GENERAL

From Telomeres to Time, The Molecular Science of Aging

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Aging is universally experienced and biologically mysterious. This has fascinated scientists, philosophers, and physicians for centuries. In developmental biology, aging is termed as ***senescence***, which shows gradual decline of physiological function leading to increased vulnerability and ultimately death. But what causes this decline? Is aging programmed into our genes, or is it an accumulation of damage over time?

What is Senescence?

It refers to the progressive deterioration of biological functions. It occurs at nearly all organisms and affect cells, tissues, and organs. From wrinkled skin to decreased immunity, these are visible signs of molecular changes happening beneath the surface.

Types of Senescence:-

1. Cellular senescence: when individual cells stops dividing and enter a state of permanent growth arrest.
2. Organismal senescence: The overall aging of an organism, involving system-wide changes in physiology and function.

Now, big question arises that ***" Why do we Age? "***

Over times, biologists and researchers have proposed several theories that explain why aging occurs. **These fall broadly into two main categories:-**

Genetic Theories :-

There theory says that aging is pre-programmed by our genes, much like development itself. It may serve evolutionary purpose such as :-

- ***Limiting lifespan*** to avoid overpopulation
- ***Allowing younger, genetically diverse individuals to thrive.***
- Examples: Telomere shortening, the Hayflick limit (cell division cap), and age-regulated genes.

Stochastic Theories :-

This theory propose that aging is caused by random, cumulative damage to cells and molecular over time. This damage exceeds the body's repair capacity and results in:-

- Mutations
- Oxidative stress
- Protein misfolding
- Mitochondrial dysfunction

Most scientists have believe that aging results from a ***combination of genetic programming and accumulated damage.***

Cellular Mechanisms of Aging

Telomere Shortening

- Telomeres protects the chromosome ends but shorten with each cell division.
- When too short, cells stops to divide.
- Telomerase , an enzyme that replenishes telomeres sequences and is usually inactive in most somatic cells.

DNA Damage and Repair Decline

- cells accumulates and mutations happens.
- The efficiency of DNA repair mechanisms decreases, increasing the risk of diseases like cancer.

Mitochondrial Dysfunction

- Mitochondria generate energy but also produce harmful ***Reactive oxygen species (ROS)***
- ROS damages the cellular components and accelerating aging.

Senescence-Associated Secretory Phenotype (SASP)

- Senescent cells secrete inflammatory signals and affects the neighbouring cells.
- SASP contributes to tissue degeneration and chronic inflammations.

How Aging can causes systemic changes to our whole body :-

- **Immune system :** It shows weakened response and causes more infections.
- **Musculoskeletal :** Muscle loss (sarcopenia), bone thinning
- **Cardiovascular system :** Arteries gets stiffs and causes high blood pressure.
- **Nervous system :** Shows slower reflexes , cognitive decline
- **Skin :** Less elasticity, wrinkles and pigmentation

Can Aging be Slowed or Reversed ?

Aging is the process where it cannot be entirely stopped, but science is exploring different ways to manage its effects. That includes:-

- **Caloric restriction :** Shown to extend lifespan in animals.
- **Antioxidants :** Helps to neutralize ROS
- **Genetic interventions :** Modifying the age-related genes (e.g., FOXO, sirtuins).
- **Senolytics :** Drugs that target and eliminate senescent cells.

Evolutionary Perspective of Aging :-

- Natural selection acts strongly on traits affecting early-life reproduction.
- Traits that causes aging may persist, as their effects manifest after reproduction. This is known as antagonistic pleiotropy theory where the genes beneficial in youth and may be harmful in old age.

CONCLUSION

Aging is a natural part of development biology and the final stage of life cycle. It is a result of same genetic and cellular machinery that builds and maintains us through youth. Understanding the biology of senescence does not help us extend life ; it help us enrich the quality of the lives we already live gracefully, meaningfully, and with awareness of the science within.

Competing interests

The authors declare that they have no competing interests.

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