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ARTICLE

Fractality of Aging of Living Systems

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ABSTRACT

On the basis of the basic model of the kinetic theory of aging of living systems, mathematical modeling of various characteristics of aging of mankind, state, generation, human body, organs and cells has been carried out. These results are compared with experimental and calculated data of other authors. The analysis of the works presented here and those carried out earlier gave reason to believe that the basic mathematical model of the evolution of aging of living dynamic systems of various hierarchical levels and nature is the invariant differential equation of the kinetic theory of aging, as a manifestation of the fractality property of living systems.

1. Introduction

The theory of fractals finds application in various fields of scientific knowledge, including in the sciences of human society [1-3]. Self-similarity is one of the main properties of fractals. The definition of a fractal, given by the founder of the theory of fractal geometry, B. Mandelbrot, is quoted as follows: "A fractal is a structure consisting of parts that are in a sense similar to the whole" [3]. Global living systems, by which we mean primarily humanity and the animal world, are self-organizing dynamic biological systems with various hierarchical levels - species, populations, generations, individual representatives of a species, functional systems of an individual organism, its organs, tissues, cells. Modeling the development of living dynamic systems (LDS) of various levels from a unified methodological standpoint can be attributed to one of the tasks of the fractal-synergetic approach, represented, in particular, as a universal theory of evolution, suggesting the similarity of the processes of emergence and development of complex, open, nonequilibrium systems of various

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hierarchical levels and nature [2,4,5]. Fractality of DS has great predictive potential. A living dynamic system is self-organizing in the form of a system of coordinatedly interacting structural elements, such as, for example, human society - in the form of a state and its structures, and can be that fractal, the evolution of which is similar to the evolution of both its subsystems and systems of a higher structural level. In the mathematical formulation, the DS is considered given if its characteristics are known that uniquely determine its state, and a mathematical model of the evolution of the state of the system in time is determined [6].

Earlier in the works [7-12], the similarity of the dynamics of aging of populations of humans, some species of animals and the fruit fly, described by the mathematical model of the kinetic theory of aging [7,8], was illustrated.

The aim of this work is to assess the similarity of aging in the characteristics of living dynamic systems of human society and its structural elements.

2. Research Method

Aging is the most important characteristic of the evolution of any IDA. Aging processes are most studied for the characteristics of the dynamic systems of human society.

Below we consider the similarity of mathematical models of aging of systems of various hierarchical levels of human society, based on the basic model of the kinetic theory of aging, considered in [7,8,12]. First, the main the provisions of the kinetic theory of aging are briefly outlined, and then, using individual examples, the invariance of the basic mathematical model for describing the evolution of various aging characteristics of dynamic systems, ranging from humanity as a whole and ending with cancer cells of the human body, is illustrated.

In the initial theoretical concept of the phenomenological kinetic theory of aging of living systems within their life cycle, a basic mathematical model of aging in general form was formulated. The main postulate of the kinetic theory is the assertion that the state of a dynamic system is determined by the speeds of simultaneously occurring and oppositely directed processes that accelerate and slow down the evolution of the system.

The second postulate of this theory corresponds to the assumption that evolutionary processes can be adequately described by nonlinear equations of biochemical kinetics - differential equations of autocatalytic reactions, which represent a wide class of analytical functions that allow one to take into account, among other things, the feedback that exists in self-organizing systems [13]. The third provision is the scale invariance of the differential model, due to the representation of the time coordinate, objective function and model parameters in dimensionless form.

Thus, in accordance with the above, the basic kinetic equation of the aging rate in a dimensionless form is written as the rate of the “gross process” that simulates the evolution of a certain characteristic of the aging of the LDS in time by the competition of two oppositely directed processes [7,8]:

$$\frac{\partial D}{\partial \tau} = (1-D)^{m_d} \cdot \exp\left[\frac{\mu}{1-\theta D}\right] - \mathrm{k} \cdot D^{m_r} \cdot (1-D)^{m_{em}} \quad (1)$$

where D is the probability, that the characteristic X of the system will reach the current value X (τ) by some time τ: D (τ) = X (τ) / X_m ,X (τ = 1) = X_m is the limiting (maximum or minimum) value of X, achieved at the end of the life cycle of a railroad network; τ = Δt / Δt_m - dimensionless time (0≤τ≤1), Δt - calendar time interval calculated from the beginning t_0 of the development of the railway characteristic to the current time t, Δt = t-t_0; Δt_m is the duration of the life cycle (or its stage): $\Delta t_m = t_m - t_0$, t_m is the calendar time of the end of the life cycle of the railway system; μ is the main parameter of the “tension” of the system, which determines approximately the average rate of evolution of the characteristic X (τ) and allows, in principle, to take into account in time the i-th factors of influence of different nature, intensity and duration, i.e. μ (τ) = $\Sigma_i\ \mu_i$ (τ); k is a parameter reflecting the influence of a process that counteracts an increase in X (τ); $m_{d,\ r,\ em} \geq 0$ are the exponents of the terms of the right-hand side of the equation that determine the nature of the change in the components of the rate of evolution of the characteristic; θ is a parameter (0≤Θ≤1), with an increase in which the average speed increases and tends to ∞ as Θ → 1. All parameters of the model are dimensionless and, in the general case, can depend on the time τ. The solutions of Equation (1) are found by its numerical integration, since it does not have an analytical solution in general form. The terms on the right side of Equation (1) can be simplified depending on the nature, level of complexity of the described object and the required accuracy of interpolation and forecasting. Figure 1 illustrates the typical dynamics of D (τ) for variants of the parameters of the model (1).

Table 1. Values of model parameters (1) for the calculation options shown in Figure 1.

Curve №.	1	2	3	4	5	6
μ_i	1,58	1,6	1,62	1,58	1,6	1,62
k_i	40	35	40	35	40	35

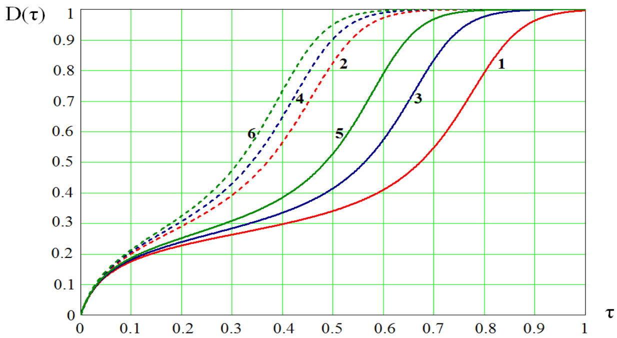

Figure 1. Examples of dependences D (τ) obtained by solving the kinetic Equation (1) with the parameters md, r, = 1; m, em = 2; θ = 0.5, for various values of the parameters μ ∈ [1.58; 1.62], k ∈ [35; 40], indicated in Table 1 [9].

Generalizing the previous results [7,8], it can be argued that the evolution trajectories of the characteristics of systems for any values of the control parameters μ, Θ, k, m_i tend to the attractor of the system, which in the investigated phase space is the point (D = 1, τ = 1) .The bifurcation point is the point of unstable equilibrium of the system, a critical state with a breakdown in adaptation, corresponding to the transition of dynamic equilibrium to evolutionary development [4,5].

3. Research Results

The results illustrating the modeling of the aging characteristics of dynamic systems by the invariant basic mathematical model (1) and its simplified modifications by examples require clarification.

First of all , we note that only dynamic states that are far from critical are considered here [7,8]. It is advisable to start with complex dynamic systems of generations, the population of individual states and humanity as a whole.

An equation of the form (1) with a certain selection of parameters allows calculating the cumulative function of mortality of generation D (the probability of death) in the entire range of its variation from birth to death, as well as calculating the intensity of mortality $I = (\partial D / \partial \tau) / (1\text{-}D)$ (analytical approximation of the mortality rate - KS) [8,10,12]. In general, the function D ("life line") is monotonically increasing, but at different ages with different rates (Figure 1). The main feature of a change in a person's life line is observed approximately in the first 18-20 years after birth, when the predominant process is the structuring of the body's systems - the development of the body with the formation of the immune system and adaptation to the environment. The high intensity of mortality at birth decreases with age and reaches a minimum in the area of about 5-10 years of age, then increases and changes little in the areas of 18- (25-30) years. Approximately from 30-35 years old to 75-85 years old she again increases approximately exponentially, and then tends to the final limit corresponding to the moment of death (D = 1) [12]. The area of increasing mortality intensity in the interval from about 30-35 years to 75-85 years is well approximated by an exponent known as "Gompertz's law". The real boundaries of the characteristic age areas of the change in the life line are blurred and depend, first of all, on the geographical and climatic conditions of the places of residence.

The dynamics of aging characteristics of the world's population as a whole, as well as of various countries of the world and regions of residence, is typical [7,10,12,14,15]. Figure 2 shows, for illustration, the dynamics of aging characteristics of residents of Russian regions, based on demographic data.

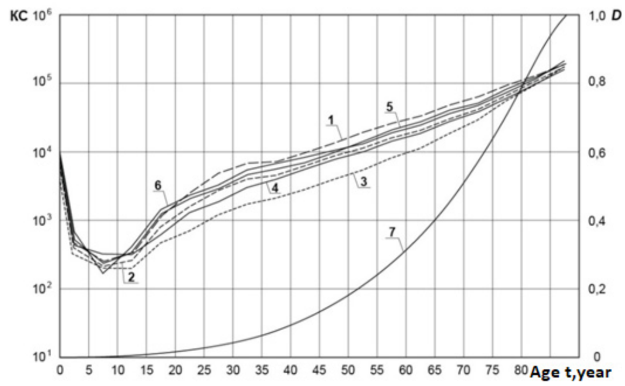

Figure 2. Kinetics of the mortality rate I (KC) of the population (values increased by 10^6 times) in the regions of the Russian Federation (1–6) and the cumulative mortality function D for the population of the Central Federal District of the Russian Federation in 2015.

The curves in Figure 2 are based on demographic data of the Center for Demographic Research of the Russian School of Economics [12]: 1 - Central Federal District, men; 2 - Central Federal District, both sexes; 3 - Central Federal District, women; 4 - Krasnodar Territory, both sexes; 5 - Republic of Sakha (Yakutia), both sexes; 6 - Primorsky Territory, both sexes. Curve 7 - the result of the calculation according to the simplified Equation (2) (see below) the probability of death for the population of the Central Federal District with the parameters of the model (1): μ = 1.518; θ = 0.620; k = 4.480; Δt_m = 100 years, m_r = 0; m_d, = m_{em} = 1.

For example, the work [10] presents a model approximation of aging characteristics using the kinetic Equation (1) for the male population of Russia, Japan and Sweden from birth to death (Δt_m = 100 years) with the parameters m_{d}, $_{r}$, = 1, m_{em} = 3 and the values of other parameters given in Table 3.

Table 3. Values of model parameters (1) for describing the dynamics of aging characteristics of the male population of Russia, Japan and Sweden in 1990-1994.

Country	μ	Θ	k
Russia	2.60	$0.06 \le \Theta \le 0.40$	$90.9 \le k \le 121.4$
Japan	1.40	0.60	31.4
Sweden	1.61	0.49	41.1

It should be noted, that the description of the evolution of aging characteristics in the full cycle of life by Equation (1) with a satisfactory error at constant parameters is difficult because of the significant non-monotony of their change in childhood. In this case, it is necessary to introduce the dependence of the parameters on age or to perform the approximation by piecewise continuous functions, as, for example, it is done for the population of Russia [10]. The error of description by the model in the area of small ages (0-15) years can reach 30%-40%. In addition, the mathematical model of the dynamics of the full aging cycle in the form of Equation (1) is difficult for solving specific practical problems, for example, those performed in [17-19]. To improve the accuracy of the description and simplify the practical application, the full dynamics of the life line was divided into two different stages - the predominant growth and structuring of the human body systems from birth to about 25 years and the subsequent predominant destruction of structural and functional connections - "visible" aging. In [12], two simplified types of kinetic mathematical models of aging of human generations were proposed for these two stages. For the life line of the second "Gompertz" stage, within the approximate range of values $0.03<D\le1$, a simplified equation is proposed in comparison with the basic one ($m_d = m_{em} = 1$, $m_r = 0$):

$$\partial D/\partial\tau = (1-D)\exp(\mu/(1-\theta D)) - k(1-D) \quad (2)$$

Approximation of the results of processing demographic data of the population of different regions of the Russian Federation by continuous functions D (τ) and $I = (\partial D / \partial\tau) / (1-D)$, calculated by Equation (2) with constant values of parameters, is performed with an error of at least 15% in the range $0.03\le D\le1$ ($0.21\le\tau\le1$) (typical model curve 7 in Figure 2) [12].

However, not only every person is aging, but also the population of the state and humanity as a whole [20,21]. One of the integral indicators of the aging of human society is the calendar age of a person, averaged over all living beings, which increases in the observed historical time. For example, Figure 3 shows the predicted dynamics of the increase in the average age of the population, averaged over the whole of humanity and over the living population of Russia, calculated using Equation (2).

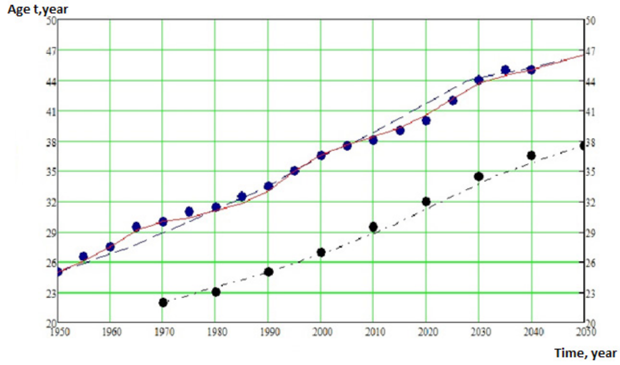

Figure 3. Dynamics of an increase in the average age of the population for World (lower curve) and Russia (upper curve) with an increase in historical time.

In Figure 3 the following designations are introduced: points - data from [20], dash-dotted and dotted lines - respectively, the results of the calculation of this work with constant parameters of model (2), solid line - for Russia with time dependence of the parameter μ (τ) in the form of a harmonic function μ (τ).

The age of a person B (t) is calculated for the world's population by the formula

$$B(t) = [20D(\tau) + 22] \text{ years} \quad (3)$$

where: $\mu = 1.532$; $\Theta = 0.395$; $k = 3.78$; $\tau = (t-1970) / 130$; $1970\le t\le2050$.

For the population of Russia, two versions of the model were calculated - with constant parameters and with the dependence of the parameter μ on time τ in the form of a harmonic function $\mu(\tau) = \mu_0 + A\sin(\alpha D(\tau))$. The average age of Russians is calculated using the formula

$$B(t) = [22.5\, D(\tau) + 25] \text{ years,} \quad (4)$$

where : for both options $\Theta = 0.395$;$k = 3.78$; $\tau = (t-1950) / 120$; $1950\le t\le2050$; for the first variant $\mu = 1.532$; for the second variant $\mu = 1.532 + \sin(18.84D(\tau))$.

The "harmonious" scenario makes it possible to reflect more accurately the real dynamics of the average age of the population of Russia, which is apparently associated with the consequences of the Great Patriotic War, the collapse of the USSR, and other possible periodic socio-economic events. Their reasons are not analyzed here. The discrepancy between the results of modeling characteristics in comparison with the data of [20] for the population of the World and Russia, taking into account the harmonic component, is within (3-4) %, while for Russia, with constant model parameters, it is up to 7%.

The aging of mankind and the population of certain countries of the world is also manifested in the rate of change in the population size - the rate of growth of its population decreases, and in some countries, the total population also decreases [14,15,21,22]. A decrease in population is already observed, for example, in European countries. This process is due to a tendency towards a decrease in the birth rate of the population and an increasing proportion of the elderly population in relation to the young population. In [15], the applicability of the mathematical model (2) was shown for describing and forecasting the dynamics of the population of the USA, China and Russia for a period of 150-200 years. The parameters of the model (2), the areas of its applicability and the equations for calculating the population of the countries of the world N (t) are given in Table 4. Examples of modeling the dynamics of the population size of Russia and China are shown in Figure 4 and Figure 5. The dynamics of the population of all mankind was calculated in a similar way.

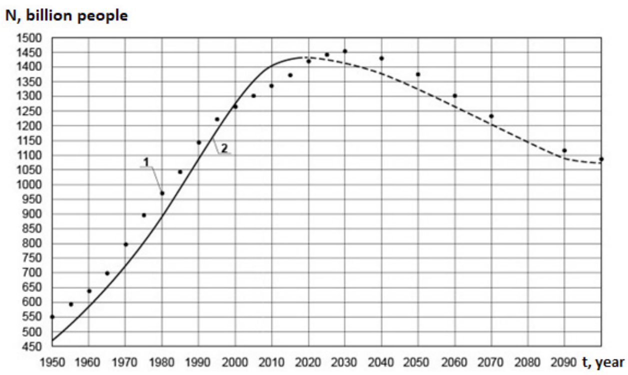

Figure 4. Time dependence t of the population size N (t) of China: points(1) - data from [22], solid and dashed lines (2) are the results of calculations in [15].

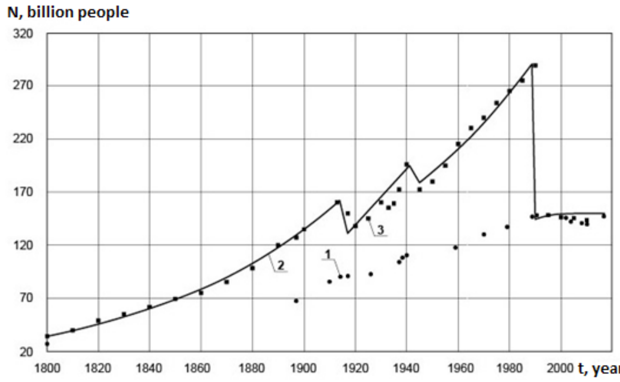

Figure 5. Time dependence of the population size N (t) of the Russian Empire (1790-1914), the RSFSR (1918-1922), the USSR (1922-1991) and Russia (1991-2018).

In Figure 5 the following designations are introduced :points (▪) - demographic data from works [23,24], solid line - results of calculation of work [15], carried out taking into account the losses of the population in Two World Wars and the collapse of the USSR in 1991. The dots (•) show the demographic data of only Russia, which is sequentially part of the Russian Empire, the RSFSR and the USSR.

In cases of population calculations, the function D (τ) is the ratio of the current population N (τ) to the maximum (or minimum) value of N_m that is expected to be achieved in the future at the end of the considered life cycle. To describe the complete dynamics of changes in the population size, the ascending and descending sections are stitched in the region of the maximum [15]. The discrepancy between the calculation results of this work and the comparable data of other authors is approximately within 5%.

Table 4. Parameters of model (2), areas of its applicability and equations for calculating the population of the countries of the world N (t).

Country	μ	q	k	N_m, mln. people	t,year	N(t), mln. people
USA	1,520	0,605	4,472	520	1700+400τ	$N_m \times D(t)$, (1900-2050) г.
China	1,539	0.584	4.468	N_{m1}=1570	1850+200τ	$N_{m1} \times D_1(t) - N_{m2} \times D_2(t)$, (1950-2050) г. $N_{m1} - N_{m2} \times D_2(t)$, (2050-2100) г.
	1,539	0.584	4.468	N_{m2}=500	1930+200τ	
Russian Empire	1.520	0.675	4.472	450	1670+400τ	$N_m \times D(t)$ 0,3≤τ≤0,610, (1790-1914) г.
RSFSR, USSR	1,520	0.675	4,472	450	1670+400τ	$N_m \times [D(t) - 0,08]$ 0,620≤τ≤0,677, (1918-1941) г.
USSR	1.520	0,607	4,472	450	1670+400τ	$N_m \times D(t)$ 0,687≤τ≤0,802,(1945-1991) г.
Russia	1,520	0,652	4.472	150	1740+300τ	$N_m \times D(t)$ 0,837≤τ≤0,923, (1991-2018) г.

Let us now move on to the lower hierarchical levels of organization of living systems - human functional systems, his organs and cells. For example, the age-related changes in testosterone concentration (T) and basal metabolic rate (BMR-basal metabolic rate) were modeled in comparison with literature data [25,20,26] (Figure 6, Table 5). An important feature of the application of Equation (1) for these cases of modeling should be noted: the rate of the process is considered directly as a function of the change in the studied characteristic from the life time:

$$\partial X/\partial \tau = C\{(1-\tau)^{m_d}\cdot \exp\left[\frac{\mu}{1-\theta\tau}\right] - k\cdot \tau^{m_r}\cdot (1-\tau)^{m_{em}}\} \quad (3)$$

where C=const, the dimension of which corresponds to the dimension of the studied characteristic X.

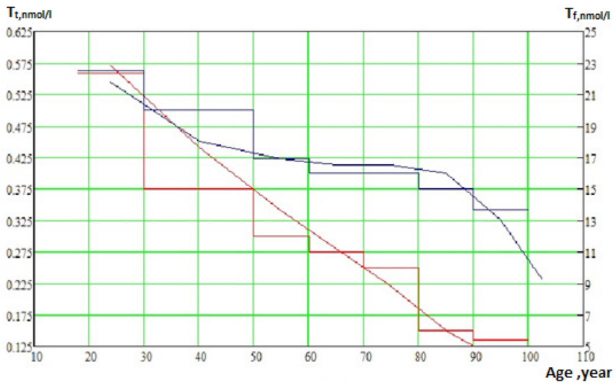

Figure 6. Dependence of changes in the concentration testosterone of total (T_t -upper curve) and free (T_f- lower curve) with age t of a person.

In Figure 6 the following designations are introduced: histograms indicate the data of [26], smooth solid lines are the results of the corresponding model calculations according to formula (3) with the model parameters indicated in Table 5.

The discrepancy between the results of model calculations and the data presented by other authors, on average, does not exceed 5%.

Table 5. Parameters of model (3) for testosterone concentration and basal metabolic rate

Characteristic	m_i	μ	Θ	k	C	t, year
Total testosterone concentration, T_t(nmol/L)	$m_d = m_r = 1$, $m_{em} = 1.5$	1.52	0.52	9.5	7.53	t=110τ;18≤t≤110
Free testosterone concentration, T_f(nmol/L)	$m_d = 2$, $m_r = 1$, $m_{em} = 2.5$	1.55	0.59	7.0	0.21	t=110τ;18≤t≤110
Basal metabolic rate for males, (kcal / m^2 hour)	$m_d = m_r = 1$, $m_{em} = 1.5$	1.55	0.55	7.0	11.61	t=100τ;0≤t≤100

In some cases, for a comparative description of the development of characteristics of dynamical systems with a small number of sufficiently reliable quantitative data, starting from birth, a very simple model is successfully used in comparison with the presented Equation (3) and is its special case (μ = -∞, k = - 1):

$$X(\tau) = C\cdot \tau^{m_r}\cdot (1-\tau)^{m_{em}} \quad (4)$$

This equation reflects the simple physical meaning of the dialectic nature of the aging process, as the probability of simultaneous structuring and destruction of the system, occurring from birth, which is realized in this equation as the product of the probabilities of two independent events simultaneously occurring in time τ - the probability of creating a new structure ≈τ ^ (m_r) and the probability of her death ≈ (1-τ) ^ (m_{em}) .This model can be used in practice when high accuracy of interpolation of results and forecast is not required. Figure 7 illustrates, by way of example, the applicability of such a model to describe the averaged probabilities of the residual functional abilities of some human organs. A complete schematic picture of such age-related loss of properties, similar for seven types of organs and tissues, is given in [27].

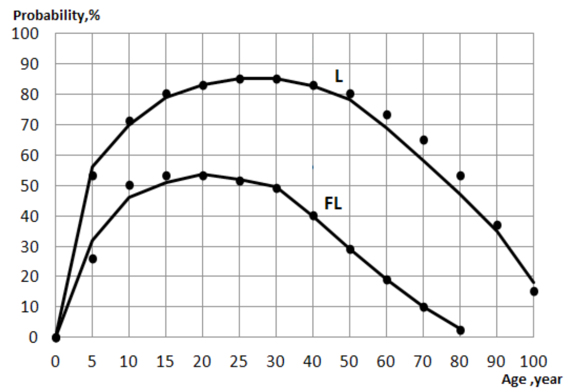

Figure 7. Dependence of the change in the average probability of the residual value of the lung function (L) and the function of the lymph nodes (LF) with the age t of a person.

In Figure 7 the following designations are introduced: the dots indicate the data of [27], the solid lines are the results of the model calculation according to the formula (4) with the following model parameters: for L (%): C = 1.73; m_r = 0.333, m_{em} = 0.9; t = 110τ; 0≤t≤110; for FL (%): C = 2.64; m_r = 0.650, m_{em} = 2.5; t = 100τ; 0≤t≤100.

Modeling the dynamics of aging of healthy cells in the body was complicated by the fact that the author did not find any reliable numerical information about this in the literature. Nevertheless, the data of gamma therapy were processed on the kinetics of the death probability of cancerous malignant neoplasms (MNP) in ten separate systems and human organs, depending on the absorbed dose D_r under gamma irradiation, given in [28]. Taking into account that during gamma therapy, the radiation power P_r can be considered constant, the dependence of the probability D of death of cancer cells of malignant neoplasms on the value of the absorbed dose D_r is a function directly proportional to the exposure time t ($D_r = P_r t$). Taking this into account, modeling of the dynamics of the probability of death of cancer cells was carried out using a simplified model (2), in which the dimensionless time τ was calculated as the ratio of the current absorbed dose to the maximum D_{rm} corresponding to the death of all cancer cells ($\tau = D_r / D_{rm} = t / t_m$) .

Interpretation of the results of such modeling corresponds to the ideology of this work, since radiation exposure can be considered as a factor of accelerated aging, taking into account also the fact that the form of the mathematical model when describing the aging of biological systems under radiation gamma irradiation does not change [11,29]. For example, Figure 8 shows the results of a model description of the dynamics of the probability of death of cancer cells of cancer in some systems and human organs, depending on the value of the absorbed dose of gamma radiation D_r.

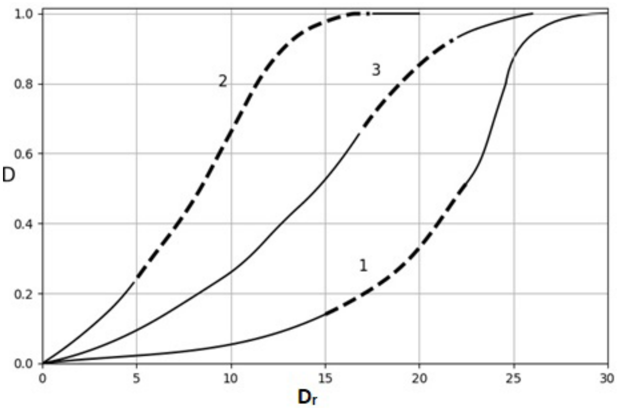

Figure 8. Dependence of the change in the probability D of death of cancer cells in some systems and human organs on the absorbed dose of gamma radiation D_r ($D_r = \tau D_{rm}$).

In Figure 8 the following designations are introduced: the dashed lines denote fragmentary data from [28], solid lines are the results of a model calculation using Equation (2). Curve numbering: curve 1 - Nasoph T 3.4 (nasopharyngeal cancer), curve 2 - Hodgkins (Hodgkin's lymphoma - cancer of the lymphatic system), curve 3 - Prostate (prostate cancer). The parameters of the model (2) are as follows: for the MNP of the lymphatic system $\mu = 1.498$; $\Theta = 0.51$; $k = 3.8$; $\tau = D_r / 20$; for cancer of the nasopharyngeal $\mu = 1.497$; $\Theta = 0.70$; $k = 4.4$; $\tau = D_r / 130$; for prostate cancer $\mu = 1.497$; $\Theta = 0.50$; $k = 4.1$; $\tau = D_r / 26$. The discrepancy between the results of the model calculation and work [28] is within a few percent.

The generalized results of the mathematical description of the dynamics of aging characteristics of biological systems of various hierarchies are shown in Table 6.

4. The Discussion of the Results

Differential Equation (1) was originally written as a general view of the basic mathematical model of the phenomenological kinetic theory of aging of living systems, the structure of which formed general ideas about the stress state of a person and his adaptation to the environment with the possibility of parametric accounting for the influence of factors of various nature [7-12].

The advantage of the model over other mathematical models of the aging process of systems was the idea of introducing dimensionless coordinates (scale invariance) for the characteristics and aging time, dialectical unity of simultaneously going processes of creation and destruction of structures and functions of any living system during its full life cycle from birth to death (or transition to a new state) and the assumed invariance of mathematical models of biochemical kinetics to describe the rates of competing aging processes for various hierarchical systems. On this basis, the invariance of the basic mathematical model was confirmed for describing the characteristics of aging of various biological species (fruit flies, mice, rats, dogs, horses and humans), including the possibility of parametric accounting for radiation and chemical factors of external influence [4,8,10], its generality in comparison with the special case of describing the intensity of mortality in the adult population - the empirical formula of Gompertz. It was also demonstrated that this mathematical model is promising in solving important practical problems in predicting the quality and survival time of patients after radiation therapy of cancer and the population with external radiation exposure in emergency situations [17-19]. This work was a conceptual continuation of the study of the invariance of the basic mathematical model (1) from the standpoint of its possible application for modeling the aging processes of living dynamic systems of various hierarchical levels and biological species. As a result of the research carried out here and the generalization of previous results, the fractality of the aging processes of dynamic systems - mankind, state, generations, general systems of the human body, its organs and cells, insects and animals of various species - has been illustrated. The studies were carried out on individual examples of the application of the basic mathematical model and its particular cases for modeling the evolution of aging characteristics of the considered systems in their life cycle. In order to improve the accuracy of the model description, the possibility of using the base model was demonstrated with the introduction

Table 6. List of considered systems, characteristics of their aging, models and areas of their applicability.

Dynamic system	Characteristic aging	Model, area applicability
Humanity	Population size, N (t) (billion people)	Equation (2) N(t)=10 D(τ)+2.53; 1950 ≤ t≤ 2050
	Average age of a person, B (t) (years)	Equation (2); B(t)=20 D(τ)+22 1970 ≤ t≤ 2100
State	Population N (t) (billion people) (USA, China, Russia)	Equation (2); Table.№4
	Average age of a person, B (t) (years), (Russia)	Equation (2); B(t)=22.5 D(τ)+25 1950 ≤ t≤ 2070
Generation, population	The density of the probability of human death ∂D /∂τ; (Russia, Japan, Sweden)	Equation (1); 0 ≤ t≤ 100
	Human death probability, D (τ) (Russia, Japan, Sweden)	Equation (1); 0 ≤ t≤ 100
	Mortality rate, (∂D / ∂τ) / (1-D), (Russia, Japan, Sweden)	Equation (1); 0 ≤ t≤ 100
Human: body systems	Basal metabolic rate, BMR (kcal / m^2 hour) for males	Equation (3); 0 ≤ t≤ 100
	Testosterone T concentration (nmol / l) general and free	Equation (3); 18 ≤ t≤ 110
organs	Residual value of lung function, L (%)	Equation (4); 0 ≤ t≤ 110
	Residual lymph node function, FL(%)	Equation (4); 0 ≤ t≤ 100
cells: malignant neoplasms in human systems and organs	Probability of death of cancerous MNP lymphatic systems during gamma radiation therapy with a dose D_r(Gr)	Equation (2); $0 \le D_r \le 20$ Gr
	Probability of death of cancerous MNP nasopharynx with gamma radiation therapy with a dose D_r(Gr)	Equation (2); $0 \le D_r \le 30$ Gr
	Probability of death of cancerous MNP of the prostate with gamma radiation therapy with a dose D_r(Gr)	Equation (2); $0 \le D_r \le 26$ Gr

of the dependence of its main parameter μ on the aging time. The possibility of a significant simplification of the model for individual special cases of the evolution of aging characteristics is shown when neglecting the non-monotonicity of the complex structure of the dynamics of aging in the region of the initial lifetimes of the system or when modeling the evolution of the system from birth to death for a comparative description that does not require a high accuracy of approximation of experimental data.

The results of the studies carried out in this work, as well as the previously mentioned published works on modeling the aging characteristics of living systems of various biological species, allow us to draw the following conclusions.

5. Conclusions

There is reason to believe that modeling the aging of characteristics of living systems of various hierarchical levels and nature with a single basic mathematical model and its simplified modifications reflects the fractal property of aging in living dynamic systems.

Conflict of Interest

The Author declare that there is no conflict of interest.

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