Lynn Margulis [available from http://en.wikipedia.org/wiki/File: Lynn_Margulis.jpg]

which expanded on the aspect of The Endosymbiotic Theory in which the relationship between the prokaryotic cells becomes so strong that the two grew to be dependent on one another. Margulis suggested that this process may have also occurred at other times during evolution. This theory challenges Darwin's idea that mutations occur by genes being passed down from parents to offspring, rather than the genetic material of unrelated organisms being brought together.

About the Author

Cleodie Swire is doing Biology, Chemistry, Physics, Further Maths and Spanish at AS Level, and has already taken French. She is currently at The King's School Canterbury, and hopes to do Medicine at University. She enjoys doing sport - especially hockey - and travelling.

Lynn Margulis (born on the 5th March1938, died on the 22nd November 2011), who was mentioned in the article, sadly died at home after a stroke, aged 73. Many tributes can be for her glorious scientific life can be seen in various obituaries (see the Daily Telegraph Newspaper - http://www.telegraph.co.uk/news/obituaries/science-obituaries/8954456/Lynn-Margulis.html, the New York Times News Paper - http://www.nytimes.com/2011/11/25/science/lynn-margulis-trailblazing-theorist-on-evolution-dies-at-73, the Nature 22/29 December 2011 issue - http://www.nature.com/nature/journal/v480/n7378/full/480458a.html, Scientific American - http://blogs.scientificamerican.com/cross-check/2011/11/24/r-i-p-lynn-margulis-biological-rebel/ and Discovery News - http://news.discovery.com/earth/lynn-margulis-pioneer-of-evolutionary-biology-dies-at-73-111124.html).

Dr. Lynn Margulis at work (Photo: Lynn Margulis at work in a greenhouse, circa 1990. (Nancy R. Schiff/Getty Images))