Extranuclear Inheritance

Organelle Heredity Involves DNA in Chloroplasts and Mitochondria
• Some observations indicate an apparent extranuclear influence on the phenotype.
• With the discovery of DNA in mitochondria and chloroplasts, extranuclear inheritance is now recognized as an important aspect of genetics.
1 - One variety of extranuclear inheritance is **organelle heredity**, in which DNA contained in mitochondria or chloroplasts determines certain phenotypic characteristics of the offspring.

2 - A second type involves infectious heredity, resulting from the **symbiotic or parasitic** association of a microorganism.
3 - The third variety involves the maternal effect on the phenotype, whereby **nuclear gene products** are stored in the egg and then transmitted to offspring from the female parent in the cytoplasm of the ovule.
Chloroplasts: Variegation in Four O’Clock Plants (Mirabilis jalapa)
<table>
<thead>
<tr>
<th>Source of Pollen</th>
<th>White branch</th>
<th>Green branch</th>
<th>Variegated branch</th>
</tr>
</thead>
<tbody>
<tr>
<td>White branch</td>
<td>White</td>
<td>Green</td>
<td>White, green, or variegated</td>
</tr>
<tr>
<td>Green branch</td>
<td>White</td>
<td>Green</td>
<td>White, green, or variegated</td>
</tr>
<tr>
<td>Variegated branch</td>
<td>White</td>
<td>Green</td>
<td>White, green, or variegated</td>
</tr>
</tbody>
</table>
• *Chlamydomonas* is an excellent model system for studying organelle heredity because it has a single large chloroplast that exhibits a uniparental inheritance pattern.
Organelle Heredity Involves DNA in Chloroplasts and Mitochondria

Chloroplast Mutations in Chlamydomonas

\[
\begin{align*}
\text{str}^R \text{ mt}^+ & \times \text{str}^S \text{ mt}^- \\
1/2 \text{ mt}^+ & \quad 1/2 \text{ mt}^- \\
\text{all str}^R
\end{align*}
\]

\[
\begin{align*}
\text{str}^S \text{ mt}^+ & \times \text{str}^R \text{ mt}^- \\
1/2 \text{ mt}^+ & \quad 1/2 \text{ mt}^- \\
\text{all str}^S
\end{align*}
\]
Organelle Heredity Involves DNA in Chloroplasts and Mitochondria

Mitochondrial Mutations: The Case of *poky* in *Neurospora*

Eterocarion
Suppressive mutation
Organelle Heredity Involves DNA in Chloroplasts and Mitochondria

Normal colonies

Petite colonies
Segregational

Haploid petite × Haploid normal → Diploid zygote (normal) → Sporulation, meiosis → Haploid ascospores

petites normals

Neutral

Haploid petite × Haploid normal → Diploid zygote (normal) → Sporulation, meiosis → Haploid ascospores

All normal

Suppressive

Haploid petite × Haploid normal → Diploid zygote (usually petite) → Sporulation, meiosis → Haploid ascospores

All petite
Knowledge of Mitochondrial and Chloroplast DNA Helps Explain Organelle Heredity

Organelle DNA and the Endosymbiotic Theory
• The endosymbiotic theory states that mitochondria and chloroplasts arose independently about 2 billion years ago from free-living bacteria that possessed the abilities now attributed to these organelles—aerobic respiration and photosynthesis, respectively.
Origin of extranuclear genes

Generally believed

‘Endosymbionts’

Lost

Integration

Most modern eukaryotic cells

Fully dependent on the organelle genes for their normal function

cf.) The yeast, ‘Saccharomyces cerevisiae’

Without mitochondria → obtain energy from fermentation
• These bacteria were engulfed by larger eukaryotic cells, and a beneficial symbiotic relationship developed.

Chloroplast DNA ranges from 100 to 225 kb in length, and the genes carried on the DNA encode products involved in photosynthesis and translation.
• Mitochondrial DNA (mtDNA) is smaller than the DNA in chloroplasts, and introns are absent. Most of the protein encoding genes are located on a single strand.
<table>
<thead>
<tr>
<th>Organisms</th>
<th>Size (kb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>16.6</td>
</tr>
<tr>
<td>Mouse</td>
<td>16.2</td>
</tr>
<tr>
<td><em>Xenopus</em> (frog)</td>
<td>18.4</td>
</tr>
<tr>
<td><em>Drosophila</em> (fruit fly)</td>
<td>18.4</td>
</tr>
<tr>
<td><em>Saccharomyces</em> (yeast)</td>
<td>75.0</td>
</tr>
<tr>
<td><em>Pisum sativum</em> (pea)</td>
<td>110.0</td>
</tr>
<tr>
<td><em>Arabidopsis</em> (mustard plant)</td>
<td>367.0</td>
</tr>
</tbody>
</table>
Structure of organelle chromosomes

How many copies?

**Nuclear chromosome**: 1 copy / cell (haploid)
2 copy / cell (diploid)

**Organelle chromosome**: ~00~x,000 copy/ cell

* regulation of copy number is relatively loose

ex.) Chloroplast: Leaf cells of the garden beet

~ 40 chloroplast / cell
4 ~ 8 nucleoids / chloroplast

(nucleoid: Specific heavily DNA area in chloroplast)

4 ~ 18 cpDNA molecules / nucleoid

MAX : 40 x 8 x 18 = 5760 copy of cpDNA / cell

Chlamydomonas

1 chloroplast / cell → 500 ~ 1500 cpDNA molecules
How many copies?

ex.) Mitochondria : haploid yeast

1 ~ 45 mitochondria / cell
10 ~ 30 nucleoids / mitochondria
4 ~ 5 mtDNA molecules / nucleoid
MAX : 45 x 30 x 5 = 6750

Human

2 ~ 10 mtDNA mol. / mitochondria

Fluorescent staining of a cell of *Euglena gracilis.*
Some of the proteins: ~ oxidative phosphorylation

tRNA, rRNAs, some proteins: ~ mitochondrial protein synthesis

(some genes are encoded in nucleus)

mRNA is translated outside the mitochondria on cytosolic ribosomes

Synthesized proteins are transported into the mitochondria

Complete system is assemble in mitochondrial inner membrane

The mitochondrial respiratory chain.

Red: Nuclear DNA-encoded subunits

Green: mtDNA-encoded subunits

Structure of organelle chromosomes

Mitochondrial genomes

Function
Mitochondrial genomes

Structure of organelle chromosomes

The genetic code of the human mitochondria.

22 tRNA types by the 22 boxes that do not contain stop codons

<table>
<thead>
<tr>
<th>First letter</th>
<th>Second letter</th>
<th>U</th>
<th>C</th>
<th>A</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ile (Met)</td>
<td>Thr</td>
<td>Phe</td>
<td>Ser</td>
<td>Tyr</td>
<td>Cys</td>
</tr>
<tr>
<td>Ile</td>
<td>Asn</td>
<td>Phe</td>
<td>Ser</td>
<td>Tyr</td>
<td>Cys</td>
</tr>
<tr>
<td>Ile (Ile)</td>
<td>Thr</td>
<td>Leu</td>
<td>Ser</td>
<td>Stop</td>
<td>Trp</td>
</tr>
<tr>
<td>Met (Ile)</td>
<td>Asn</td>
<td>Leu</td>
<td>Ser</td>
<td>Stop</td>
<td>Trp</td>
</tr>
<tr>
<td>Ile</td>
<td>Lys</td>
<td>Arg</td>
<td>Pro</td>
<td>Arg</td>
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<tr>
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<td>Val</td>
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<td>Val</td>
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<td>Asp</td>
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<td>Asp</td>
<td></td>
</tr>
</tbody>
</table>

Differ with nuclear code
Mitochondrial genomes

Yeast

The intron in several mitochondrial gene

Ex.) Subunit I of cytochrome oxidase - 9 introns
nuclear gene - rare intron

The existence of unassigned reading frames (URFs) within the yeast intron

* URF - sequences that have correct initiation codons & are uninterrupted by stop codons
* some URF - important in the splicing out of the introns themselves at the RNA level ∴ Specifying proteins

Human

Much smaller & more compact than yeast mtDNA

>> much less spacer DNA
Chloroplast genomes

cpDNA: 120 ~ 200 Kb in different species

ex.) Liverwort Marchantia: 136 genes

- 4 kinds of rRNA
- 31 kinds of tRNA
- 90 proteins (20: photosynthesis & electron-transport functions)
- half the chloroplast genome: relate with translational function

Large inverted repeats of virtually all species of plants

(the sequences of the repeats are same!)

Like mtDNA, cpDNA cooperates with nuclear DNA to provide subunits for functional proteins
Mutations in Mitochondrial DNA Cause Human Disorders
Mutations in Mitochondrial DNA Cause Human Disorders

• **Heteroplasmmy** is the condition in which a deleterious mutation arises in an organelle, such that an adult will have cells with a variable mixture of normal and abnormal organelles.
• For a human disorder to be attributed to mitochondrial DNA, the inheritance must exhibit a maternal inheritance pattern, the disorder must reflect a deficiency in the bioenergetic function of the organelle, and there must be a specific mutation in a mitochondrial gene.
• Three disorders arising from mtDNA are myoclonic epilepsy and ragged red fiber disease (MERRF), Leber’s hereditary optic neuropathy (LHON), and Kearns–Sayre syndrome (KSS).
The study of hereditary mitochondrial-based disorders provides insights into the critical importance of this organelle during normal development, as well as the relationship between mitochondrial function and neuromuscular and neurological disorders.
Mitochondria and aging

Wear-and-tear theory

: one of the theories of the mechanism of aging

Aging process

Mitochondria - Reduction in oxidative phosphorylation
Accumulation of deletion and point mutations

Mitochondria replacement: Age dependent correlation in oxidative phosphorylation

Ex...

A ages

B ages

mtDNA

A ages
Infectious Heredity Is Based on a Symbiotic Relationship between Host Organism and Invader Kappa in *Paramecium*
CO$_2$ sensitivity: Affected flies do not recover normally from CO$_2$ anesthesia. They become permanently paralyzed and die.

Madri suscettibili passano questo carattere a tutta laprogenie.

The condition is due to a sensitivity to a virus, **sigma**.
Sex ratio: **Affected flies** produce predominantly female offspring if reared at 21°C or lower. The condition is transmitted only to daughters, not to the small number of males produced.

The responsible element is a **protozoan**. When ooplasm from affected individuals or the protozoan itself is injected into oocytes of normal individuals, the temperature-sensitive, altered sex ratio condition results.
In Maternal Effect, the Maternal Genotype Has a Strong Influence during Early Development
Maternal effect implies that an offspring's phenotype is under the control of nuclear gene products present in the egg. These factors influence patterns established early in development. For maternal effect genes, the genotype of the female parent and not that of the embryo determines the phenotype of the offspring.
Pigmentation in *Ephestia*

Eye

---

**Aa** ♂ brown × **aa** ♀ red

- **Aa** ♂ and ♀ brown
- **aa** ♂ and ♀ red

---

**Aa** ♀ brown × **aa** ♂ red

- **Aa** ♂ and ♀ brown
- **aa** ♂ and ♀ brown
La spiralizzazione in Limnea
Figure 9-13-02  Copyright © 2006 Pearson Prentice Hall, Inc.
The gene \textit{bicoid} (\textit{bcd}) is a gene that is involved in creating the anterior portion of the developing embryo. Embryos that are \textit{homozygous} for a mutation in this gene fail to develop the embryonic portions that give rise to the head and thorax.

Embryos whose mothers contain at least one wild-type allele develop normally, even if the genotype of the embryo is homozygous for the mutation.
Anterior Formation

Bicoid protein accumulates in what will be the anterior portion of the embryo.
If the protein is not produced, the head/thorax structures will not form.
Il seguente albero genealogico raffigura una famiglia in cui diversi individui presentano i sintomi della malattia mitocondriale detta MERRF. Un fratello e una sorella (II-5 e II-2) si rivolgono a voi per sapere se anche i loro figli saranno affetti da MERRF. Cosa rispondete?
Sulla base di questo albero filogenetico (analizzando il DNA mitocondriale), cosa concludete relativamente alla potenziale ibridazione interspecifica tra lupi e coyote?