ORGANELLES AND OTHER STRUCTURES IN CELL BIOLOGY

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Contents

1. Introduction

That the eukaryote cell is large and contains complex subcellular structures has been obvious since the beginning of light microscopy and this, of course, contrasts with the smaller and prokaryote cell without any major subcellular structures. Of the eukaryote subcellular structures observed, the mitochondrion and the chloroplast stand out because both are highly complex even under the light microscope. The latter also is the defining structure by which, in general, it is possible to tell plants from animals. The importance of both mitochondria and chloroplasts goes well beyond their visual impact even when viewed by electron microscopy.

Without these structures, life as we know it would not exist on Earth, They both provide, by two different mechanisms, the energy that allows eukaryotes to exist, evolve and change the Earth to what it is today. They have also helped to create the oxygen rich and temperate environment that we live in on Earth at present. Although the prokaryotes, particularly the photosynthetic cyanobacteria were probably responsible for the initial changes on Earth towards the present aerobic mild environment, without the plants in particular, today's environment would be very different; and without the animals, the environment would be much more bare. Plants and animals as such would not exist without the two organelles, the mitochondrion and the chloroplast.

2. The distribution and function of the mitochondrion

Mitochondria are found in both animal and plant cells. Very few eukaryotic cells are without at least one mitochondrion although examples do exist, but in these cases it is not clear whether they lack of a mitochondrion is an ancestral or derived character. They are the sites of oxidative cell respiration. That is they generate large amounts of adenosine triphosphate (ATP) from the oxidation of glucose using oxygen as a final electron acceptor. Without the mitochondrion, eukaryotic cells are limited to fermentation which produces only a limited amount of ATP and would not allow the evolution of complex multicellular organisms with vast energy requirements.

2.1 The structure of the mitochondrion

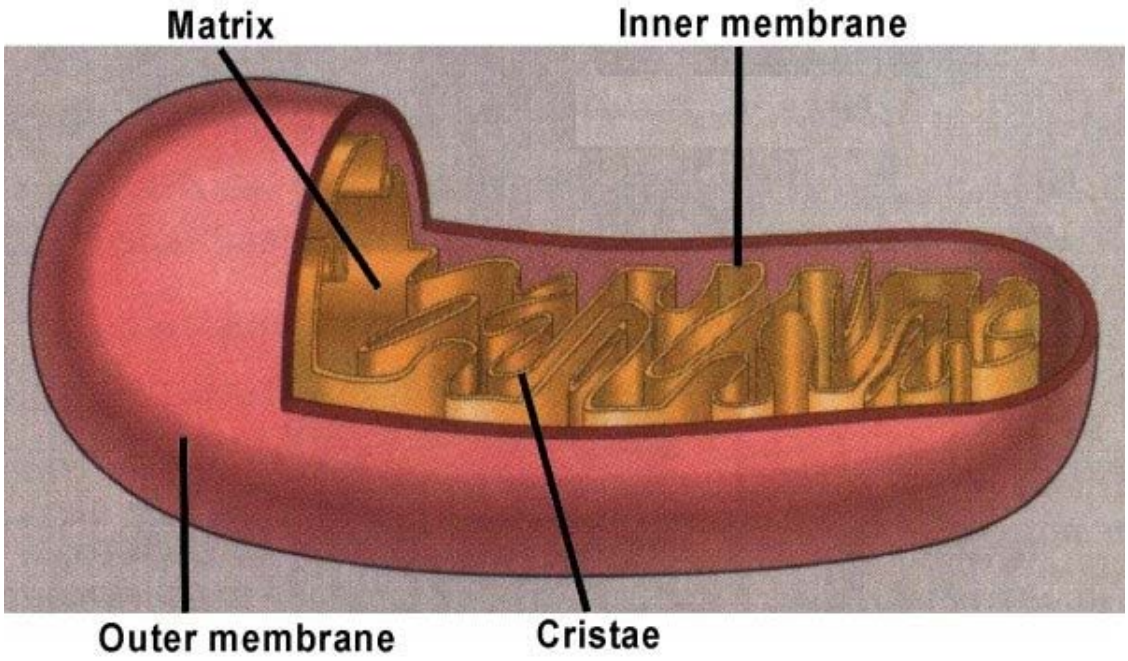

Figure 1: Diagram of mitochondrion

Figure 1 show a basic structure for the mitochondrion as seen by electron microscopy with a double membrane and internal invaginations or cristae. Mitochondria range in size from 0.5 to 1 μm in diameter and a few μm in length. The respiratory proteins reside in the membrane and create ATP via a proton pump mechanism. However, the most significant piece of structural information about the mitochondrion is that it contains its own genetic material. That is that it has it own genome, separate from the DNA in the eukaryote nucleus. The presence of this DNA led to the hypothesis that mitochondria evolved from an endosymbiotic gram negative prokaryote and that the genome found in these organelles resembles that of their prokaryote ancestor (See 4.0). The mitochondrion have their own protein synthetic machinery, which is different from that of the eukaryotic cytoplasm and resembles to some extent that found in prokaryotes. These ribosomes have a different size (70S) from the cytoplasmic ribosomes (80S), being close to prokaryotic ribosomes in size. They also show sensitivity to antibiotics that affect prokaryotic ribosomes and resistance to antibiotics that inhibit protein synthesis by eukaryotic ribosomes. However, they are not completely self sufficient organisms, and although they

reproduce by fission independently of the cell nucleus, they are unable to reproduce if purified. This is because they are required to import a range of molecules including enzymes that are encoded by cell nucleus and synthesized outside of the mitochondrial membrane. Specific import systems are present to transport these molecules across the double mitochondrial membrane (Figure 1).

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Bibliography

Bermudes D, Margulis L, Tzertzinis G. Prokaryotic origin of undulipodia. Application of the panda principle to the centriole enigma. Ann N Y Acad Sci. 503, 187-197 (1987). (Endosymbiotic origin for microtubules).

Black, G.B. Microbiology. Principles and Explorations. 5th Edition. John Wiley and Sons Inc, USA. (2002). (Good basic microbiology textbook with structural and evolution information on organelles)

Chu KH, Qi J, Yu ZG, Anh V. Origin and Phylogeny of Chloroplasts Revealed by a Simple Correlation Analysis of Complete Genomes. Mol Biol Evol. (2003). (Excellent paper using recent data to support endosynbiotic theory of origin of chloroplasts).

Conway,D.J., Fanello,C., Lloyd,J.M., Al-Joubori,B.M.A., Baloch,A.H., Somanath,S.D., Roper,C., Oduola,A.M.J., Mulder,B., Povoa,M.M., Singh,B., Thomas,A.W. Origin of Plasmodium falciparum malaria is traced by mitochondrial DNA Mol. Biochem. Parasitol. 111, 163-171 (2000). (Basic paper on malarial parasite mitochondrial genome).

Hoffmeister M, Martin W. Interspecific evolution: microbial symbiosis, endosymbiosis and gene transfer. Environ Microbiol. 5, 641-649 (2003). (Recent review of interspecific evolution).

Ingman,M., Kaessmann,H., Paabo,S. and Gyllensten,U. Mitochondrial genome variation and the origin of modern humans Nature 408, 708-713 (2000). (Recent paper on human mitochondrial evolution).

Klug, W.S., Cummings, M.R. Concepts of Genetics. Prentice Hall, USA (1994). (Good basic genetics textbook including organelles)

Lang,B.F., Burger,G., O'Kelly,C.J., Cedergren,R., Golding,G.B., Lemieux,C., Sankoff,D., Turmel,M. and Gray,M.W. An ancestral mitochondrial DNA resembling a eubacterial genome in miniature. Nature 387, 493-497 (1997). (Paper supporting mitochondrial endosymbiotic theory).

Lang BF, Gray MW, Burger G. Mitochondrial genome evolution and the origin of eukaryotes. Annu Rev Genet. 33, 351-397 (1999). (Good recent review of mitochondrial genome evolution).

Li JY, Wu CF. Perspectives on the origin of microfilaments, microtubules, the relevant chaperonin system and cytoskeletal motors--a commentary on the spirochaete origin of flagella. Cell Res. 13, 219-227 (2003). (Recent review of the spirochaete endosymbiosis hypothesis).

Lopez-Garcia P, Moreira D. Metabolic symbiosis at the origin of eukaryotes. Trends Biochem Sci. 24, 88-93. (1999). (How eukaryotes arose)

Margulis L. Undulipodia, flagella and cilia. Biosystems. 12, 105-108 (1980). (Where did flagellae and cilia come from?).

Margulis L, To LP, Chase D. Microtubules, undulipodia and Pillotina spirochetes. Ann N Y Acad Sci. 361,

356-368 (1981). (Where did microtubules come from?)

Martin W, Hoffmeister M, Rotte C, Henze K. An overview of endosymbiotic models for the origins of eukaryotes, their ATP-producing organelles (mitochondria and hydrogenosomes), and their heterotrophic lifestyle. Biol Chem. 382, 1521-1539 (2001). (Recent review of endosymbiosis and organelles).

Raven JA, Allen JF. Genomics and chloroplast evolution: what did cyanobacteria do for plants? Genome Biol. 4, 209. (2003). (Chloroplasts and cyanobacteria)

Roger AJ. Reconstructing Early Events in Eukaryotic Evolution. Am Nat. 154, S146-S163 (1999). (review of eukaryotic evolution in general).

Singer M., Berg, P. Genes and Genomes. Blackwell Publishers, UK. (1991). (Excellent molecular genetics textbook, but a little out of date).

Turmel,M., Otis,C. and Lemieux,C. The complete chloroplast DNA sequence of the green alga *Nephroselmis olivacea*: insights into the architecture of ancestral chloroplast genomes. Proc. Natl. Acad. Sci. U.S.A. 96, 10248-10253 (1999). (Paper giving information on the evolution of chloroplasts).

Van Ham, R.C., Kamerbeek, J., Palacios, C., Rausell, C., Abascal, F., Bastolla, U., Fernandez, J.M., Jimenez, L., Postigo, M., Silva, F.J., Tamames, J., Viguera, E., Latorre, A., Valencia, A., Moran, F., and Moya, A. "Reductive genome evolution in Buchnera aphidicola." Proc. Natl. Acad. Sci. USA 100, 581-586. (2003). (What happens to bacterial genomes during endosymbiosis)

Wolfe,K.H., Morden,C.W. and Palmer,J.D. Function and evolution of a minimal plastid genome from a nonphotosynthetic parasitic plant. Proc. Natl. Acad. Sci. U.S.A. 89, 10648-10652 (1992). (what happens to a chloroplast genome in a plant that does not use photosynthesis).

Biographical Sketch

Ralph Kirby is Professor of Microbiology at Rhodes University, Grahamstown, South Africa. He has held this position for the last ten years. He graduated with his B.A. at Trinity College, Cambridge, UK, in 1972, and completed his Ph.D. at the University of East Anglia, UK, in 1976. Post-doctoral research followed at the University of Bristol, UK, then a lectureship and senior lectureship at the University of Cape Town, South Africa. His major interests are the molecular genetics of Actinomycetes, horizontal gene transfer, molecular population genetics, and the interaction between law and science. He is presently completing a LL.B.

Timeline

Full Professor, Department of Life Science, National Yang-Ming University, Peitou, Taipei, Taiwan. 2003-onwards.

Full Professor, Department of Biochemistry, Microbiology and Biotechnology, Rhodes University, Grahamstown, South Africa. 1990-2003.

Senior Lecturer, Department of Microbiology, University of Cape Town, Rondebosch, Cape Town, South Africa. 1980-1989.

Postdoctoral Research Fellow, Department of Bacteriology, University of Bristol, Bristol, UK. 1975-1979.

John Innes PhD Studentship, Department of Genetics, John Innes Institute, Norwich, UK. 1972-1975.

Undergraduate, Trinity College, Cambridge, UK. , 1969-1972.

Qualifications

LLB (UNISA)	Intellectual Property and DNA Profiling in Criminal Procedure.
MA (Cantab)	Genetics.
PhD (UEA)	Genetic studies on Streptomyces coelicolor Plasmid One.
Pr. Nat. Sci.	Registered Professional Natural Scientist.
LLM (UNISA)	In Intellectual Property. Registered 2004-onwards.

Research Interests

Molecular Population Genetics

1) Molecular Microbial Ecology of Sulfate Reducing Bioreactor System.

2) Molecular Microbial Ecology of thermophilic Actinomycetes.

3) Molecular evolution of lignin degrading enzymes.

Actinomyces

1) Evolution, linear chromosomes and horizontal gene transfer in Actinomycetes.

2) Biotechnology application of lignin degrading enzymes from thermophilic Actinomycetes.

3) Genome scale analysis of various Streptomyces and the Actinomycetales using a Streptomyces coelicolor microarray.

4) Use of membrane bioreactors to produce Actinomycetes secondary metabolites.

5) Genome scale analysis of Streptomyces and related organisms using microarrays.

6) Development of a differential microarray between Streptomyces coelicolor A3(2) and Streptomyces.

Other

1) The law and molecular biotechnology.

Although Ralph Kirby has made a career as a full-time academic with research interests in genetics and Actinomycetes from PhD onwards, he have also had a long time interest in the law and is a qualified lawyer, although he does not practice. His legal interests revolve around DNA profiling in both criminal and civil cases as well as biotechnology as intellectual property and have involved both the academic aspects and court work. Also, he have been and am involved in a number of biotechnology start-up companies.