ORIGIN, ULTRASTRUCTURE AND FUNCTIONS OF MITOCHONDRIA

Dr. M. Roy

M.Sc. Sem-III
(2018-20)

MBOTCC-10
Unit-I

Introduction:

Mitochondria are cytoplasmic organelles of eukaryotic cells which act as the centres of intracellular energy transformations, and contain enzymes of the TCA cycle, respiratory electron transport chain and of oxidative phosphorylation as well as many others. They are characterized by a series of morphological, biochemical and functional properties.

Altman (1894) first of all described these structures as "bioblasts" while Benda (1897) proposed the term mitochondria. With diverse kinds of recent studies, mitochondria are known today as dynamic semiautonomous structures interacting extensively with other cellular structures.

Morphology, Size & Distribution:

(i) Dark field and phase contrast microscopy of living plant cells using the stain Janus Green B have revealed that mitochondria undergo considerable changes of shape as they move around by cytoplasmic streaming. They may be globular, cylindrical or branched.

(ii) Globular mitochondria have a diameter of 0.5 - 1.5 μm.
Cylindrical mitochondria have a size of 5 - 10 μm × 0.3 - 1.0 μm.

... Contd. p. 2

- In higher plant cells they are most commonly short rod-shaped.

(iii) Number of mitochondria per cell in higher plants: 100 - 1000 or even more depending on the size and type of cell.

(iv) In metabolically active cells (eg.; companion cells of phloem) about one fifth of the cytoplasmic volume is taken up by mitochondria.

(v) Some algae (e.g., Chlorella) and the Yeast (Saccharomyces) have one large mitochondrion per cell.

(vi) Ratio between mitochondrial and cytoplasmic volume is constant.

Mitochondrial Ultrastructure & Functional Attributes:

(i) Mitochondria are surrounded by a double-membraned envelope.

(ii) Inner membrane is thrown into a series of folds or invaginations known as cristae.

(iii) Cristae of many algae and fungi are tubular.

- A range of different shapes of cristae have been observed.
- Cristae of higher plant mitochondria are globular or plate-like structures.

(iv) Except at the points of cristae, there is an intermediate space of constant width (6-8 nm) between the two membranes known as perichondrial space, which is continuous with the intercristal space.

(v) Inner membrane divides the mitochondrion into two chambers or compartments:

(a) Outer chamber between the two

...Contd. p. 3

membranes and in the core of the cristae, and

(b) Inner chamber filled with a relatively dense finely granular proteinaceous matrix

(vi) Mitochondrial matrix contains two types of electron-dense particles — ribosomes and Ca-containing granules and a circular DNA.

(vii) Mitochondrial ribosomes are of 70S sedimentation constant composed of 50S and 30S subunits.

- Larger subunit contains at least two rRNA molecules, one of 23S and one of 5S, while the smaller subunit contains one rRNA molecule of 16S.
- All these rRNA molecules are coded by mitochondrial DNA.

(viii) Both subunits also contain a considerable number of different species of proteins, the majority of which are coded by nuclear DNA.

(ix) Ca-containing granules contain mainly Ca-phosphate.

- Calcium is taken into the mitochondria as Ca^{2+} ions in a process osmotically coupled to electron transport.
- This uptake of Ca^{2+} ions is accompanied by the uptake of equivalent amount of phosphate.

(x) Mitochondrial DNA comprises several copies of histone-free circular DNA molecules of 15,000 - 75,000 base pairs.

- They can code for 70-80 proteins each having 300 amino acids.
- Some of this DNA codes for ribosomal RNA.

(xi) Mitochondrial DNA does not have the capacity to code for the 100 or so different proteins estimated to be present in the mitochondria.

...Contd. p. 4

- Thus most mitochondrial proteins must be coded by nuclear DNA.

(xii) Mitochondrial matrix contains all the enzymes of TCA cycle with the exception of the flavoprotein succinate dehydrogenase, which is built into the inner surface of the inner membrane where it is folded into cristae.

- TCA cycle enzymes are structurally organized as a loose multienzyme complex in the matrix adjacent to the membrane-bound succinate dehydrogenase.

(xiii) Inner membrane, particularly the cristae, is characterized by the presence of stalked particles on the surface facing the matrix.

- These particles have a spherical head (diameter about 9 nm) linked to the membrane by a short stalk. They are part of a complex structural unit which contains an ATPase.

- ATPases are capable of catalyzing the hydrolysis of ATP to ADP and orthophosphate and the formation of ATP from ADP and orthophosphate.

- ATPase of the inner membrane has the latter function; it couples the electron flow down the respiratory ETC to the phosphorylation of ADP.

(xiv) The inner membrane in the cristae appears covered by particles of 8.5 nm that have a stem linking each with the membrane. These headpieces are called elementary particles or F_1 particles.

- F_1 particles consist of at least five different proteins.

- ATPase activity appears to be located in the two heaviest of these proteins. - The intramembrane part of the

... contd. p.5

complex is known as the F_o component and consists of at least four different proteins

– A further protein is required to bind F_1 to F_o and is presumably located in the stalk.

(xv) F_1 proteins are coded by nuclear DNA while the F_o proteins are coded by mitochondrial DNA.

(xvi) Components of the respiratory electron transport chain are built into the inner membrane as structural units.

– About 10% of the area of the inner membrane is taken up by these units.

(xvii) There are two NADH dehydrogenases both of which contain flavoproteins. One is located on the inner side of the membrane and catalyzes the oxidation of NADH produced in the mitochondrial matrix during TCA cycle, while the other is located on the outer face of the membrane and catalyzes the reoxidation of NADH produced outside the mitochondrion.

(xviii) TCA cycle enzyme succinate dehydrogenase (another flavoprotein) is located on the inner face of the inner membrane.

– These flavoproteins pass electrons via iron-sulphur proteins to ubiquinone which is probably located in the lipid core of the membrane.

(xix) Outer membrane of the mitochondrion has a higher lipid content than the inner and has a totally different component of enzymes.

(xx) Two mitochondrial membranes also have different permeability properties.

...Contd. p.6

– Outer membrane is freely permeable to low mol. wt. compounds and to several proteins while the inner membrane presents a barrier to many ions, low mol. wt. compounds and proteins and possesses specific trans-membrane transport systems.

Origin of Mitochondria :

(i) New mitochondria arise by division of the existing mitochondria.

(ii) Mitochondrial division follows their growth and differentiation.

(iii) It is possible that division is initiated when a critical DNA content is reached.

(iv) Division is accomplished by the invagination of the inner membrane.

– This invagination extends and eventually divides the matrix compartment into two distinct compartments both of which are enclosed within the same outer membrane. – A constriction then forms between the compartments and separation is ultimately achieved.

(v) The mechanism by which both daughter mitochondria receive nucleoid regions is not known.

(vi) The ultimate origin of mitochondria is an interesting question.

– It has been suggested that they evolved from symbiotic prokaryotic organisms. (Fig. – below)

—— X ——

Fig. 11–3. Three-dimensional diagram of a mitochondrion cut longitudinally. The main features are shown. Observe that the cristae are folds of the inner membrane and that on their matrix side they have the F_1 particles. The inset shows an F_1 particle with the head piece and stalk.