On Aging and Life Span of Human Species Based on its Evolution from Australopithecus up to Modern Human

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Abstract: Applying the mathematical model of vitality in human aging we have estimated the total life duration of human species and the follow up of its involution. The increase of cranial capacity during genus homo evolution and the rise of life span in different periods from ancestral times have been used as parameters. We postulated that increasing longevity negatively influences the species maintenance. The data used for calculations are supported by publications of well-known palaeontologists.

The vitality of human species progressively increased during its evolution up to a maximum at about 3.45 million years of species age (1.3 million years ago). From that time vitality slowly declined. The species life span has been calculated between 10.1 and 11.9 million years. The results point out that the slow growth during the evolutionary process positively influences the species life duration throughout delaying the age of maximum vitality. On this basis we try to explain the extremely great longevity of the Homo floresiensis; from around 4 million years ago up to 18,000 years from now.

INTRODUCTION

Each and every existing element has a beginning and an end. Outstanding is the case of living beings, such as mammalians, which posses a dynamic existence with a growth period in which the vitality continuously increases. Once the growth and differentiation have concluded, the organism reaches maximum vitality. This corresponds biologically to optimal life [1]. The decline of vitality expresses aging in which wear, repair, and entropy are mutually interacting. Some years ago, Beier and co-workers described this process mathematically using a model which allows detecting the age of maximum vitality, the rate of aging, and the expected life span on the basis of the development of individual growth and differentiation [2, 3].

The concept of vitality, as deduced from such a mathematical model, has shown how useful it is to understand and estimate the biological age [4-6]. The present work aims to apply this concept of individual vitality to human evolution. Its decreasing behaviour would be understood as the process of biological regression or involution of human species. Furthermore, we take into account the fact that longevity may be a "risk factor" for species extinction. For this reason, the increasing life span of individuals from ancestral times until nowadays could be seen as a biomarker of species regression. Finally, based on both brain-growth evolution and individual life span increase, our aim is to estimate the expected life of human species.

In this context it seems of interest the question on the "long life" of homo floresiensis, who lived up to relatively "recent" times in spite of showing a very early evolution stage; probably starting at the age of australopithecus/homo. Homo floresiensis, exemplified by the fossil of Ling Bua1 (LB1), was found about 18.000 years ago [7], but his cranial capacity was drastically reduced to 417 cm^3 compared with that of Homo sapiens [8]. There is a relationship between brain size and evolution state of genus homo. Indeed, the cranial capacity enlarged from around 700 cm^3 in Australopithecus/Homo Australopithecus to 1330 cm^3 in Homo sapiens [9]. Compared with that type of measurements and considering these values in relation to those of the evolution scale, Homo floresiensis should "biologically" belong to the age of Australopithecus afarensis (Lucy), about 4 million years ago.

Homo sapiens appeared, approximately 500,000 years ago. From Homo erectus subsequently Homo sapiens developed in the preneanderthal line (homo antecesor of Atapuerca [10] and homo heidelbergensis) and in that of protocromagnon. Homo heidelbergensis developed in Homo sapiens neandertalensis, which would have disappeared 30,000 years ago, while the protocromagnon in our ancestor Homo sapiens. Nevertheless the major increase of encephalisation in genus Homo occurred during the Middle Pleistocene, 600,000 -150,000 years before present. In fact that period between 150,000 and 100,000 years ago saw how the absolute brain size reached approximately modern ranges [11]. It is not well known how long the Homo managed to live, nor how long was their growth period.

There was probably no stop in evolution. Therefore, human species life shows a continuous development. In this sense, some changes during the last century are remarkable: a). Human beings became taller so that the body size increased progressively. Remarkable is the case of males who have reached a mean height of more than 12 cm approximately compared to early 20th century [12], showing also an increase of brain size [13]. b). Body growth period was shortened of more than 4 years if compared with the beginning of 20th century [14] as the maximum of growth was reached at age of 25. In that time males in Italy grew around

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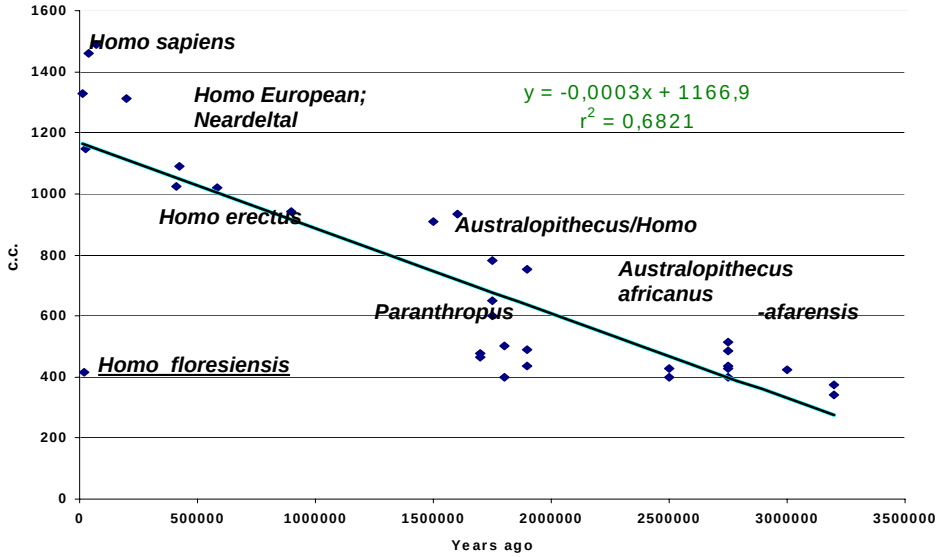

Fig. (1). Cranial volume from australopithecus up to homo sapiens (Data recorded by Falk [18] following Holloway *et al.* [9] and Falk *et al.* [22]).

6.3 cm from 21 to 23 years old [15]. c). Life span increased each decade continuously up to present times, probably related to slower aging rates. It is unclear, however, if such changes interact linked together or independently. Indeed the impact of these changes on the life expectancy in the future is unpredictable.

METHODOLOGY

The methodology is based on parameters pointing out the development of the brain along the evolution of genus homo. For this purpose, it was necessary to analyse the evolution of the cranial capacity alone or in relation to body length with the aim to find out data which could be used as parameters in the mathematical model of vitality. In fact, while early Homo (from habilis to ergaster) had cranial capacities from 500 cm^3 to 800 cm^3, Homo erectus showed drastic brain enlargement from 750 to 1250 cm^3 (see Fig. **1**). Therefore, from early Homo to Homo erectus there is an increase of cranial capacity between 25 and 40 percent (depending on the starting point of the comparative sample). Nevertheless there are variations in such measurements. A fossil skull of Homo erectus of 1.4 million years ago found in Oldvai (East Africa) had an estimated capacity of 1067 cm^3 [16], while that of East Turkana of 1.8 million years had 848 cm^3 [17]. Similarly, the fossil of a boy in West Turkana had 880cm^3 , being the estimated adult capacity of 909 cm^3 . Yet, as Fig. (**1**) shows, the cranial capacity increased according a lineal regression with r^2 0.7. Therefore, these data could be used as a valid reference for our mathematical model.

One the other hand, parallel to what has been mentioned above, Homo erectus displayed an increase of body size [19]. On the basis of a skeleton found in Kenya it has been calculated that his adult stature was 180 cm (!). Other authors estimate that Homo erectus reached an adult stature of 167.5 cm having a body weigh a little more than 45.5 kg [20, 21]. It should be taken into account that Homo erectus lived during a period of more than 1.5 million of years. In any case, the body size increased up to Homo sapiens, although the recorded values are not very consistent, as the Fig. (**2**) shows. Indeed, they indicate great variation; the r^2 value is never over 33%. For this reason these data are not sufficiently valid for basic applications.

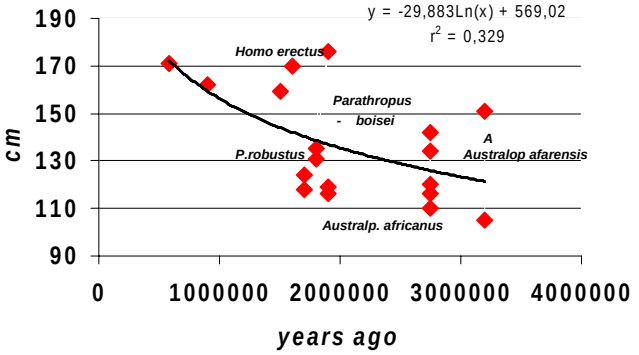

Fig. (2). Changes in stature during human evolution (homo floresiensis is not included) (According to data from McHenry [20]).

Nevertheless, indeed there is a relationship between cranial capacity and stature in hominids, but the r^2 is low and the number of values is small. Fig. (**3**) shows the weakness of these points which force one to exclude them as reliable parameters.

In conclusion, rather than body size, cranial capacity is a more reliable parameter to indicate growth. On the other hand, cranial capacity increased along the evolution showing similarities with the growth process of human individuals. As Fig. (**4**) shows, 3 growth phases are also observed, the last two having the greatest accelerations, especially the last one.

In order to have age as a reference within the evolution time we set the date of Australopithecus appearance up to present in a *total living time* of around 5 million years (5,002008 years). In doing so, the age of one hominid results from such *total living time*. For instance, the Australopith-

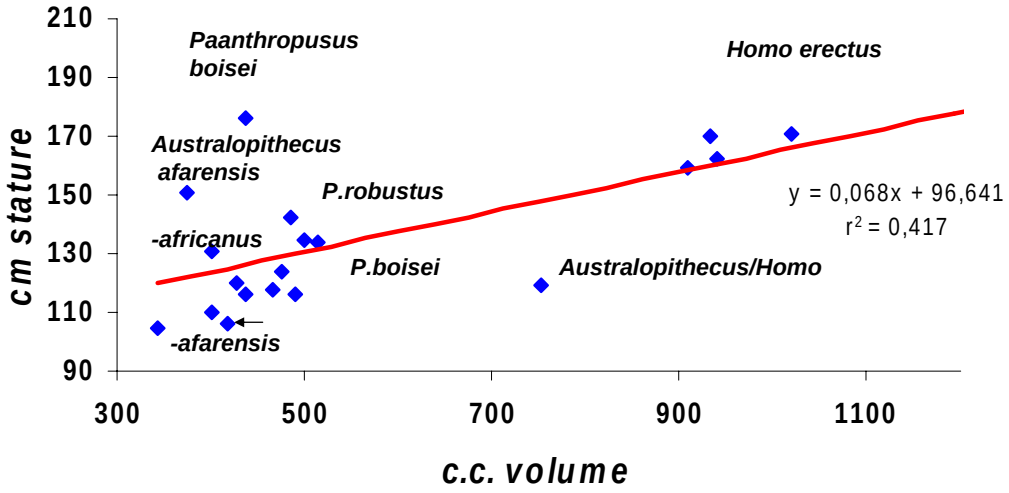

Fig. (3). Relationship between cranial capacity and stature in hominids including Homo floresiensis(with arrow) (According to data records from Falk [18] and McHenry [20]).

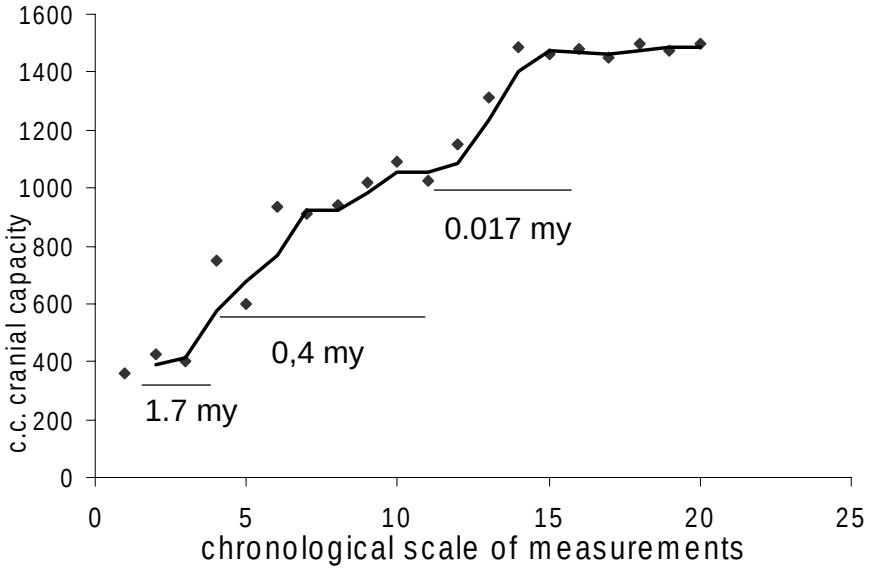

Fig. (4). Development of cranial capacity in around 5 million years. The shortest time but the major increase corresponds to the last period of evolution of approximately 17000 years. The longest time has the lowest growth rate which belongs to the first period. (Cranial capacities of adult hominids based on data from Falk [18]).

ecus afarensis, found around 4.5 million years (milly) ago (Lucy), is a very young hominid as deduced from his age of 502,008 (5.0- 4.5=0,5) years. On the contrary, Homo erectus is remarkably older. He was dated in 950000, so that his age is 4.052 milly (5.0-0.95=4.05). In such a manner, the values of cranial capacity, which were obtained from several publications [9, 18, 23], were expressed in dependence on age.

The vitality dependent on the evolution age (Vt) was calculated according to the vitality concept (6), which has growth and aging as factors for respective calculations,

$$Vt = \exp(\exp(-kt)\ln w0 - ßt) \quad (1)$$

being k the growth constant of the cranial capacity, and w0 the quotient between the first registered value in the evolution scale and the highest one; ß represents the regression (aging) factor. So that

$$k = (1/tmgr)\ln(\ln cctm)/\ln w0) \quad (2)$$

being tmgr the relative age of hominid when the cranial capacity(cc) shows the highest rate of increase, and cctm the quotient of the respective value / maximum reached at the end of evolution. Plotting cc against t (age calculated as above) tmgr results at relative ages between 4.4 and 4.8 million years (date 600000- 200000 before present) for k 0.312 and $0{,}52 \cdot 10^{6} year^{-1}$ respectively. It was at that time when it should have taken place the major increase of encephalisation, in agreement with the range already reported [11].

Regarding the factor ß, we postulated that the species regression (=aging) is linked to the reduction of descendents. As this reduction seems to be related to longevity, we collected data on life expectancy from publications [24-27] and general informative reviews [28]. In order to fix the ß value for equation (1) we obtained the slop of the exponential-regression of life span against relative age from early hominids to modern human. These values satisfactorily fit with

the function $y=80,4x^{-0.137}$ having r^2 63.3%. The exponent value of -0.137 was taken as aging factor ß.

The maximum vitality reached during evolution (Vtm), may be calculated according to

$$Vtm=(1/k)\ln(-(k/ß)\ln w0) \quad (3)$$

Furthermore, deduced from the already mentioned vitality concept, we calculated the total life span (T) of genus homo as we already have published for individuals [29, 30]

$$T=1/ß-(1/k)\ln w0 \quad (4)$$

When T is known, ß may be calculated from the above equation as

$$ß =1/(T+(1/k)\ln w0) \quad (5)$$

On the other hand, when ß is directly deduced from the growing up process during species evolution, based on equation (3)

$$\ln(-(k/ß)\ln w0 = z \ln(-\ln w0) = \ln((-\ln wo)^z$$

$$k/ß = (-\ln w0)^{z-1}$$

$$ß = k/(-\ln w0)^{z-1} \quad (6)$$

RESULTS

The curve of species vitality shows an increase up to a maximum and then a decline (Fig. **5**). Since the first component depends on factor k, which indicates the growth up acceleration, the second one means aging or regression. As Fig. (**5**) shows there are essentially two types of curves dependent on the growth constant k when the aging factor ß remains unaltered. Nevertheless curve **a** and **b** have a similar behaviour. As from their shape may be deduced, the species vitality reaches the maximum at a relative age between 3 and 4 million years.

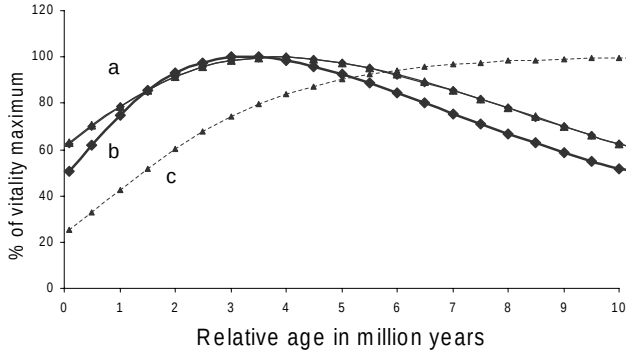

Fig. (5). Vitality curves according to equation (1) in human species during its evolution showing a behaviour dependent on the constants used. Curves **a** and **b** have the same regression factor ß (0,137) but different growth constant k (0,312 versus 0,52).The higher value in **b** indicates more growth acceleration and increase of regression rate as the declining curve shows. Curve **c** demonstrates the influence of the hypothetical low value of ß (0.0004) which may delay the vitality maximum despite having the same k value as for **b**.

Table **1** shows the results applying the equation number (3) and (4), respectively.

Table 1.

	Vtm (million years)	(k)	T (million years)	(ß)
a	3.8	(0.312)	11.9	(-0.137)
b	3.1	(0.52)	10.1	(-0.137)
c	14.5	(0.52)	2502	(-0.0004)

Vtm = relative age of vitality maximum; T = species life span; k = growth constant according to equation (2); ß = regression factor of human species calculated as mentioned in the methodology.

The results show that a longer life span is related to a later age of maximum vitality. Moreover, when the factor ß does not change, differences in life span are due to variations of the growth constant. In that sense, higher growth acceleration causes an early decline of vitality, meaning that life span becomes shorter. On the other hand, low regression (aging) rates clearly influence this result throughout diminution of the slop in declining vitality; consequently, life span becomes longer. In any case, according to our methodology criteria, the result for the species life-span lays between 10.1 and 11.9 million years.

DISCUSSION

This work aims to answer the question of how long will exist the human species. When there is a limit, it is to assume that there is a biological regression. Its progressive advance would end after crossing this limit. Moreover, such regression should start from a maximum value. In human biology, the age dependent decline means aging.

Our results are not easy to demonstrate, but there are some reasons to support them. It seems logical that vitality behaves in human species during evolution as in human individuals during their life. Similar to human individuals, there is a maximum of vitality reached after the end of the growth period which agrees with the curve of encephalisation. But the main question is how long the species life period is. This has been calculated between10.1 and 11.9 million years. It spans the total existence of human species, from the date of Australopithecus around 5 million years ago. Therefore, the human species would further exist about 5-7 million years from now. This seems to be a valid estimation.

First of all, it must be said that the age dependent increase of cranial capacity during human evolution behaves as a Gompertz-function, similar to body size in human individuals with increasing age (see Fig. **4**). Regarding the aging factor as indicator of biological regression of the species, it must be stressed that, as mentioned in the methodology, this factor has been calculated according to the criterion that increasing longevity negatively influences the species existence. Its dimension has no primary link to growth process.

On the contrary, the original vitality model of human individuals deduces both the k constant and the aging factor ß from growth process. Therefore it seems necessary to compare procedures as following: A) The relationship between k/ß is around 4.68 (0,089 $year^{-1}$/ 0,019 $year^{-1}$) for individuals. According to our calculations, this quotient is for human species 0.52/0.137 = 3.79 or 0.312/0.137= 2.28.

Bearing in mind a great variation, these differences are not significant. B) Applying equation (6) when z = 5,001 milly /4.41milly =1.33 (age of maximum cranial capacity reached during evolution/age of respective highest growth acceleration) and using k 0.312 $.10^{-6}$ $year^{-1}$, the ß factor results in $0.186 \cdot 10^{-6}$ $year^{-1}$ .With the help of these constants, the species life span is T =10.03 million years, close to our range shown in table 1. C) Considering that the growth period of human organism ends with 20 years (mean value between 22 years in the past and 18 at present), and that the maximum life span is 122-100 years, the period of body growth (in percent of life span extrapolated to cranial growth up to reaching the end during human evolution) may permit to calculate the total species life. The result varies between 12.95 - 10.55 million years. This range is also close to our calculations. D) According to equation (5), when using k from cranial growth as above mentioned, and T empiric for species life as above, the ß value is $0.170- 0.098 \cdot 10^{-6} year^{-1}$. This value is not remarkably different from that obtained with the help of the longevity criterion. Table **2** compares the mentioned results following either procedures.

It is known that, quite opposite to short livers, long living mammalians have few descendents. The species maintenance seems to be related to the proper turnover. From demographic data collected in the past century until to day, it may be deduced that there is a close relationship between increasing longevity and reduction of descendents [31]. Nevertheless, there are many causes which could contribute to the sudden extinction of human species as in the case of dinosaurs or due to super volcano (Toba) eruptions [32]. Moreover, there would be other factors causing regression as those related to environment pollution which are not included in the vitality concept. Nevertheless, it seems logical to postulate that longevity could be a biomarker of species regression.

As it has been already said, the slow growth prolongs the life span. The best example is obtained when delaying the maximum vitality either throughout low growth constant k or very reduced aging factor ß (see Fig. **5**). This point seems to be of interest in relation to Homo floresiensis. According to phenotypic features, the Homo floresiensis would be a hominid in an evolution stage of around 3.5 - 4 million years ago (see Fig. **1**), despite he lived 18,000 years ago. The relative age of Homo floresiensis suggests that it was biologically young, at the beginning of genus homo evolution. Having a small cranial capacity, less than what would be expected in relation to the short stature (see Fig. **3**), two explanations are possible: 1.-Homo floresiensis belongs to a proper species, different from Homo sapiens. 2.-The alteration causing a microcephalic dwarfism is due to IGF-1 (insulin growth factor-1) deficiency by primary growth hormone (GH) insensitiveness (Laron syndrome) [33, 34]. Affected individuals have a slow growth process which explains the low stature mainly the small brain, among other features present in Homo floresiensis [34]. In relation to the slow growth process, it is well known that Laron syndrome affected individuals live longer [35]. Such influence on life span has been reproduced in experiments inducing GH insensitiveness [35, 36].

Extrapolating the influence of growth retardation on life span of human individuals in terms of evolution, it could be said that hominids with a very slow growth process had a delayed evolution of brain and stature. The mathematical model of vitality shows an inverse relationship between growth constant and life span. On this basis, assuming a very slow growth in Homo floresiensis related to low regression, it would be possible that the evolution was delayed and the life span enlarged. Assuming that longevity has a negative influence on descendents, this fact could have caused the "precocious" extinction of Homo floresiensis.

Because a small brain is the main characteristic which differentiates the Laron Syndrome from other types of dwarfism [37], it is interesting to consider the role of brain size indicating human evolution. In fact, the cranial capacity has enlarged from Australopithecus to Homo sapiens progressively, from around 700 cm^3 to 1330cm^3 [9]. Compared with aforementioned measurements, Homo floresiensis had a cranial capacity drastically reduced to 417 cm^3 [8]. Therefore from this point of view, the evolution of Homo floresiensis was remarkably delayed due to IGF-1 deficiency or not. Furthermore, according to the linear regression of cm stature against cm^3 skull capacity in genus homo evolution, Liang Bua1 should have had around 120 cm stature instead 106 cm. Therefore, Homo floresiensis would be neither a homo sapiens dwarf with microcephaly, nor a pathological microcephalic specimen of Homo sapiens [38]. Finally, it should be mentioned that recent studies point out the role of IGF-1 in the control of longevity [39].

Mechanisms of biological aging are poorly understood. They are molecular processes that cause gradual decline over time determining the biological age. As the different intensity of such processes is related to particular interindividual variations, aging may be different in individuals with same chronological age. This fact could be extrapolated to populations and also to hominids living in separated world regions. Despite the fact that we do not know how long the growth period in the remote past was, we may guess that it was much shorter than at the present, although probably not homogeneous in all regions where hominids lived. For similar reasons, the evolution changes would be dependent on how quick or low was the "turn-over" of individuals in one specific region. This fact may explain some differences in biological differentiation of, for instance, Homo erectus who lived in different parts of the world. Likewise is the case of Homo floresiensis, whose anthropoid differentiation could have been delayed by a remarkable slow biological devel-

Table 2. Species Regression Factor (ß) and Species Life Span (T) Dependent on the Calculation Manner (More Details in Text)

Based on:	Growth + Life Expectancy	Growth	Empiric Life Span
ß: ($\cdot 10^{-6} year^{-1}$)	0.137	0.186	0.17-0.098
T: (million years)	10.1-11.9	10.03	10.5-12.9

opment. It may be possible that an especial environment could have conditioned very low rates in biological aging, so that the anthropometric features would remain practically unchanged during millions of years. Nevertheless, as a result of delayed progression of body development, it is possible that the life span of these hominids was remarkably longer if compared with those of other regions. Therefore, they would have had a longer adulthood with less evolution changes, but more time for specialisation in finding out, for example, how to elaborate stone tools [40]. Furthermore, a deceleration of individual body size development would delay mortality rates enlarging life span. As said above, the latter reduced the turn-over of individuals and therefore affected the evolution.

CONCLUSION

The mathematical vitality model for human aging may be applied in human evolution, when the increase of cranial capacity during evolution of genus homo is taken as growth parameter.

Similar to human individuals, the cranial growth acceleration is negatively related to species life span, so that the species vitality declines earlier.

As it has been observed in individual aging, the species regression is dependent on growth, but its acceleration is reversely dependent on increasing longevity. The latter may be a marker of species regression and therefore predictor of species extinction.

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