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The Tiny Genome That Powers Life

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Abstract:

The mitochondrial genome (mitogenome) is a small, circular, double-stranded DNA molecule that is maternally inherited and lacks recombination, making it an ideal marker for studying evolutionary genetics, population structure, and phylogenetic relationships. Its high mutation rate though relatively constant over evolutionary time, allows for the tracing of maternal lineages and the reconstruction of demographic histories. The mitogenome's compact size and high copy number per cell facilitate sequencing and analysis even from degraded or low-quality samples. Importantly, because mitochondria are inherited solely from the mother, the mitogenome provides a clear, non-recombining record of maternal ancestry, free from the complexities of biparental inheritance. Mitogenome is considered a powerful material for phylogenetic studies because of its small size, lack of recombination, and lack of repair mechanisms. Mitogenome is typically circular double-stranded DNA molecule, 16-kb long and encodes 37 genes in mammals. It also has a massive copy rate compared to the nuclear genome, and its maternal inheritance pattern precludes recombination, with the result of that the sequence of the mitogenome is usually stable through generations. In future, Mitogenome research will be crucial to conservation genetics as it will aid in the identification of endangered lineages and provide direction for methods to maintain genetic variety. As genomic databases continue to expand deeper understanding of an organism's evolutionary history and capacity for adaptation will be possible through the integration of nuclear genomic data with mitogenome information.

Keywords: Ancestry, Mitogenome, Phylogenetic, Recombination

Introduction:

Deep inside each of our cells is a microscopic energy factory. This factory comes with its own instruction manual, a compact, circular genome that works independently from the DNA in the nucleus.

This is the mitogenome, a small yet influential genetic system that fuels life and reveals clues about ancestry, diversity, and biological organization.

Mitochondrion is commonly referred to as the Power house of cell. This power house has got its own genome called the mitogenome or mitochondrial genome (Mt DNA). It was discovered in the 1963 by Margit M. K. Nass and Sylvan Nass by electron microscopy as DNase-sensitive threads inside mitochondria.

Mitogenomics is the study of mitochondrial genomes (mitogenomes) using genome scale sequencing and bioinformatic techniques. It involves assembling and analysing the complete mitochondrial DNA of organisms.

What Does the Mitogenome Contain?

The mitochondrial genome is a small, circular DNA molecule of approximately 16–17 kb in mammals and typically encodes 37 genes, including 13 protein-coding genes, 22 transfer RNA genes, and 2 ribosomal RNA genes, along with a non-coding control region.

All of these genes contribute to the process of cellular respiration, the chemical pathway that generates ATP, the energy currency of the cell.

Characteristics of Mitogenome:

- Mitochondrial DNA is maternally inherited in most species and the first evidence for uniparental, maternal inheritance of mtDNA in animals was provided by David & Blackler in 1972.
- Mitogenome is typically circular double-stranded DNA molecule and has a massive copy rate compared to the nuclear genome, and its maternal inheritance pattern precludes recombination, with the result the sequence of the mitogenome is usually stable through generations.
- It evolves faster than nuclear DNA and has a very high mutation rate.
- Generally mitochondrial DNA does not recombine.
- Presence of variable and conserved region within same molecule, rapid evolution but at a constant rate makes mtDNA an ideal genetic marker.

Comparison of Mitogenome with Nuclear Genome:

- Size of nuclear DNA is approximately 3.2 billion base pairs while as that of mtDNA is around 16 thousand base pairs.
- Nuclear DNA contains around 20000 genes while mtDNA contains around 37 genes in most species.
- Nuclear DNA is inherited both maternally and paternally in contrast to mtDNA which has only maternal inheritance.

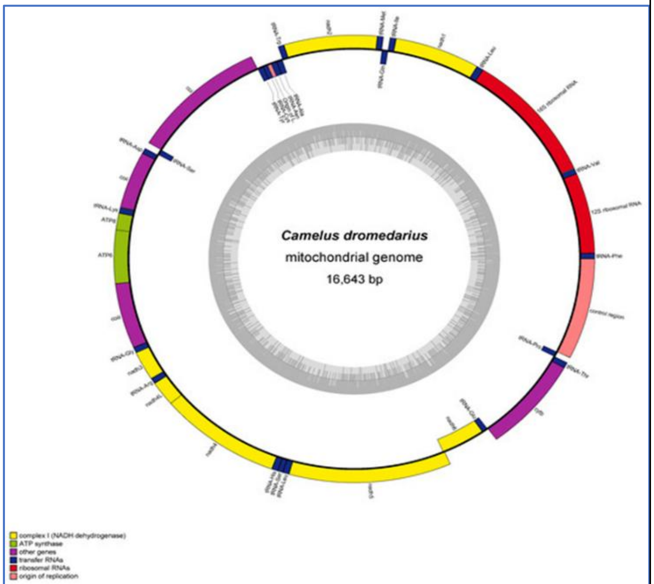

Figure 1: Organization of the complete mitogenome of *Camelus dromedarius* (Arabian camel) (Manee *et al.*, 2024)

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- Nuclear DNA is linear while as mtDNA is circular in structure.
- There is a single copy of nuclear DNA in a cell while as there are 100-1000s of copies of mtDNA per cell.
- Nuclear DNA possesses introns but there are no introns in mtDNA.

A Special Pattern of Inheritance:

One of the most remarkable features of mitochondrial DNA is how it is inherited. Unlike nuclear DNA, which comes from both parents, mitochondrial DNA is passed down almost exclusively from the mother.

This happens because during fertilization, the egg contributes most of the cellular material including the mitochondria to the developing embryo. As a result, mitochondrial DNA follows a clear maternal lineage across generations.

This unique inheritance pattern makes the mitogenome especially useful for studying ancestry, genetic diversity, and population history. By examining mitochondrial DNA, scientists can trace maternal lines far back in time.

In simple terms, mitochondrial DNA connects directly to maternal ancestors.

Why do we study Mitogenome?

a) **Evolutionary studies:**

Mitochondrial DNA (mtDNA) is considered an ideal marker, being extremely mutable within species and has been used to study demographic expansion, genetic diversity and phylogenetic structure.

b) **Maternal lineage tracing:**

Mitogenome has a massive copy rate compared to the nuclear genome, and its maternal inheritance pattern precludes recombination, with the result that to the sequence of the mitogenome is usually stable through generations and thus useful in maternal lineage tracing.

c) **Identification of genetic disorders:**

Some genetic disorders are linked to mutations in the mitochondrial genome. By sequencing mtDNA, breeders can identify these mutations and make informed decisions to avoid passing on these disorders to future generations.

d) **Understanding ecological speciation:**

Mitogenomes can reveal signals of reproductive isolation and adaptive divergence in response to environmental pressures.

e) **Detection of introgression and migration:**

Unidirectional gene flow via maternal lines can be traced through mitogenome haplotypes.

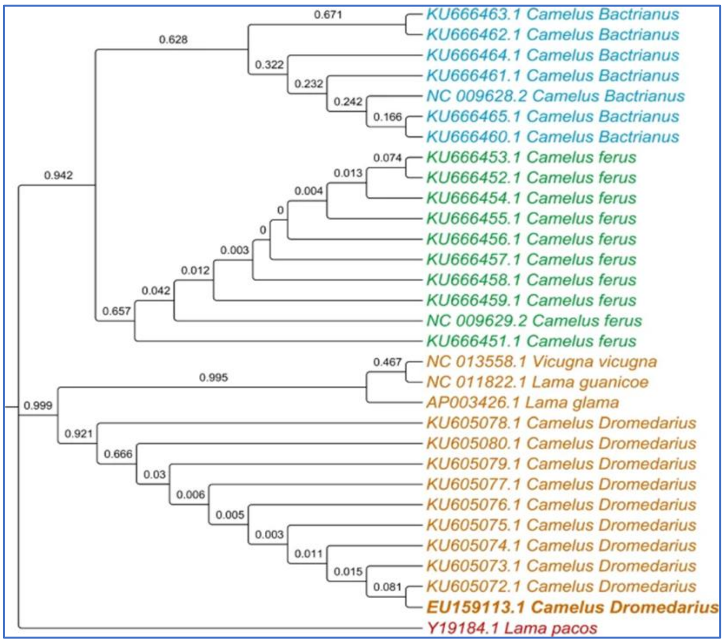

Figure 2: Maximum likelihood phylogenetic tree based on intergenic regions from the mitochondrial genomes of seven camelid species. *C. dromedarius* mitogenome (EU159113) is denoted in bold (Manee *et al.,* 2019)

Conclusion:

Despite being tiny in comparison to the enormous nuclear genome, the mitochondrial DNA is crucial for sustaining life and maintaining a distinct genetic heritage. It is one of the most intriguing parts of the cell because of its small size, maternal inheritance, and crucial function in energy generation. The mitogenome serves as a reminder that even the tiniest components may have the biggest effects in the complicated field of genetics.

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