Scientific Research Publishing

Advances in Aging Research, 2026, 15(2), 13-20
https://www.scirp.org/journal/aar
ISSN Online: 2169-0502
ISSN Print: 2169-0499

The Evolution of Aging: Implications for Human Health and Geriatric Research

Rebecca Yeboah, Philip Appiah

Department of Biological Sciences, Western Illinois University, Macomb, Illinois, USA
Email: rebeccayeboah21@gmail.com

How to cite this paper: Yeboah, R. and Appiah, P. (2026) The Evolution of Aging: Implications for Human Health and Geriatric Research. *Advances in Aging Research*, **15**, 13-20.
https://doi.org/10.4236/aar.2026.152002

Received: March 2, 2026
Accepted: March 27, 2026
Published: March 30, 2026

Abstract

Aging, or senescence, varies markedly among living organisms. Some experience progressive physiological decline while others show negligible or negative senescence. This review examines diverse aging patterns across taxa, focusing on evolutionary mechanisms such as antagonistic pleiotropy and mutation accumulation. We argue that extrinsic mortality-death caused by environmental factors such as predation and accidents rates, shapes the force of natural selection across all ages, resulting in different evolutionary trajectories of senescence. Fitness, which is defined as an individual's ability to survive and reproduce, declines with age in most species. Negative senescence, referring to improved fertility or survival with age, is however, observed in a minority of taxa. Importantly, this review highlights the relevance of these evolutionary theories to human geriatric research, including potential therapeutic interventions.

Keywords

Senescence, Lifespan, Accumulation, Extrinsic Mortality, Fitness, Negative Senescence, Mutation Accumulation, Antagonistic Pleiotropy, Geriatric Relevance, Gene Editing, Telomerase

1. Introduction

Aging refers to the progressive decline of physiological functions over time [1]. Although aging is common across many species, it is not a universal phenomenon [2]. Some organisms show little or no physiological deterioration with age, while others, including humans, experience significant decline in fitness. This variation raises key questions that this review addresses: Why do some species "age" while others do not? Why do mammals, particularly humans, experience progressive health decline? And if natural selection improves survival and reproduction, why does aging evolve at all? This review focuses on applying evolutionary theories of aging to the context of human geriatric circumstances.

2. History of the Concept of Aging

In 1891, August Weismann proposed that aging eliminates worn-out members from a population [3]. Later, Fisher and Haldane argued that aging arises because natural selection has a weaker impact on survival and reproduction at old age [4] [5]. Hamilton, Medawar, Rose, and Williams extended these ideas, emphasizing that extrinsic mortality weakens selection against late-acting deleterious mutations [6] [7]. By the mid-20th century, evolutionary biologists formulated a theory of aging based on population genetics: the force of natural selection declines with age, allowing deleterious mutations that manifest later in life to accumulate [1] [8]. Thus, aging is not an adaptive benefit to species but a non-adaptive consequence of declining selection efficacy with age [8] [9].

3. Is the Concept of Aging Universal?

Patterns of aging differ across species. Some show clear senescence, others negligible senescence (little or no decline of fitness), and a few exhibit negative senescence (improved performance with age) [10]. For example, the aquatic cnidarian *Hydra* displays negligible senescence under laboratory conditions [11]. About 95% of angiosperms show no clear signs of aging, and many trees live for centuries [12]. Aging tends to evolve in species with a clear germline-soma distinction and age structure [13]. Thus, aging is not a universal phenomenon [2].

4. Mechanisms of Aging

The evolutionary theory of aging is founded on three fundamental mechanisms: mutation accumulation, antagonistic pleiotropy, and the disposable soma theory [8] [14]. Together, these mechanisms provide complementary explanation for why senescence evolves. Mutation accumulation and antagonistic pleiotropy describe how genetic variants with late-life costs can persist in populations. The disposable soma-theory adds a resource-allocation logic: because natural selection prioritizes early reproduction over indefinite somatic maintenance, organisms are evolutionarily constrained from investing fully in repair, allowing damage to accumulate with age. A summary of these three mechanisms and their relevance to human geriatric research is provided below (see **Table 1**).

Table 1. Summary of evolutionary mechanisms of aging.

Mechanism	Key Proponent	Core Idea	Human Geriatric Relevance
Mutation Accumulation	Medawar (1952)	Accumulation of late-acting deleterious mutations	Explains late-onset genetic diseases (e.g., Huntington's)
Antagonistic Pleiotropy	Williams (1957)	Early benefits, late costs	Genes for inflammation may protect infection in youth but drive diseases like arthritis in old age

Continued

Disposable Soma Theory	Kirkwood (1977)	Trade-off between reproduction and repair	Caloric restriction mimics resource allocation to repair

4.1. Mutation Accumulation

Proposed by Medawar (1952), this mechanism argues that rare, deleterious mutations accumulate at higher frequencies because natural selection weakens with age [15]. Medawar defined aging as a change in the faculties and senses of the body that renders the individual more likely to die from extrinsic or accidental causes. Because hereditary factors express themselves at a certain age, natural selection tends to postpone the expression of unfavorable conditions to later in life [16]. Importantly, this evolutionary argument is distinct from the proximate cellular processes that accompany aging, such as the buildup of damaged tissues, chronic inflammation, or impaired immune clearance. While these cellular phenomena may result from mutation accumulation, it is not the mechanism itself but rather its physiological consequences.

4.2. Antagonistic Pleiotropy

Williams came up with the mechanism of antagonistic pleiotropy [3], which occurs when a single gene has multiple effects, enhancing fitness early in life but reducing it later. Such alleles are favored because early benefits outweigh late costs [3]. For example, cellular senescence aids wound healing early in life but later contributes to pro-inflammatory states [3] [17]. In humans, this mechanism helps explain why genes that promote reproductive fitness may also predispose individuals to age-related diseases such as cancer or neurodegeneration [18].

4.3. The Disposable Soma Theory

The disposable soma theory, proposed by Thomas Kirkwood, suggests that organisms encounter a trade-off in allocating limited metabolic resources between reproduction and somatic maintenance [19]. It predicts a decrease in investment in somatic maintenance after reproductive events and explains a gradual decline in physiological functions over time [19]. Because extrinsic mortality ensures that no individual lives indefinitely, natural selection tends to invest resources into early reproduction rather than costly, long-term somatic repair [19]. Consequently, somatic tissues accumulate damage over time, leading to aging. This theory complements mutation accumulation and antagonistic pleiotropy by explaining why maintenance is evolutionarily limited.

5. Empirical Validation: Cross Species and CRISPR Evidence

Recent comparative studies across species have quantified the relationship between extrinsic mortality and senescence. Species with higher extrinsic mortality (e.g., small fish, rodents) exhibit rapid senescence with mortality rates exceeding 50%, while species with low extrinsic mortality (e.g., elephants) exhibit slower ag-

ing [20] [21]. Bats provide a particularly striking case: despite their small body size, many bat species have very low extrinsic mortality due to flight and nocturnal habits, and they exhibit exceptional longevity—some live up to 40 years with minimal age-related decline. Comparative genomics has revealed that long-lived bats have evolved enhanced DNA repair pathways and reduced inflammatory signaling, consistent with the disposable-soma theory's prediction that reduced extrinsic mortality favors investment in somatic maintenance [21].

While comparative studies reveal correlations, CRISPR-Cas9 gene editing has enabled direct, causal tests of genes known to mediate trade-offs between early fitness and late-life decline. For example, CRISPR-mediated knockdown of IGF-1R in mice extends lifespan, supporting antagonistic pleiotropy [22]. These experiments provide stronger causal evidence than observational studies alone. Cross-species data relating patterns of senescence to extrinsic mortality rates is shown in Table 2 below.

Table 2. Cross-species evidence linking extrinsic mortality to senescence.

Species/ Group	Extrinsic Mortality Rate	Senescence Pattern	Lifespan (Max, Years)	Support for Theory
Wild mice	Very high (>70%/yr)	Rapid senescence	1 - 2	Mutation accumulation
Bats (e.g., Myotis)	Very low (<10%/yr)	Negligible senescence	30 - 40	Disposable soma
Naked mole rat	Very low (protected burrows)	Negligible senescence	30+	Multiple mechanisms
Birds (general)	Moderate (flight reduces predation)	Slower aging than similar-sized mammals	10 - 20	Reduced extrinsic mortality

6. Does Aging Always Come with Deterioration?

Although aging is mostly associated with deterioration of physiological functions, laboratory environments can alter their expression. Dietary restriction (reducing food intake without malnutrition) extends lifespan and delays age-related diseases in many vertebrates and invertebrates [8] [23]. In rhesus monkeys, caloric restriction reduces insulin and triglyceride levels, limiting diabetes and cardiovascular diseases [24]. Protein restriction, rather than overall caloric reduction, may drive many of these benefits in rodents and primates [24]. Translation to humans remains uncertain, and current evidence does not justify recommending protein restriction for longevity without further research.

7. Trade-Offs with Life

Trade-offs between reproduction and longevity are common; bats that produce more offspring have shorter lifespans than those that produce fewer offspring [21]. Social insects such as termites and bees also show unusual aging patterns:

queens live longer than workers despite their high fertility [25]. These patterns likely arise from protection from extrinsic mortality and social structures rather than from an absence of aging. Species such as naked mole rats and *Hydra* are often described as exhibiting negligible senescence, but this does not mean they are exempt from aging; rather, their aging patterns are unusually slow or non-progressive under specific conditions.

8. Human Lifespan Extension: Possibilities and Interdisciplinary Perspectives

Ongoing research aims to extend human lifespan by studying slow-aging species. Naked mole rats exhibit negligible senescence and cancer resistance [10]. Planarian flatworms possess pluripotent stem cells capable of regenerating aged tissues [11]. Although no species is truly immortal, these models reveal mechanisms that slow aging. In humans, clinical interventions include the use of metformin (originally for diabetes), which improves cognitive function and slows brain aging in male monkeys [26] [27]. Senotherapy, which targets senescent cells, has also proven effective in improving conditions such as osteoporosis and reducing chronic inflammation [28] [29].

Recent discoveries in molecular biology have provided insight into cellular mechanisms that govern aging, with telomerase regulation emerging as a central player [30]. Telomeres—protective DNA repeats at chromosome ends—shorten with each cell division due to the end-replication problem. When telomeres become critically short, cells enter senescence or apoptosis, contributing to tissue dysfunction, inflammation, and age-related disease [30]. Telomerase, the enzyme that elongates telomeres, is tightly regulated in somatic cells but active in germ cells, stem cells, and many cancer cells. Ecologically, species with lower extrinsic mortality (e.g., birds, bats) tend to have longer telomeres and higher telomerase activity, supporting an evolutionary link between environment and molecular aging mechanisms [31].

The table below compares the patterns of aging among few species and their relevance to humans (see **Table 3**).

Table 3. Comparing aging patterns across species.

Species	Aging Pattern	Key Mechanism	Human Relevance
Hydra	Negligible senescence	High regenerative capacity	Insights into stem cell maintenance
Naked mole rat	Negligible senescence, cancer resistance	High DNA repair, low oxidative stress	Cancer prevention strategies
Planarian flatworm	Regeneration-based rejuvenation	Pluripotent stem cells	Regenerative medicine
Humans	Progressive senescence	Telomere shortening, cellular senescence	Direct therapeutic targets

9. Future Directions: Translational Implications and Gene Editing

The translational implications of evolutionary aging theories are vast. Gene-editing technologies such as CRISPR-Cas9 offer potential therapeutic strategies to delay human aging [32]. For example, editing pro-aging genes (e.g., PCSK9) for cardiovascular health, or targeting senescent cells via CRISPR-based knockout of BCL-2 family members, is being explored in preclinical models [33]. However, ethical considerations and off-target effects remain barriers. Future research should therefore prioritize:

- Extensive human cohort research relating evolutionary hypotheses to clinical results
- CRISPR-based screening to identify geroprotective gene variants
- Clinical trials of senolytics and metformin in diverse populations

It should be noted however, that converting the interdisciplinary integration of molecular biology, ecology, and clinical gerontology will be essential to translating evolutionary theories into safe and effective human therapies.

10. Conclusion

The evolution of aging is a complex subject in evolutionary biology and varies across different taxa. Natural selection acts more strongly on early-life traits, leading to fitness decline with age in humans. Rather than viewing aging as inevitable, research should focus on ecological and genetic factors that shape aging patterns. Clinical interventions are promising but may present side effects; hence, their benefits must outweigh risks. Nevertheless, extrinsic factors such as accidents and infections remain difficult to control and can cut lives short before old age. A pragmatic goal is to reduce the burden of age-related diseases and extend health span.

Acknowledgements

I would like to thank Dr. Peer, for reviewing this paper.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Fabian, D. and Flatt, T. (2011) The Evolution of Aging. *Nature Education Knowledge*, **3**, Article 9.

[2] Munné-Bosch, S. (2015) Senescence: Is It Universal or Not? *Trends in Plant Science*, **20**, 713-720. https://doi.org/10.1016/j.tplants.2015.07.009

[3] Williams, G.C. (1957) Pleiotropy, Natural Selection, and the Evolution of Senescence. *Evolution*, **11**, 398-411. https://doi.org/10.1111/j.1558-5646.1957.tb02911.x

[4] Fisher, R.A. (1958) The Genetical Theory of Natural Selection. 2nd Edition, Clarendon Press. https://doi.org/10.5962/bhl.title.27468

[5] Haldane, J.B.S. (1941) New Paths in Genetics. George Allen & Unwin.

[6] Hamilton, W.D. (1966) The Moulding of Senescence by Natural Selection. *Journal of Theoretical Biology*, **12**, 12-45. https://doi.org/10.1016/0022-5193(66)90184-6

[7] Rose, M.R. (1991) Evolutionary Biology of Aging. Oxford University Press.

[8] Flatt, T. and Partridge, L. (2018) Horizons in the Evolution of Aging. *BMC Biology*, **16**, Article No. 93. https://doi.org/10.1186/s12915-018-0562-z

[9] Finch, C.E. (1990) Longevity, Senescence and the Genome. University of Chicago Press. https://press.uchicago.edu/ucp/books/book/chicago/L/bo3684707.html

[10] Buffenstein, R. (2008) Negligible Senescence in the Longest Living Rodent, the Naked Mole-Rat: Insights from a Successfully Aging Species. *Journal of Comparative Physiology B*, **178**, 439-445. https://doi.org/10.1007/s00360-007-0237-5

[11] Schaible, R., Scheuerlein, A., Dańko, M.J., Gampe, J., Martínez, D.E. and Vaupel, J.W. (2015) Constant Mortality and Fertility over Age in Hydra. *Proceedings of the National Academy of Sciences*, **112**, 15701-15706. https://doi.org/10.1073/pnas.1521002112

[12] Baudisch, A., Salguero-Gómez, R., Jones, O.R., Wrycza, T., Mbeau-Ache, C., Franco, M., *et al.* (2013) The Pace and Shape of Senescence in Angiosperms. *Journal of Ecology*, **101**, 596-606. https://doi.org/10.1111/1365-2745.12084

[13] Ackermann, M., Chao, L., Bergstrom, C.T. and Doebeli, M. (2007) On the Evolutionary Origin of Aging. *Aging Cell*, **6**, 235-244. https://doi.org/10.1111/j.1474-9726.2007.00281.x

[14] Charlesworth, B. (2000) Fisher, Medawar, Hamilton and the Evolution of Aging. *Genetics*, **156**, 927-931. https://doi.org/10.1093/genetics/156.3.927

[15] Medawar, P.B. (1952) An Unsolved Problem of Biology. H.K. Lewis & Co. https://openlibrary.org/books/OL14215231M

[16] Mueller, L.D. (2019) Mutation Accumulation Aging Theory. In: Gu, D. and Dupre, M., Eds., *Encyclopedia of Gerontology and Population Aging*, Springer International Publishing, 1-5. https://doi.org/10.1007/978-3-319-69892-2_48-1

[17] Austad, S.N. and Hoffman, J.M. (2018) Is Antagonistic Pleiotropy Ubiquitous in Aging Biology? *Evolution, Medicine, and Public Health*, **2018**, 287-294. https://doi.org/10.1093/emph/eoy033

[18] Carter, A.J. and Nguyen, A.Q. (2011) Antagonistic Pleiotropy as a Widespread Mechanism for the Maintenance of Polymorphic Disease Alleles. *BMC Medical Genetics*, **12**, Article 160. https://doi.org/10.1186/1471-2350-12-160

[19] Kirkwood, T.B.L. (1977) Evolution of Ageing. *Nature*, **270**, 301-304. https://doi.org/10.1038/270301a0

[20] de Magalhães, J.P. (2023) The Longevity Bottleneck Hypothesis: Could Dinosaurs Have Shaped Ageing in Present-Day Mammals? *BioEssays*, **46**, 1-5. https://doi.org/10.1002/bies.202300098

[21] Wilkinson, G.S. and South, J.M. (2002) Life History, Ecology and Longevity in Bats. *Aging Cell*, **1**, 124-131. https://doi.org/10.1046/j.1474-9728.2002.00020.x

[22] Valenzano, D.R., Aboobaker, A., Seluanov, A. and Gorbunova, V. (2017) Non-Canonical Aging Model Systems and Why We Need Them. *The EMBO Journal*, **36**, 959-963. https://doi.org/10.15252/embj.201796837

[23] Lane, M.A., Ingram, D.K. and Roth, G.S. (1999) Calorie Restriction in Nonhuman Primates: Effects on Diabetes and Cardiovascular Disease Risk. *Toxicological Sciences*, **52**, 41-48. https://doi.org/10.1093/toxsci/52.suppl_1.41

[24] Colman, R.J., Anderson, R.M., Johnson, S.C., Kastman, E.K., Kosmatka, K.J., Beasley,

T.M., *et al*. (2009) Caloric Restriction Delays Disease Onset and Mortality in Rhesus Monkeys. *Science*, **325**, 201-204. https://doi.org/10.1126/science.1173635

[25] Kramer, B.H., van Doorn, G.S., Weissing, F.J. and Pen, I. (2016) Lifespan Divergence between Social Insect Castes: Challenges and Opportunities for Evolutionary Theories of Aging. *Current Opinion in Insect Science*, **16**, 76-80. https://doi.org/10.1016/j.cois.2016.05.012

[26] Yang, Y., Lu, X., Liu, N., Ma, S., Zhang, H., Zhang, Z., *et al*. (2024) Metformin Decelerates Aging Clock in Male Monkeys. *Cell*, **187**, 6358-6378.e29. https://doi.org/10.1016/j.cell.2024.08.021

[27] Barzilai, N., Crandall, J.P., Kritchevsky, S.B. and Espeland, M.A. (2016) Metformin as a Tool to Target Aging. *Cell Metabolism*, **23**, 1060-1065. https://doi.org/10.1016/j.cmet.2016.05.011

[28] Mikawa, T., Yoshida, K. and Kondoh, H. (2024) Senotherapy Preserves Resilience in Aging. *Geriatrics & Gerontology International*, **24**, 845-849. https://doi.org/10.1111/ggi.14949

[29] Childs, B.G., Gluscevic, M., Baker, D.J., Laberge, R., Marquess, D., Dananberg, J., *et al*. (2017) Senescent Cells: An Emerging Target for Diseases of Ageing. *Nature Reviews Drug Discovery*, **16**, 718-735. https://doi.org/10.1038/nrd.2017.116

[30] Shay, J.W. and Wright, W.E. (2019) Telomeres and Telomerase: Three Decades of Progress. *Nature Reviews Genetics*, **20**, 299-309. https://doi.org/10.1038/s41576-019-0099-1

[31] Armanios, M. (2022) The Role of Telomeres in Human Disease. *Annual Review of Genomics and Human Genetics*, **23**, 363-381. https://doi.org/10.1146/annurev-genom-010422-091101

[32] Wen, L., Zhao, C., Song, J., Ma, L., Ruan, J., Xia, X., *et al*. (2020) CRISPR/Cas9-Mediated TERT Disruption in Cancer Cells. *International Journal of Molecular Sciences*, **21**, Article 653. https://doi.org/10.3390/ijms21020653

[33] Azani, A., Sharafi, M., Doachi, R., Akbarzadeh, S., Lorestani, P., Haji Kamanaj Olia, A., *et al*. (2025) Applications of CRISPR-Cas9 in Mitigating Cellular Senescence and Age-Related Disease Progression. *Clinical and Experimental Medicine*, **25**, Article No. 237. https://doi.org/10.1007/s10238-025-01771-3