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# Comment on “The plateau of human mortality: Demography of longevity pioneers”

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Barbi *et al.* (Reports, 29 June 2018, p. 1459) reported that human mortality rate reached a “plateau” after the age of 105, suggesting there may be no limit to human longevity. We show, using their data, that potential lifespans cannot increase much beyond the current 122 years unless future biomedical advances alter the intrinsic rate of human aging.

Barbi and colleagues provide new high-quality data that show a mortality rate plateau for Italy after age 105 from birth and death records (*1*). Calculating from annual mortality rates of 0.475, the life expectancy at age 105 is 1.5 years. Lower plateaus are indicated for the growing survival to extreme age [figure 1A of (*1*)], and the authors conclude that a limit to longevity, “if any, has not been reached.”

However, our calculations suggest that the current record of 122 years cannot be exceeded by much without major advances in combatting mortality at both younger and advanced ages. Two very different models yield similar estimates of maximum survival age,  $T_{\max}$ . The simplest “radioactive decay” model assumes exponential decline of survival at a fixed mortality rate and calculates the age of the last survivor (*2*). Starting at the plateau level of mortality for age 105 in Barbi *et al.*, the upper part of Table 1 calculates the  $T_{\max}$  by gender for different numbers of initial survivors,  $N$ . Thus, the  $T_{\max}$  for a constant rate of annual mortality at age 105 for Italy would be at least 2 years below the record 122-year  $T_{\max}$  of Jeanne Calment, even for a cohort size of 10,000 at age 105. Notably, the impact of increasing cohort  $N$  on  $T_{\max}$  is attenuated logarithmically ( $\ln N$ ) (*2*). To attain a 50:50 chance of someone reaching 150 years of age given this plateau would take more than 4 trillion 105-year-olds, about 450 times the current world population of 7.5 billion (*3*). Further calculations based on the Gompertz model of Barbi *et al.* (lower part of Table 1) or on the basic Gompertz equation (*4*) also show limits to  $T_{\max}$  that differ by gender for different numbers of initial survivors. These calculations challenge conclusions that mortality plateaus allow unlimited longevity potential.

Since Calment’s death in 1997 at the age of 122, the numbers of people reaching 110 years have increased by a factor of 2 (*3*). Yet no subsequent lifespan has exceeded 120 years. The longest-lived Italian was Emma Morano, who

died at 117.3 years in 2017. Our calculations of  $T_{\max}$  from Gompertz exponential mortality rates closely agree with reported records, with greater potential  $T_{\max}$  for women by 7 years (*4*). Although Barbi *et al.* state that the Gompertz model does not hold after age 80, >95% of adult mortality in the Italian cohorts is described by the Gompertz model (*5*), which would concentrate the mortality plateau to a critically narrow domain of <5% of the Italian mortality regime. Moreover, the Gompertz slope has become steeper for both genders within the 20th century with the decline of baseline mortality (*4*). We share the caveats of Barbi *et al.* that mortality rates after age 105 have uncertainties in many populations.

In sum, regardless of whether one chooses an extrapolation assuming a mortality plateau after age 105 as calculated by Barbi *et al.* or by a continued Gompertzian increase in mortality after that age (*4*), the likelihood of anyone surviving much beyond the longevity record of Calment becomes remote unless unexpectedly large biomedical advances prove to ameliorate the basic biology of human aging.

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**Table 1. Calculations of remaining lifespan at age 105 for Italian data and projections of population sizes required to reach selected age maxima.** Each model begins with the 463 males and 3373 females in the Barbi *et al.* 1904 birth cohort;  $P$  represents initial population size. In the “radioactive decay” model,  $N/P = \exp(-mt)$ , where  $m$  is the annual mortality rate; for age of the last survivor,  $N$  is set at 1, yielding  $T_{\max} = -(1/m) \ln(1/P)$ . In the Gompertz model as calculated in Barbi *et al.*,  $m(x) = a \times \exp(bx) \times \exp(\beta_1 C + \beta_2 M) \rightarrow S(x) = \exp\{a/b \times [1 - \exp(bx)] \times \exp(\beta_1 C + \beta_2 M)\}$ , where  $a$  and  $b$  are the Gompertz parameters;  $C$  is cohort birth year minus 1904;  $M = 1$  for males and 0 for females;  $\beta_1$  and  $\beta_2$  are coefficient estimates for cohort and sex, respectively; and  $S(x)$  is the survival function at age  $x$ . Then, the expression  $1/P = \exp\{a/b \times [1 - \exp(bx)] \times \exp(\beta_1 C + \beta_2 M)\}$  yields  $T_{\max} = \ln\{1 + [b \times \ln(P)]/[a \times \exp(\beta_1 C + \beta_2 M)]\}/b$ .

Male			Female		
$P$	$T_{\max}$	$T_{\max}$ age	$P$	$T_{\max}$	$T_{\max}$ age
<i>Radioactive decay model</i>					
463	9.43	114.43	3,373	12.92	117.92
4,630	12.97	117.97	33,730	16.58	121.58
46,300	16.51	121.51	337,300	20.24	125.24
463,000	20.05	125.05	3,373,000	23.90	128.90
4,630,000,000,000	44.82	149.82	3,373,000,000,000	45.86	150.86
<i>Gompertz model as calculated in Barbi et al. (1)</i>					
463	8.90	113.9	3,373	11.94	116.9
4,630	12.00	117.0	33,730	15.01	120.0
46,300	15.00	120.0	337,300	17.97	123.0
463,000	17.81	122.8	3,373,000	20.81	125.8
46,300,000,000,000,000	43.77	148.8	33,730,000,000,000,000	44.64	149.6



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