Inheritance of mitochondrial and chloroplast DNA

Mitochondrial and chloroplast DNA and why its inheritance does not follow Mendelian patterns

Introduction

If you were asked to name the organelle that contains DNA, what would you say? If you said the nucleus, you'd definitely get full points, but the nucleus is not the only source of DNA in most cells.

Instead, DNA is also found in the mitochondria present in most plant and animals cells, as well as in the chloroplasts of plant cells. Here, we'll explore how mitochondrial and chloroplast DNA are inherited.

Mitochondrial and chloroplast DNA.

The DNA molecules found in mitochondria and chloroplasts are small and circular, much like the DNA of a typical bacterium. There are usually many copies of DNA in a single mitochondrion or chloroplasts.

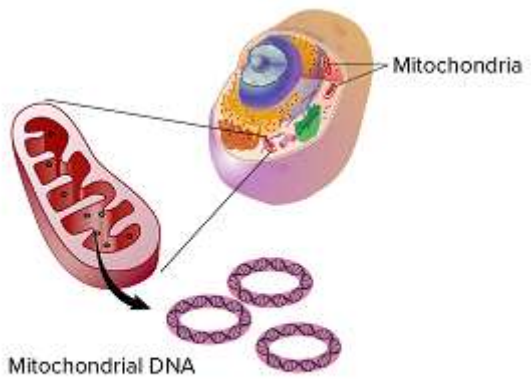


Image modified from "Mitochondrial DNA," NIH Talking Glossary of Genetic Terms, NHGRI (public domain).

Similarities between the DNA of mitochondria and chloroplasts and the DNA of bacteria are an important line of evidence supporting the endosymbiont theory, which suggests that mitochondria and chloroplasts originated as free-living prokaryotic cells.

Here are some ways that mitochondrial and chloroplast DNA differ from the DNA found in the nucleus:

High copy number. A mitochondrion or chloroplast has multiple copies of its DNA, and a typical cell has many mitochondria (and, in the case of a plant cell, chloroplasts). As a result, cells usually have many copies – often thousands – of mitochondrial and chloroplast DNA.

Random segregation.

Mitochondria and chloroplasts (and the genes they carry) are randomly distributed to daughter cells during mitosis and meiosis. When the cell divides, the are the copies identical within a single organelle? Organelles that happen to be on opposite sides of the cleavage furrow or cell plate will end up in different daughter cells.

Single-parent inheritance. Non-nuclear DNA is often inherited uni-parentally, meaning that Off-spring get DNA only from the male or the female parent, not both. In humans, for example, children get mitochondrial DNA from their mother (but not their father).

Chloroplast inheritance: Early experiments

At the turn of the 20th century, Carl Correns, a German botanist, did a series of genetic experiments using four o'clock plants (Mirabilis jalapa). We now know that his work demonstrated how chloroplast DNA is passed on from cell to cell and from parent to offspring—though Correns himself didn't know it at the time!

Correns' experiments

The Mirabilis plants that Correns worked with came in three types: pure green, pure white, or variegated (mottled green and white). Green and white branches could appear on variegated plants, but variegated branches did not appear on green or white plants. Correns was curious about this coloration trait, and he carried out a number of crosses between plants of different colours. He found that:

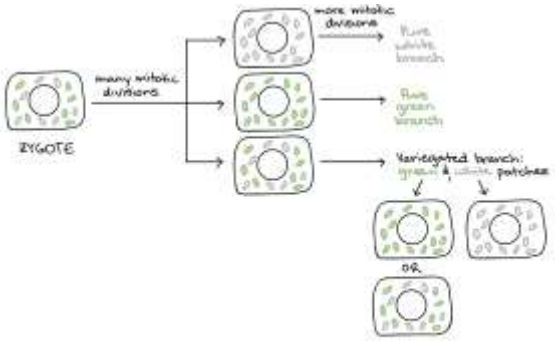
The colour of the egg cell-donating branch (female parent) determined the colour of the offspring.

Female parent branches that were pure green or pure white produced only pure green or pure white offspring, respectively. Female parent branches that were variegated could produce all three types of offspring, but not in any predictable ratios.

Correns speculated that some factor in the cytoplasm of the egg cell must determine the colour of the offspring. It was actually a different German botanist, Erwin Baur, who suggested that the chloroplasts in the cytoplasm might carry hereditary factors (genes). Baur thought that, in variegated plants, some of the chloroplasts must have mutations that made them unable to turn green (produce pigment). Today, we know that this hypothesis was exactly right!

Explaining Correns' results

How can the idea of chloroplast inheritance make variegated plants variegated? Let's follow a zygote

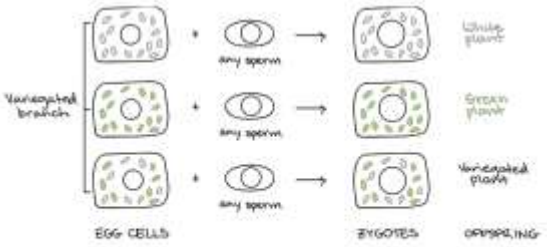


Based on similar diagram found in Griffiths et al.[7].

(1-celled embryo) with mixture of chloroplasts inherited from the egg cell. Some of the chloroplasts are green, while others are white. As the zygote undergoes many rounds of mitosis to form an embryo and then a plant, the chloroplasts also divide and are distributed randomly to daughter cells at each division.

Over the many cell divisions, some cells will end up with a pure set of normal chloroplasts, making green patches). Others will get a pure set of non-functional chloroplasts (making white patches). Others yet will have a mix of normal and non-functional chloroplasts, producing green patches that may give rise to pure green or pure white sectors.

What about the maternal pattern of inheritance? Plants make germ cells late in development,



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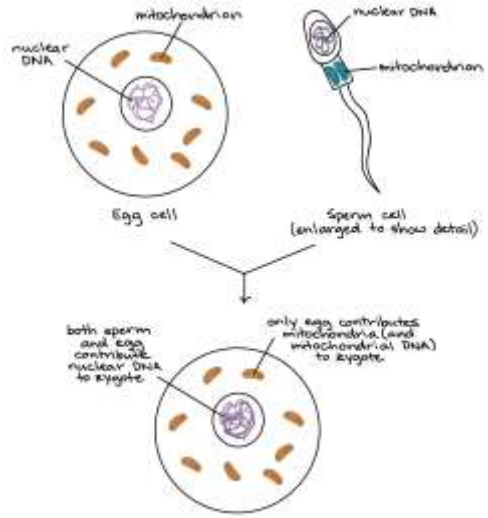
converting cells at the tip of a branch into gamete-producing cells. A branch that's pure green will make egg cells with green chloroplasts that give rise to pure green offspring. Similarly , a branch that' s pure white will make egg cells that contain only white chloroplasts and will give rise to pure white offspring. If a branch is variegated, it has a mixture of cells, some with only functional chloroplasts, some with only non-functional chloroplasts, and some with a mixture of chloroplasts. All three of these cell types may give rise to egg cells, leading to the green offspring, white offspring, and variegated offspring in unpredictable ratios.

Mitochondrial inheritance

Mitochondria, like chloroplasts, tend to be inherited from just one parent or the other (or at least, to be unequally inherited from the two parents). In the case of humans, it is the mother who contributes mitochondria to the zygote, or one-celled embryo, by way of the egg's cytoplasm. Sperm do contain mitochondria, but they are not usually inherited by the zygote. There has been a reported case of paternal inheritance of mitochondria in a human, but this is extremely rare.



Maternal inheritance of mitochondria in humans Because mitochondria are inherited from a person's mother, they provide a way to trace matrilineal ancestry (line of descent through an unbroken chain of female ancestors).

To understand how mitochondria connect you to your mother's foremothers, consider where your mitochondria came from. They were received from your mother, in the cytoplasm of the egg cell that gave rise to you. Where did your mother get her own mitochondria? From her mother, that is, your maternal grandmother.

If you keep asking this question, you can walk backward in time through your family tree, following your matrilineal ancestors and tracing the transmission route of your mitochondrial DNA.

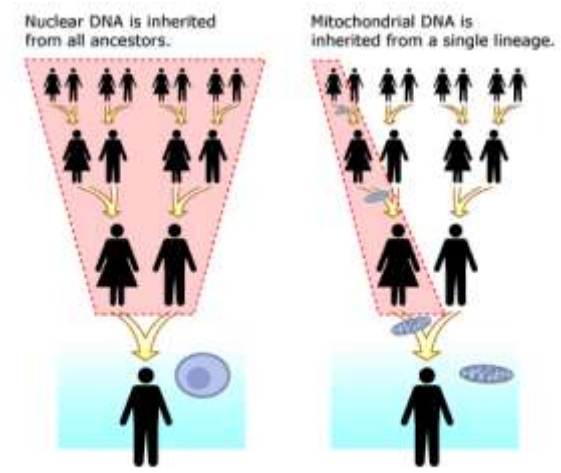


Image credit: "Mitochondrial DNA vs. nuclear DNA," by University of California Museum of Paleontology (CC BY-SA 3.0).

As shown in the diagram above, the inheritance pattern of mitochondrial DNA is different from that of nuclear DNA. A person's nuclear DNA is a "patchwork" of segments inherited from many different ancestors, while a person's mitochondrial DNA is inherited through a single, unbroken line of female ancestors.

Mitochondrial mutations and human disease

Mutations in mitochondrial DNA can lead to human genetic disorders. For example, large deletions in mitochondrial DNA cause a condition called Kearns Sayre syndrome. These deletions keep the mitochondria from doing their job of extracting energy. Kearns-Sayre syndrome can cause symptoms such as weakness of the muscles, including those that control eyelid and eye movement, as well as degeneration of the retina and development of heart disease. Genetic disorders caused by mitochondrial mutations are not transmitted from fathers to children, because mitochondria are provided only by the mother. Instead, they are transmitted from mothers to children in one of the following ways:

A person with a disease caused by a mitochondrial mutation may lack normal mitochondria (and have only abnormal, mutation-bearing ones). In this case, an affected mother will always pass on mutation-bearing mitochondria to her children. A mitochondrial disorder may occur when a person has a mix of normal and abnormal mitochondria her body. In this case, normal and mutation bearing mitochondria may go randomly into eggs during meiosis. Children who get a large proportion of mutant mitochondria may have severe disease, while those with few mutant mitochondria may have mild or no disease.

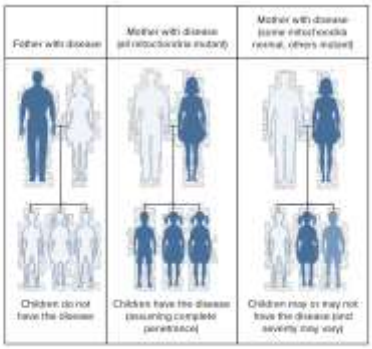


Image modified from "Mitochondrial," by the National Institutes of Health (public domain).