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EDITORIAL

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Beyond single-dimensional intervention: The scientific value and prospect of the holistic healthy aging concept

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INTRODUCTION

While human life expectancy has improved worldwide, the mismatch between prolonged lifespan and healthspan has placed enormous pressure on public health systems. Extending healthspan is now a core goal of geroscience and national population strategies.

Current anti-aging studies and industrial practices focus predominantly on the human body itself. Researchers devote tremendous efforts to exploring anti-aging mechanisms and intervention methods at cellular, tissue and organ levels, including senolytics, senomorphics, senoreverse.[1] However, a critical limitation exists: most studies separate the human body from social and ecological environments, ignoring the dual impacts of interpersonal relationships and living surroundings on aging processes. A growing body of evidence proves that social isolation, poor social bonds and long-term exposure to harmful environmental factors can significantly accelerate biological aging and increase the risk of age-related chronic diseases.[2,3]

Building on Rowe and Kahn's successful aging framework and WHO intrinsic-capacity models,[4] previous literature has established the multidimensional nature of healthy aging across physical, cognitive, psychological and social domains. Yet most frameworks give limited attention to environmental exposome hazards as core aging drivers, and few construct direct linkages between multifactorial aging determinants and actionable intervention strategies. The Holistic Healthy Aging Concept addresses this gap by proposing three interconnected pillars: healthy lifestyles targeting individual behaviors; healthy environments encompassing interpersonal bonds and ecological optimization; and precision scientific interventions leveraging biomedical advances.

THREE DRIVERS OF HUMAN AGING

Aging is a progressive degenerative process shaped by multiple interactive factors, categorized into three major types: individual endogenous factors, interpersonal social factors, and natural environmental factors.

First, individual endogenous factors act as the intrinsic basis of aging. Apart from genetic predisposition, daily behavioral patterns including diet, physical activity, sleep quality and mental state profoundly modulate the rate of physiological aging. Imbalanced nutrition, sedentary lifestyles, sleep disorders and long-term negative emotions will trigger metabolic disturbance, chronic inflammation and neuroendocrine dysregulation, collectively accelerating the decline of cells and organs throughout the body.

Second, interpersonal social factors are vital extrinsic regulators of aging. Numerous cohort studies have confirmed that social isolation and loneliness can raise biological age and amplify aging progression.[2]

Third, natural environmental factors constitute another key external driver of premature aging. From the perspective of the exposome concept, all substances and hazards that humans are exposed to in living environments, such as air pollutants, water contaminants and chemical irritants, will continuously damage tissues and cells. Long-term exposure elevates the risk of age-related diseases and shortens healthspan.[3]

THREE CORE PILLARS OF THE HOLISTIC HEALTHY AGING CONCEPT

The Holistic Healthy Aging Concept consists of three mutually supportive and interconnected pillars, forming a complete closed-loop anti-aging system from individual behaviors to social interactions and ecological adaptation (Figure 1). The healthy-lifestyle pillar covers nutrition, exercise, sleep and psychological well-being; the healthy-environment pillar includes social engagement and ecological health; the precision-intervention pillar encompasses targeted biomedical interventions against cellular and organ-level aging. Precision itself—tailoring interventions to age, functional status, biomarker profiles, environmental exposure burden and social context—is not confined to the third pillar but operates as a cross-cutting implementation principle that determines which intervention domains are prioritized for a given individual or population.

Healthy lifestyle: the fundamental guarantee for individual anti-aging

Healthy lifestyle is the cornerstone of delaying aging and maintaining physical homeostasis, directly targeting endogenous aging factors. It covers daily behaviors such as reasonable diet, regular physical activity, high-quality sleep and psychological well-being.

As the most accessible and scalable anti-aging intervention, standardized healthy daily behaviors consolidate individual health foundations and reduce premature aging risk at population scale.

Healthy environment: dual protection from interpersonal bonds and ecological optimization

This pillar is divided into two interrelated dimensions: interpersonal-social and human-nature ecological health.

Long-term lack of social interaction triggers persistent low-grade inflammation, impairs cognitive function and immune homeostasis, and shortens healthspan. Long-term community-based social support and positive group interaction can relieve psychological stress, eliminate the adverse effects of social isolation, and build a stable social protection barrier for healthy aging.[2]

In terms of human-nature ecology, this dimension is closely linked to the environmental exposome concept. The Holistic Healthy Aging Concept advocates avoiding harmful environmental exposures and building a healthy living environment.

Precision scientific intervention: professional empowerment based on traditional anti-aging research

This pillar inherits the research achievements of traditional anti-aging biology and delivers targeted biomedical interventions against cellular and organ aging, including senescence clearance, tissue regeneration and organ function maintenance. General dietary optimization belongs to the healthy-lifestyle pillar; nutritional strategies are considered here only as targeted interventions for individuals with specific deficiencies or risk profiles.

Targeted nutritional supplementation may help correct specific deficiencies or metabolic imbalances in selected populations, although evidence that it delays metabolic aging in humans remains limited.[5] Several plant-derived active ingredients and nutritional interventions have been reported to clear senescent cells, repair tissue damage and regulate aging-related signaling pathways, mainly in preclinical studies; evidence of clinical benefit in humans is still emerging.[1]

Mechanistically, the three pillars' drivers converge partly on shared aging pathways: chronic low-grade inflammation, oxidative stress, metabolic dysregulation, immune dysfunction and cellular senescence. Isolated single-domain intervention cannot fully counteract multi-factorial aging—providing the mechanistic rationale for integrated three-pillar intervention.

PIONEERING SIGNIFICANCE AND SCIENTIFIC VALUE OF THE HOLISTIC HEALTHY AGING CONCEPT

Breaking the cognitive limitations of traditional anti-aging research

The Holistic Healthy Aging Concept systematically integrates individual physiology, interpersonal society and natural ecology into a unified research and practice system, fully recognizing that aging is a comprehensive result of

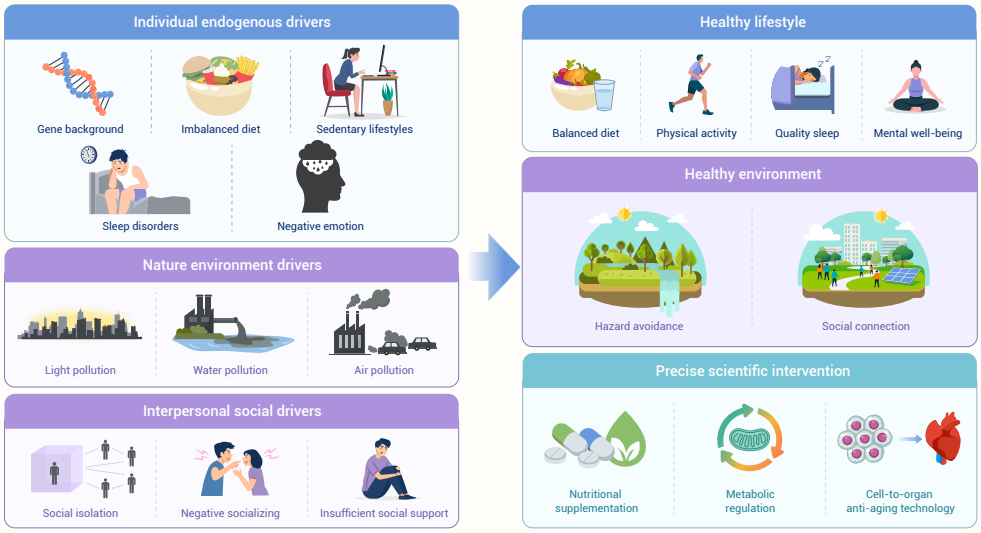

Figure 1. Classification of aging drivers and the three interventional pillars for Holistic Healthy Aging Concept Aging originates from individual endogenous, interpersonal social and natural environmental drivers. The three core interventional pillars include healthy lifestyle, healthy environment, and precision scientific intervention, which jointly form a multi-dimensional integrated strategy to delay aging and extend healthspan.

the interaction of endogenous physiological factors, social psychological factors and exogenous environmental factors. It should be noted that multi-domain interventions may exert synergistic, antagonistic or sequential time-dependent effects on healthy-aging outcomes. For instance, favorable social support may amplify the physiological benefits of lifestyle modification, while severe environmental hazards could offset benefits obtained from individual-level behavioral interventions. Current epidemiological evidence documenting such interaction remains limited, representing an important hypothesis for future cohort investigations.

Building a scalable full-population anti-aging system

Unlike professional anti-aging technologies limited to specific groups, this three-pillar framework of the concept covers all ages. From daily lifestyle guidance and community-based social support to environmental protection and precise nutritional intervention, the whole set of solutions is simple, feasible and easy to popularize.

The relative weight of endogenous, social and environmental aging drivers varies across life stages and populations. Accordingly, the framework supports risk-stratified, tiered interventions at individual, community and public-policy levels—rather than treating three pillars as merely parallel components. Intervention priorities should be adjusted according to population-specific risk profiles, optimizing resource allocation for maximum effectiveness.

FUTURE PROSPECTS

Advancing the framework from conceptual integration toward testable and actionable strategies will require three complementary lines of research. First, key aging determinants should be identified: integrating multi-omics, exposome and social-connection data from large cohorts with causal machine learning could reveal the dominant drivers of aging and heterogeneous intervention effects across populations. Second, integrated interventions require experimental validation and optimization: multi-exposure models such as *Drosophila*, organoids and organ-on-chip systems can test mechanistic interactions between lifestyle, social-stress and environmental factors, while factorial designs within the Multiphase Optimization Strategy (MOST) can identify effective intervention components and their optimal combinations. Third, dynamic prediction should guide adaptive intervention: Sequential Multiple Assignment Randomized Trials (SMART), digital twins and AI-based dynamic models could simulate individual aging trajectories, evaluate intervention responses and inform when, and for whom, strategies should be intensified or switched.

These studies will also need a common outcome measure. We propose a quantitative healthspan index whose candidate indicators cover five dimensions—molecular-cellular biomarkers, organ physiological functions, psychological-behavior status, social connection and environmental exposure—to enable objective assessment of individual and population aging status. Rather than replacing existing multidimensional healthy-aging outcomes, such as WHO intrinsic capacity, the Healthy Aging Index, frailty indices and biological aging clocks, the index is intended to integrate them and extend them with social-connection and environmental-exposure dimensions. Because previously reported composite outcomes differ in indicator composition and conceptual assumptions, indicator selection and weighting should be data-driven and adapted to research settings and populations. Validation would then test predictive validity against mortality, disability and incident chronic disease, external validity across populations, and longitudinal sensitivity to intervention-induced change. Together, these efforts would progressively refine the concept from a conceptual framework into a quantifiable, testable scientific system.

In practice, the framework could guide tiered, evidence-based implementation. For example, community-based social-support interventions could be prioritized for socially isolated older adults, whereas for residents exposed to severe environmental hazards, ecological-risk mitigation may need to precede individual-level lifestyle optimization.

CONCLUSION

The Holistic Healthy Aging Concept proposed here complements existing single-domain perspectives by constructing a three-pillar system—healthy lifestyles, healthy environments and precision scientific interventions—spanning individuals, interpersonal relationships and human-nature relationships. Future development through empirical validation, quantitative tool development and cross-cultural testing will further establish its scientific value and practical significance in addressing global aging challenges.

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AUTHOR CONTRIBUTIONS

Juntao Kan wrote the manuscript. Caili Fu and Qiming Wu revised the manuscript. Jiaoliang Hou prepared the figure. Dejian Huang and Qiang Han reviewed the manuscript. Qiang Han and Juntao Kan designed the concept. All authors contributed to and approved the manuscript.

DECLARATION OF INTERESTS

The authors declare no competing interests.

DATA AND CODE AVAILABILITY

No new data were created or analyzed in this study.