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PHYSIOLOGICAL AGE OF IXODID TICKS AND THE CONCEPT OF BIOLOGICAL AGE

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ABSTRACT: The definition concept of the «physiological age» of animals has been revised based on the studies of ixodid ticks. The physiological age of animals is considered to be a general biological notion and is equal to the notion «biological age» of human beings. The notion «physiological, biological age» expresses gradual changes of an organism during its life thus this is a level of biological ageing of an organism. These biological changes correspond with the biological index «life part that has passed». Based on these features, a general notion «physiological, biological age» is formulated that is also applied to ixodid ticks.

KEY WORDS: ixodid ticks, physiological age, biological age, concept, registering structures

The problem to define the «physiological age» of ixodid ticks still attracts a lot of attention (Uspensky 1995; Balashov 1998; Jensen et al. 1999). The index «physiological age» with a quantitative assessment of some features such as the fat content is now applied more widely while studying population ecology of ixodid ticks (Walker 2001; Randolph et al. 2002). Since the methods for defining age in the Ixodidae have been modernized and the opportunities for its applied use have been extended, the study of the notion «physiological age» is becoming topical (Walker and Fletcher 1985; Razumova and Alekseev 1991; Korenberg 2000; Razumova 2000; Jensen and Kaufmann 2003; Uspensky et al. 2006). Yu.S. Balashov was the first to apply the notion «physiological age» to the Ixodidae (1961–1962): «physiological age of ixodid ticks shows how much nutritive material an organism contains». V.N. Beklemishev gave the widest definition (1962): «physiological age (of an animal) is measured by the amount of irreversible changes occurred in an organism, which are characterized by normal vital functions». Further on we formulated our own notion of physiological age of ixodid ticks: «a level of general inevitable morpho-physiological changes in an organism during a life measured by the amount of reserve and excretory materials in it» (Razumova 1977, 1983). It is based on Beklemishev's notion (1962). Yu.S. Balashov like others extended his notion: «the physiological age of ticks reflects irreversible changes in their organisms connected to the energy reserve spending and the accumulation of the end-products of metabolism in their organisms» (Balashov 1998). In some studies there is a more simple interpretation of the notion «physiological age» of ixodid ticks as «an inevitable change raising the likelihood of death» (Jensen at al. 1999).

I.V. Uspensky (1995) in his review claims that the study of physiological age of blood-sucking arthropods should not be isolated from main aspects of gerontological studies. He also confirms the competence to equate the notion «physiological age» of Ixodidae with the notion «biological age», that was offered earlier (Razumova 1977, 1983). However I.V. Uspensky also supposes that only those irreversible changes occurring in an organism which lead forward, i.e. which raise the likelihood of death, are significant in defining what biological age is. The author considered it to be a general definition of the generally accepted concept of animals' biological age (Uspensky 1995). This definition basically concerns the changes limiting the rest of an organism's life.

It is worth mentioning, however, that the problem of defining human beings' biological age has not been solved yet, it is considered to be a problem of age physiology and gerontology (Smith and Birman, 1973; Ris et al. 1981; Voitenko 1982; Dean and Morga 1988; Wilson 1988; Jazwinski 2000; Jackson et al. 2003). In particular, in a monograph devoted to biological ageing it is said that the problem of biological age is not likely to be solved soon (Frolkis 1988). The author of a monograph gives his own definition: «biological age is how biological potential of an organism is changed in the course of time». The goal of conceptual solving of the biological age problem (its essence, exact definition, biomarkers, model objects) is still topical. All these questions are closely connected to the problem of biological ageing, the aspect of biology that is being developed now (Baker and Sprott, 1988; Masoro 1988; Carlson and Riley 1998; Mc Clearn 1992, 1997; Martin 2000; Ingram 2001; Warner 2001, 2004; Butler et al. 2004).

The concept of physiological, biological age

In this article we would like to make clear our definition of physiological age, given earlier (Razumova 1977, 1983). The assessment of an organism's age is made according to the following scheme: studying signs of age in various groups of individuals, an age changes model of an object from birth to death is made. Thus a life potential and its changes throughout the whole life of an organism with normal vital functions is estimated. What is typical for the majority of individuals is considered to be normal. This model is a kind of a matrix where a life potential and a life itself are divided into main stages of age changes — the beginning, the middle and the end. Further on it should be stated on what stage of age changes an examined individual is. It should be stated according to signs of age which this individual has. It is also estimated how this or that sign of age has been changed comparing with the possible final condition of an organism after the birth, and, at the same time, how far this organism is from the initial condition. It does not matter whether the initial condition changed or not. The important thing is that the organism took its place in a normal life span vector according to its signs of age, i.e. its real condition corresponds with the one it should be. Physiological age shows which place an examined individual took.

Physiological age is «a mark» of an organism which was put on it by its life. It shows how far an individual went away (from the point of view of physiological expenses: longevity, intensity) from the initial physiological condition after the birth and its organism's response. All this is accompanied by the accumulation of irreversible changes in an organism. The level of real changes of an organism is estimated according to changes of an organism with normal vital functions. Different animals will have different results. Also physiological age shows the life potential that is left in an organism.

So, age in a biological aspect means an organism's condition showing its place in a life with normal vital functions. Thus, the assessment may be directed to both sides of life: back, i.e. showing how much of life potential has been spent since birth; and forward, i.e. showing how much of life potential is left until an organism's death. These are two sides of one process — the process of defining where exactly an organism is now. It is evident, however, that these positions are not exact and there is no need to oppose them, to our mind. Our understanding of the problem corresponds with the literature data that the biological age «shows both the part of the life cycle undergone and the life potential left» (Voitenko 1982).

Every animal species has its specific speed of physiological ageing and its own length of life. A period of time which is the whole life for one animal may be just a very small period for another, and vice versa. That means that various animals have relatively different speed of age changes. It is evident that a life length is something integral for this or that species, something peculiar for this very species — «a life length» of this species' organism. All the age changes which an organism undergoes during a life should be corresponded with its life length. So, every physiological age marks a part of life that an organism has lived. This is the period during which irreversible changes occurred in an organism comparing to its condition after birth.

All these considerations made it possible for us to formulate our own definition of physiological (=biological) age: the level of real irreversible biological changes of an organism during the period of life it has already spent which is measured by irreversible changes in an organism with normal vital functions. The first part of this definition is true for all species of animals. It expresses the real changes of a certain individual. The second part, measurement, includes Beklemishev's point of view (1962). It indicates the changes of a certain species with normal vital functions. Every species has its own vital functions peculiar to this very species. The real level of an organism's ageing can be measured only with the help of these changes. In this case the notion «biological changes» is equal to the notion «biological ageing» and, first of all, includes morpho-physiological and molecular data. These changes correspond with the biological notion called « length of life» or with a part of it «the life part that has passed» but they do not correspond with the physical notion «time» because different species have their own speed of physiological ageing. Some authors also use the notion «length of life» studying the problem of biological ageing (Ingram et al. 2001).

We analyzed the data about age changes and methods of defining age in insects and some other groups of animals (Razumova 1983), and came to the conclusion that the notion «physiological age» should be understood much wider than it was considered concerning arthropods and other groups of animals. It is sure to be a general biological phenomenon such as birth or death. It is an age development peculiar to all living organisms as a general inevitable change of an organism during a life in a certain direction, from birth to death. The main feature of this phenomenon is the irreversible character of this process connected, primarily, to normal vital functions of an organism. Gradual biological changes of an organism during its life expresses the notion «physiological (biological) age». It should be noted that every organism comes through main biological age stages: new-born, young, mature, and old ages. Physiological (biological) age is the level of an organism's ageing.

How to apply the notion «physiological age»?

Irreversible age-related changes in the course of life are typical for all animals but they reveal themselves in various ways in different groups of animals. Concerning ixodid ticks the notion «physiological age» can be applied only to unfed individuals, which spend most of their life in such a condition. The unfed adult ticks are subject to age changes which can be clearly seen in the gut, excretory system, loose connective tissue and cuticle. To outer changes we can refer body plentitude diminution and its flattening, furrow deepening, cuticle rugosity increase and its color and density changes. During the autopsy of a tick and in the mounts the age changes are expressed in the gut: its volume becomes smaller; its color changes; hemoglobin, fat and other reserve materials inclusion becomes smaller; hematin inclusion in the cells of the gut epithelium becomes bigger; its cell structure changes. As a tick gets older its excretory system, Malpighi tubes and the rectal bladder, is filled with more guanine; some structural changes can be seen as well. The quantity of jelly-like elements and patches of adipose body in the loose connective tissue become less, the condition of some cell elements changes. According to these features there can be distinguished four main ages of unfed ticks: new-born, young, mature and old (I–IV). Individuals of the first age have a period of postmolting development (Balashov 1961, 1998), thus, they are equal to new born individuals of other animals. The most spread ticks are those of II–IV ages.

Functionally age changes of unfed ticks are closely connected to processes of reserve material spending and excretory material (final products of metabolism, according to Yu.S. Balashov 1998) accumulation. This is the main feature of ticks' age changes. The quantity of extra nutritive materials (hemoglobin inclusion, adipose body) reaches its maximum after nymphal molting. Excretory materials (hematin and guanine) are accumulated in a tick's body because of its vital functions. By the end of their life ticks practically do not have any nutritive materials due to which they used to lived, but the quantity of excretory materials increases. This leads to structural changes, which can be seen in the cell structure of the gut epithelium. All these changes are primarily connected to ticks' normal vital functions; they express the process of general physiological ageing. The processes of gradual reserve material spending and fast excretory material accumulating are the most important for an organism's life. They provide ticks an opportunity to live long while passively waiting for their food without receiving new reserve materials. The only gonotrophic cycle ends an individual's life.

Based on the general notion of «physiological age» we would like to give a new definition that will consider all the age features of unfed ixodid ticks. This is the level of real inevitable biological changes of an organism, which is measured by inevitable changes in the course of reserve material spending and excretory material accumulation. This definition generally corresponds with the definition for Ixodidae given by Yu.S. Balashov (1998). Taking into consideration the sense of this notion, it becomes clear that ixodid ticks are similar to other animals concerning physiological age, despite their specific age changes.

To solve the problem of physiological age defining in other animals, such as Diptera, the same approach was applied. There is no doubt that all the methods used to define mosquitoes' age, studying changes in their sexual systems connected to a gonotrophic cycle, are methods for defining physiological age namely. This refer to both widespread methods used earlier (Detinova 1962) and to modernized ones (Sokolova 1982, and others). According to V.N. Beklemishev (1962) «a gonotrophic rhythm embraces the majority of functions of hematophagous Diptera, so the number of undergone gonotrophic cycles shows the physiological age of a female.» So, the physiological age of a female mosquito is measured by a number of gonotrophic cycles, i.e. changes happening to organisms with normal vital functions. The analysis of age changes of ticks and insects that was made earlier (Razumova 1983) showed that all these changes had one feature in common: they were inevitable and happened, first of all, to animals with normal vital functions. Taking into consideration specific features of signs of age and relatively long length of life (up to 2.5 years), the ixodid ticks seem to be good a model to study problems of biological age and biological ageing. Concerning the Ixodidae, it becomes clear that the validity of some signs of age varies from one age to another (Razumova 2000). This corresponds with literature data on biological ageing: every biomarker of ageing may have different meaning during a life (McClearn 1992).

Physiological age and registering structures

So-called «registering structures» can be seen in some organs of various animals: annual rings on fish scales, shellfish shells, the worn out enamel on teeth of some mammals. According to these features animal calendar age is measured (Mina and Klevezal 1970; Klevezal 1988). Changes in the cuticle of mosquitoes' apodemae according to Schlein's method are referred to this category as well (Uspensky 1995). It is stated that unlike physiological age, which shows physiological abilities of an organism at the present moment and in the future, registering structures only show the past of an individual. That is the main difference between them. To our mind there is no ground to oppose these features.

Registering structures are closely connected to and correspond with seasonal phenomena in the life of some animals (when in winter rings on fish scales stop growing, etc.). Only inevitable morpho-physiological changes in organisms with normal vital functions can be clearly seen. If the biology of an animal, especially life expectancy, is known these changes are referred to specific periods of time: this or that period of life, day, night, etc. According to such periods calendar age is measured. But the possibility of such an assessment does not prove that registering structures do not refer to physiological and age features. One does not exclude the other. Not only teeth but the whole organism is likely to get older, so, this feature is also a typical diagnostic index of an organism's biological ageing level, i.e. physiological age.

Registering structures are a way of showing the category of physiological age. Registering structures themselves do not possess information about the time that an organism has already lived. Only if we know the biology of a species can we refer them (registering structures) to specific periods of time. Registering structures can be applied to assess calendar age. There is no need to oppose these phenomena as completely different according to their sense, nor is it adequate to refer them to different periods of an organism's life. Actually, this is a more precise method of calendar age assessment according to inevitable morpho-physiological changes, which at the same time characterize an organism as a young or an old one, i.e. its physiological age.

CONCLUSION

On the basis of the study that we have made we make clear our understanding of the notion «physiological age» of animals applying it to the Ixodidae (Razumova 1977, 1983). Physiological age of animals is considered to be a general biological notion, this is the level of an organism's biological ageing. It is equal to the notion «biological age» of human beings. The main feature of this notion is irreversibility of biological changes happening to organisms with normal vital functions. Thus we can make a definition of the notion «physiological, biological age» clear. It answers the question of what physiological age of animals is. We would like to apply the general notion to ixodid ticks. Extended understanding of this phenomenon makes it possible to see common traits in a variety of examples demonstrated by various animals. When studying the difference between young and old animals, taking into account inevitable biological changes but not calendar age, we speak about physiological age no matter what animal we are studying. Although age changes may be different with various animals, every animal has one common general biological feature of age development and biological ageing of the whole organism measured by an animal's biological age.

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REFERENCES

Baker, G.T. and Sprott, R. 1988. Biomarkers of aging. *Exp. Gerontol.*, 23 (4–5): 223–239.

Balashov, Yu.S. 1961. [Dynamics of stored nutritional substances and the age determination in unfed ixodid ticks]. Zoologicheskiy Zhurnal, 40 (9): 1354–1363. [In Russian]

Balashov, Yu.S. 1967. *Krovososushchie kleshchi — perenoschiki bolezney cheloveka i zhivotnykh*. [Bloodsucking Ticks (Ixodoidea), the Vectors of Diseases of Humans and Animals]. Nauka publ., Leningrad. 320 pp. [In Russian]

Balashov, Yu.S. 1998. *Krovososushchie kleshchi — parazity i perenoschiki infektsy*. [Ixodid Ticks — the Parasites and Vectors of Diseases]. Nauka Publ., St. Petersburg. 285 pp. [In Russian]

Beklemishev, V.N. 1962. Metody ustanovleniya vozrastnogo sostava dvukrylykh nasekomykh, imeyushchikh meditsinskoe znachenie, predislovie. [Foreword. Detinova T.S. Age-grouping methods in Diptera of medical importance]. WHO Monogr. Ser. 47: 9–11. [In Russian]

Butler, R.N., Sprott, R., Warner, H., Bland, J., Feuers, R., Forster, M., Fillit, H., Harman, S.M., Hewitt, M., Hyman, M., Johnson, K., Kligman, E., McClearn, G., Nelson, J., Richardson, A., Sonntag, W., Weindruch, R., and Wolf, N. 2004. Biomarkers of aging: from primitive organisms to humans. *J. Gerontol*. A. Biol. Sci. Med. Sci., 59 (6 B): 560–567.

Carlson, I.C., Riley, I.C. 1998. A consideration of some notable aging theories. *Exp. Gerontol*., 33 (1–2): 127–134.

Dean, W. and Morgan, R.F. 1988. In defense of the concept of biological aging measurement — current status. *Arch. Gerontol. Geriatr*., 7 (3): 191–210.

Detinova, T.S. 1962. Metody ustanovleniya vozrastnogo sostava dvukrylykh nasekomykh, imeyushchikh meditsinskoe znachenie. [Age-grouping Methods in Diptera of Medical Importance]. WHO Monogr. Ser. 47, 220 pp. [In Russian]

Frolkis, V.V. 1988. Starenie i uvelichenie prodolzhitelnosti zhizni. [Aging and Increase of Longevity]. Nauka Publ., Leningrad. 238 pp. [In Russian]

Ingram, D.K., Nakamura, E., Smueny, D., Roch, G.S., and Lane, M.A. 2001. Strategy for identifying biomarkers of aging in long-lived species. *Exp. Gerontol. Jul*., 36 (7): 1025–1034.

Jackson, S.H., Weale, M.R., and Weale, R.A. 2003. Biological age — what is it and can it be measured? *Arch. Gerontol. Geriatr*., 36 (2): 103–115.

Jensen, P.M., Kaufmann, U., and Smirnova, L. 1999. Diurnal activity of *Ixodes ricinus* in Denmark: Aspects of physiological age and genotypic variation. *Hereditas,* 130: 325–330.

Klevezal, G.A. 1988. Registriruyushchie struktury mlekopitayushchikh v zoologicheskikh issledovaniyakh. [Recording Structures of Mammals in Zoological Studies]. Nauka Publ., Moscow. _244 pp. [In Russian]

Korenberg, E.I. 2000. Seasonal population dynamics of *Ixodes* ticks and tick-borne encephalitis virus. *Exp. Appl. Acarol*., 24 (9): 665–681

Masoro, E.J. 1988. Physiological system marker of aging. *Exp. Gerontol*., 23 (4–5): 391–397.

Martin, P. 2000. Aging, activity and longevity. *Z. Gerontol. Geriatr*., 3, Suppl. (1): 79–84.

Mina, M.V. and Klevezal, G.A. 1970. Avtobiografiya zhivotnykh [Autobiography of animals]. Nauka Publ., Moscow. 58 pp. [In Russian]

McClearn, G.E. 1992. The reliability and stability of biomarkers of aging. *Ann. N. Y. Acad. Sci. USA,* 26 (673): 1–8.

McClearn, G.E. 1997. Biomarkers of age and aging. *Exp. Gerontol*., 32 (1–2): 87–94.

Randolph, S.E., Green, R.M., Hoodless, A.N., and Peacey, M.F. 2002. An empirical quantitative framework for the seasonal population dynamic of the tick *Ixodes ricinus. Int. J. Parasitol*., 32 (8): 979–989.

Razumova, I.V. 1977. [Physiological age of adult ixodid ticks and an express-method of its determination]. *Meditsinskaya Parazitologiya i Parazitarniye Bolezni*, 46 (5): 557–566. [In Russian] [English translation. NAMRU-3 T1409]

Razumova, I.V. 1983. [On the concept of animal «physiological age» and its application to ixodid ticks]. *Parazitologiya*, 17 (5): 347–354. [In Russian]

Razumova, I.V. 2000. A visual method for determining the physiological age of ixodid ticks in vivo. *Acarina*, 8 (2): 143–150.

Razumova, I.V., and Alekseev, A.N. 1991. [Effect of the physiological age of *Dermacentor marginatus* ticks (Ixodidae) on the infection with and penetration of the tick-borne encephalitis virus into saliva]. *Parazitologiya*, 25 (2): 147–155. [In Russian]

Ris, V., Peting, D., Guneks, I., and Zauer, I. 1981. [New research on biological age determination]. *Voprosy Gerontologii*, Kiev: 7–12. [In Russian]

Schlein, V. 1979. Age grouping of anopheline malaria vectors (Diptera; Culicidae) by the cuticular growth lines. *J. Med. Entomol*., 16: 502–506.

Schlein, V., and Gratz, N.G. 1972. Age determination of some flies and mosquitoes by daily growth layers of skeletal apodemes. *Bull. WHO*, 47: 71–76.

Smith, D.W., and Birman, E.L. 1973. *The Biological Ages of Man*. Philadelphia. 211 pp.

Sokolova, M.I. 1982. [Reproductivity of the populations of bloodsucking mosquitoes (Diptera, Culicidae)]. *Abstract of dissertation thesis*. Biological Faculty. Moscow State University. [In Russian]

Uspensky, I.V. 1995. Physiological age of Ixodid tick: aspects of its determination and application. *J. Med. Entomol*., 32 (6): 751–764.

Uspensky, I.V., Kovalevsky, Y.V., and Korenberg, E.I. 2006. Physiological age of field-collected female taiga ticks, *Ixodes persulcatus* (Acari: Ixodidae), and their infection with *Borrelia burgdorferi* sensu lato. *Exp. Appl. Acarol*., 38: 201–209.

Voitenko, V.R. 1982. [Biological age]. *In*: Chebotarev, D.F. and Frolkis, V.V (eds.). Fisiologicheskie mekhanizmy stareniya. Nauka Publ., Leningrad. P.144–156. [In Russian]

Walker, A.R. 2001. Age structure of a population of *Ixodes ricinus* (Acarina: Ixodidae) in relation to its seasonal questing. *Bull. Entomol. Res*., 91 (1): 69–78.

Walker, A.R. and Fletcher, J.D. 1985. Age grades and infection rates of *Rhipicephalus appendiculatus* Neumann (Acari; Ixodidae) to assess theileriosus challenge in the field. *Entomol. Res*., 75 (6): 653–660.

Warner, H.R. 2001. The case for supporting basic research in gerontology. *Z. Gerontol. Geriatr*., 34 (6): 486–490.

Warner, H.R. 2004. Current status of efforts to measure and modulate the biological rate of aging. *J. Gerontol. a Biol. Sci. Med. Sci*., 59 (7): 692–696.

Wilson, D.L. 1988. Aging hypotheses, aging markers and the concept of biological age. *Exp. Gerontol*., 23 (4–5): 435–438.