HISTORICAL PERSPECTIVE ON KINETICS OF HUMAN MORTALITY

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Results of studies on the kinetics of survival of organisms have recently been applied in the field of gerontology in order to determine its effectiveness [1, 2] and to verify diverse theories of aging [3-6]. This work attempts to use the kinetic approach to examine the following three questions, relating to human ecology.

1. Why has the duration of human life increased?
2. What caused the cessation of the increase in length of life, observed at present in developed countries?
3. How may the duration of human life be further increased?

To resolve these questions we used linearization of statistical data on age-related dynamics of mortality, proposed by us previously [5]. This method is based on plotting the logarithm of increase in probability of death ($\log \Delta R_t$) as a function of age (t). To verify the applicability of this method of linearization we developed 285 brief tables of human mortality, using the published data [7] for all geographical areas of the world: Africa, America, Asia, Europe, USSR, Australia, and Oceania. It turned out that in the coordinates which we proposed, 242 relations were linear with correlation coefficient $r \geq 0.98$. For 74% of the cases examined $r \geq 0.99$.*

As demonstrated previously [5], the linear nature of the dependence of $\log \Delta R_t$ on t signifies that the probability of death increases with age in accordance with the Gomperts–Meikhem equation. This equation has the following form:

$$R_t = A + R_0 \exp(\alpha t), \tag{1}$$

where R_t is the probability of death (mortality) of people at age t during a given time interval; A, R_0 and α are constants for a given biological species and constant conditions of existence. The variable portion of the equation, $R_0 \exp(\alpha t)$, characterizes the increase in mortality with age which is the result of the aging pro-

*Each curve contains 9 points at 5-year intervals. The age range included in linearization is 35-75 years.

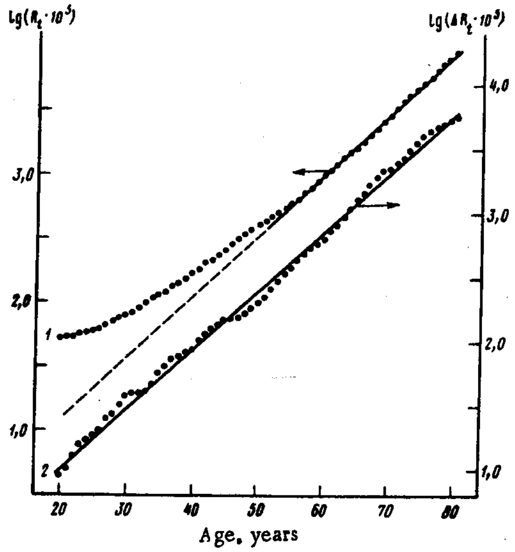

Fig. 1. Logarithm of mortality (1) and logarithm of increase in mortality (2) as functions of age for Italian women in 1964-1967. Based on an official complete mortality table [11]. A five year interval was use to compute increase in mortality (ΔR_t).

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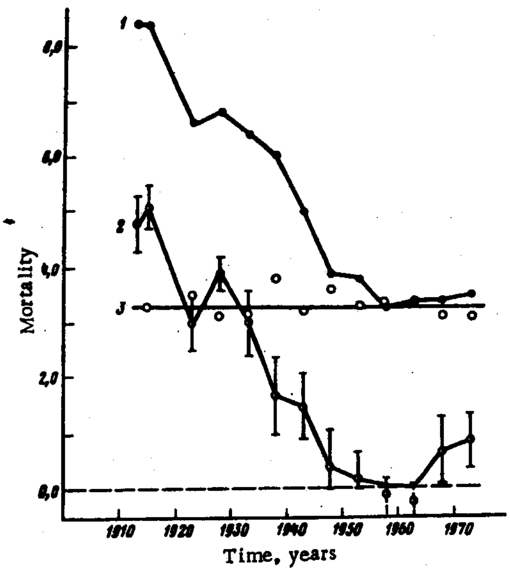

Fig. 2. Change in total mortality (1), base-line mortality (2), and age-dependent mortality (3) from 1911 to 1975. The values for mortality represent the number who died during the course of the year per 1000 45-year old men.

TABLE 1. Values for Gomperts–Meikhem Equation Parameters and Correlation Coefficients for Populations of Swedish Men*

Years	Correlation coefficient	$\log(R_0 \cdot 10^6)$ (per year)	α (year^{-1})	$(A_m \pm \sigma) \cdot 10^3$ (per year)
1911–1915	0,998	1,63	0,099	4,8 ± 0,5
1911–1920	0,998	1,55	0,101	5,1 ± 0,4
1921–1925	0,998	1,62	0,098	3,0 ± 0,5
1926–1930	0,999	1,47	0,103	3,9 ± 0,3
1931–1935	0,996	1,48	0,103	3,0 ± 0,6
1936–1940	0,996	1,66	0,098	1,7 ± 0,7
1941–1945	0,996	1,56	0,100	1,5 ± 0,6
1946–1950	0,996	1,63	0,098	0,4 ± 0,7
1951–1955	0,997	1,59	0,099	0,2 ± 0,5
1956–1960	0,998	1,60	0,098	−0,1 ∓ 0,3
1961–1965	0,998	1,61	0,099	−0,2 ± 0,3
1963–1967	0,997	1,57	0,099	0,2 ± 0,5
1966–1970	0,997	1,52	0,101	0,7 ± 0,6
1967–1971	0,997	1,52	0,101	0,8 ± 0,6
1968–1972	0,997	1,50	0,101	1,0 ± 0,7
1969–1973	0,998	1,53	0,100	0,8 ± 0,7
1970–1974	0,998	1,55	0,100	0,7 ± 0,5
1971–1975	0,999	1,52	0,101	0,9 ± 0,5

*The values of parameters were calculated for the age interval 45–80 years, using the linearization method which we proposed. The methods for calculating the coefficients R_0 and α were described in detail in our previously published work [5]. The standard deviations for α and $\log(R_0 \cdot 10^6)$ were 1-2% and 2-4% respectively. The coefficient A was calculated by the formula $A_m = \frac{1}{31}\sum_{t=45}^{75}(R_t - R_0 \exp(\alpha t))$.

cess. The value A represents base-line mortality due to causes unrelated to age. Gomperts' well known formula is a special case of equation (1) with A = 0. However, it can be demonstrated that base-line mortality cannot be ignored for human populations and so Gomperts' equation is not applicable in the given instance. Fig. 1 presents the logarithm of mortality ($\log R_t$) and the logarithm of increase in mortality ($\log \Delta R_t$) as functions of age. We should note that a reliable linear relation is observed only for the second case. This means that increase in mortality with age is described by Equation (1), where A is not zero. We should note that not only does the Gomperts–Meikhem equation hold for human populations [5], it may be derived theoretically using reliability theory [5, 8]. This provides a basis for using the Gomperts–Meikhem equation to analyze statistical data on human mortality from a historical viewpoint. We have previously demonstrated the possibilities of such an approach [9].

We applied the Gomperts–Meikhem equation for statistical investigation of the mortality of Swedish men from 1911 to 1975. The Swedish data was chosen for its detail, since it was published in the form of 18 complete mortality tables [10]. The results are presented in Table 1. First of all, within our proposed coordinates, we found the correlation coefficient $r \geq 0.996$ for all functions,* which demonstrates the applicability of our linearization method in this instance. However, the most surprising fact is that the coefficient A was the only parameter of the Gomperts–Meikhem equation which reliably changed during the period from 1911 to 1975. Figure 2 illustrates the biological meaning of this fact. Thus, the sole cause for the decrease in human mortality is the decrease in base-line mortality (A). Age-dependent mortality, $-R_0 \exp(\alpha t)$, hardly changed from 1911 to 1975. In 1946-1950 the base-line mortality of Swedish men decreased to a limiting level close to zero, exhausting the reserve which could increase length of life. These results suggest that further reduction of mortality and lengthening of human life must be pursued by new means, not previously employed. This presupposes the reduction of age-dependent mortality, $-R_0 \exp(\alpha t)$. Thus, in developed countries the prospects for further increase in length of life are limited by the possibilities of experimental gerontology.

In conclusion we should note that our proposed method for analyzing age dynamics of mortality is not limited to usefulness in solving demographic and ecological problems. This method may also be applied to the biology of aging insofar as it clarifies the effects of various factors on length of life, as shown in survival tables. The precision of these results suggests that splitting total mortality into two components (base-line mortality, not dependent on age, and age-dependent mortality) is not formal and artificial, but rather a reflection of objective reality. Finally, the very existence of base-line mortality implies that rate of aging cannot be determined from length of life.

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*Each line contained 31 points with one year intervals between them. The age range of the linearization was 45 to 75 years. Five year intervals were used to calculate increase in mortality (ΔR_t).