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THE ROLE OF THE NEUROENDOCRINE SYSTEM IN THE FORMATION OF BIOLOGICAL AGE: SIGNIFICANCE OF ADRENAL CORTICAL FUNCTION

Kilicheva I.B., *PhD*
Department of Normal Physiology
Andijan State Medical Institute

Abstract

Biological age is an integral indicator reflecting the functional state, adaptive capacity, and health status of the human organism more accurately than chronological age. It provides an objective assessment of aging processes and may serve as a predictor of life expectancy. Among the regulatory systems involved in aging, the neuroendocrine system—particularly the hypothalamic–pituitary–adrenal (HPA) axis—plays a central role. Age-related changes in adrenal cortical function significantly influence metabolic regulation, stress responses, immune activity, and homeostasis. This article analyzes key neuroendocrine mechanisms underlying biological aging, with special emphasis on adrenal cortex activity as an objective marker of biological age at both individual and population levels.

Keywords

Biological age, aging, neuroendocrine regulation, hypothalamic–pituitary–adrenal axis, adrenal cortex, stress

Introduction

Aging is a complex, multifactorial biological process characterized by a gradual decline in adaptive capacity and increased vulnerability to disease and mortality. Chronological age does not adequately reflect the heterogeneity of aging; therefore, the concept of biological age has gained increasing importance in gerontology and preventive medicine. Biological age represents the cumulative functional, metabolic, structural, and psychological characteristics of the organism and provides a more precise evaluation of aging dynamics.

Neurohumoral regulation, integrating nervous and endocrine mechanisms, constitutes the fundamental basis of adaptation to environmental changes. Within this system, the hypothalamic–pituitary–adrenal (HPA) axis plays a pivotal role in maintaining homeostasis, especially under conditions of stress and aging.

Neuroendocrine Regulation and Aging

Throughout ontogenesis, neuroendocrine regulation undergoes gradual and often heterogeneous (mosaic) changes. In later stages of life, these alterations contribute to the preservation of homeostasis despite declining physiological reliability. However, reduced regulatory reserves limit adaptive responses and modify the clinical course of diseases in older individuals.

Age-related endocrine changes involve not only altered hormone secretion but also modifications in tissue sensitivity to hormonal signals. In elderly individuals, increased tissue sensitivity to hormones may compensate for decreased endocrine gland activity and serve as an adaptive mechanism. In advanced or pathological aging, this compensatory capacity diminishes, leading to impaired regulation and metabolic imbalance.

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Adrenal Cortical Function as a Marker of Biological Age

The adrenal cortex plays a crucial role in stress adaptation, energy metabolism, immune modulation, and cardiovascular regulation. Glucocorticoids, synthesized by the adrenal cortex, are particularly important in mediating age-related neuroendocrine changes. Alterations in glucocorticoid secretion and action are closely associated with aging-related metabolic and immunological disturbances.

Numerous studies indicate that adrenal cortical function can be considered an objective and sensitive marker of biological age. Both hyperactivation and exhaustion of the HPA axis contribute to dysregulation of homeostasis and accelerate degenerative processes. After the age of 45, significant changes occur in the central regulation of the HPA axis and its interaction with the hypothalamic–pituitary–gonadal system, contributing to climacteric conditions, osteoporosis, and metabolic syndrome.

Stress, Aging, and Neuroendocrine Similarities

Neuroendocrine changes observed during aging closely resemble those occurring under chronic stress conditions. Activation of the sympathoadrenal system, increased glucocorticoid activity, reduced insulin effectiveness, thyroid hormone alterations, and enhanced lipid peroxidation are commonly observed. These changes promote immunosuppression, oxidative stress, hypercholesterolemia, and free radical–induced cellular damage.

This phenomenon, often described as a “stress return syndrome,” limits adaptive capacity and increases susceptibility to pathological aging. Subclinical hyperinsulinemia, relative hypothyroidism, and chronic distress are considered key contributors to degenerative aging processes.

Clinical and Preventive Significance of Biological Age

Biological age serves as an integral measure of organismal vitality, health status, and anticipated life expectancy. A lower biological age relative to chronological age indicates slower aging and greater longevity potential. Assessment of biological age requires a comprehensive evaluation of metabolic, hormonal, functional, and psychological parameters.

In advanced age, distinguishing physiological aging from pathology becomes increasingly complex and necessitates longitudinal, dynamic studies and multidisciplinary expertise. Understanding individual aging trajectories allows for early identification of risk factors and the development of targeted preventive and therapeutic strategies.

Conclusion

Aging is a natural, genetically determined, yet highly modifiable biological process. Neuroendocrine regulation plays a central role in aging mechanisms at all levels of biological organization. The adrenal cortex, as a key component of the HPA axis, represents an important objective marker of biological age. Assessment and modulation of neuroendocrine function may contribute to preventing premature aging, improving health outcomes, and extending healthy life expectancy.