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# Exceptional longevity in Okinawa: Demographic trends since 1975

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Demographers have studied the Japanese mortality pattern since Japan became the most longevous population worldwide, half a century ago. Nutrition and lifestyle were considered by epidemiologists, gerontologists and other scientists as the most important reasons explaining the Japanese superiority. In Okinawa, the mortality pattern is even more exceptional, but few demographers have pointed out this exception. Other scientists proposed different explanations – for example some genetic characteristics, less salt and more animal protein in the food, a mild climate, a higher level of activity, a better consideration of the oldest in the population and, globally speaking, a more traditional lifestyle. At the end of the 1980s, lower improvements of mortality among young adults were identified in Okinawa. In 2002, Okinawa fell from the 4th to the 26th place in the ranking of the 47 Japanese prefectures by male life expectancy. This has been considered by the population of Okinawa as a 'shock'. Our in-depth analysis of available life tables and associated mortality rates proves that the population of Okinawa is divided into two groups of generations: those born before World War II and those born after. The older generations clearly experience a highly favourable mortality pattern, whereas the younger generations show mortality levels that are definitively higher compared to mainland Japan. This contribution considers which factors may explain such a situation, including the plausible invalidation of the age of some oldest in the population. We plea for in-depth demographic age validation that will enhance all scientific findings so far and boost the exceptional longevity in Okinawa.

**Keywords:** age validation, blue zone, centenarian, longevity, Okinawa

## Introduction

The first demographic assessment of Okinawa's population development was published by Taueber in 1955 [1]. This island is the Japanese prefecture that was the scene of the bloodiest battle of World War II (WWII) and then remained under US control until 1972. Taueber described the significant emigration flows between the two wars and the major impact of WWII – with more than 150,000 casualties – on the age structure of Okinawa's population. Nevertheless, she did not point to any signs of exceptional longevity among the Okinawan people, since 'estimates of the "true" level of mortality in 1920 and the rates of decline thereafter would have to involve so many assumptions that their value would be slight' [1]. Since 1976, when the first list of centenarians living on the island was released, the fact of the exceptional longevity on the island was largely disseminated. Nevertheless, very few demographers paid attention to Okinawa's exceptional situation, although many other scholars proposed several explanations for it. The present contribution aims at analysing the demographic aspects of that exceptional longevity and the evolution to present day by comparison with the situation in mainland Japan.

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## The emergence of exceptional longevity in Okinawa

The assumption that there are areas of the world where people live longer than others began to spread in the 1970s when American physician and scientist Alexander Leaf organized expeditions sponsored by the National Geographic

 

Society to explore areas of the world where heart disease was rare and some people reportedly lived to 140 or longer. In his seminal contribution published in January 1973 in *National Geographic*, Leaf described three long-living populations – living, namely, in Abkhazia in the Caucasus Mountains, in the Hunza Valley of Pakistan and in Vilcabamba in Ecuador – and detailed their exceptional longevity [2]. During the same decade, the life expectancy in Japan surpassed the one in Sweden, which was at that time the leader in terms of longevity [3]. In this context, it was not surprising that the first article on the existence of exceptional longevity in Okinawa was published in 1976 by Yasuo Kagawa et al., including Leaf as co-author [4]. The 1975 population census in Okinawa enumerated 37 centenarians in its population of 1.04 million (a prevalence of 35.5 per million), whereas in Japan as a whole, 568 centenarians were identified in a total population of 111.25 million (a prevalence of 5.1 per million). Okinawa's extraordinary longevity was immediately confirmed by Makoto Suzuki, a clinical cardiologist and geriatrician who came from Tokyo to establish the first medical school on the island. With his team, he presented a first report on the subject based on a social and medical survey on centenarians alive in Okinawa in 1976 at the eighth meeting of the Okinawa public health association [5].

At the same time, on the other side of the Pacific Ocean, Leaf's results from Vilcabamba were called into question by Mazess and Forman [6], who pointed out an exaggeration of the ages of the oldest in the population. Thus, the scientific debate about the validity of the age of the oldest in the population erupted again in the work of Thoms [7]. In the absence of conclusive documentation, Leaf was forced to acknowledge that the exceptional longevity of Vilcabamba was due to age exaggeration as he himself had found people in Vilcabamba whose declared age had suddenly increased faster than the chronological years would allow [8]. Age exaggeration was also considered to be responsible for the apparent extraordinary longevity of the oldest in the population in Abkhazia in the Caucasus Mountains and the Hunza valley of Pakistan due to the lack of reliable birth registration systems. Accordingly, all cases of alleged long-living populations were invalidated [9]. Concretely, in Georgia (Caucasus), more in-depth verifications of individual records in family registers dated from 1938 to 1948 have demonstrated the obvious falsification of birth dates for still unclear reasons [10]. These cases demonstrate that to identify the exceptional longevity of a population, thorough age validation is needed.

In Japan – Okinawa not included – nominative lists of centenarians were established yearly since 1963 [11], and the first list of Okinawan centenarians was published in 1975, enumerating the centenarians alive on a comparative basis with all other Japanese prefectures. In their study, Kagawa et al. [4] divided the number of centenarians on the 1976 list to the population aged 65 and over as enumerated in the 1975 census. They identified Okinawa as the prefecture with the highest proportion of centenarians in Japan. Thereafter, the 14th completed life table – released by the Ministry of Health, Labour and Welfare – ranked Okinawa as having the highest life expectancy among all 47 Japanese prefectures. This first position was maintained up to the end of the 20th century in all longevity indicators: the life expectancy at birth, the life expectancy at 65 and the proportion of nonagenarians and centenarians in the total population for both men and women [12]. The Japanese birth registration system, the Koseki – that in parallel to censuses provides data on the age composition of the population – has been considered exhaustive since 1872 and highly reliable [13]. Moreover, in his comparative study of the mortality data at older ages in 28 developed countries, Kannisto classified Japan in the high-quality category [14].

### Factors favouring exceptional longevity

As soon as the primacy of longevity in Okinawa was announced, the quest for longevity factors to account for Okinawa's exceptional longevity was initiated. Suzuki launched the 'Living Centenarian Study' supported by funding from the Japan Ministry of Health, Labour and Welfare. With his team, he visited 32 of the oldest in the population (aged 99 years and above) alive in Okinawa and published a first paper on their characteristics [5]. Thereafter, Kagawa et al. presented their hypothesis, with the aim of highlighting the factors likely to explain – or at least be associated with – this exceptional longevity. Their explanations were the first covering a large spectrum of factors supporting the exceptional longevity in Okinawa [15]:

In Okinawa, very few people had a serious disease before 60 years of age. (…). Their blood pressure, especially the minumum blood pressure, was lower

 

than for the average Japanese over 70 years. The preference for salty food and sugars was 33% and 48% respectively, but it was very low in the centenarians. (…) The intake of total energy and sugar was lower and that of green-yellow vegetables and meat was much higher for Okinawa than for the average Japanese. (…) People in Okinawa are very small: the average 14 year old Okinawan girl is 4.1 cm smaller and 4.3 kg lighter than one who lives on mainland Japan. The heights and weights are lower than those of the average Japanese over 70 years (male 155.2 cm and 52.5 kg ; female 142.2 cm and 44.8 kg). (…) Caloric restriction in younger ages, provided that nutrients are balanced, is reported to cause both low growth and longevity. In Okinawa, along with nutrition, the warm climate, hard continuous work and genetic factors, etc. must be taken into account.

Subsequently, the growing body of scientific research on the subject was brought together in a programme entitled the 'Okinawa Centenarian Study' [16] under the leadership of Suzuki. At the same time, several demographers have focused their investigations on the various reasons why the life expectancy has risen so sharply in Japan in the last decades of the 20th century [3, 17–19]. Nevertheless, except for Kaneko [20] and Takahashi [21], researchers showed very little interest in analysing the demographic aspects of the exceptional longevity in Okinawa. Instead, gerontologists, physicians, nutritionists, geneticists and other public health researchers attempted to explain why mortality in Okinawa was lower than in Japan as a whole. As already suggested by Kagawa et al. [15], the explanatory factors cited by these researchers are genetic, nutritional, climatic, cultural and social, all of which help to explain the primacy of the longevity in Okinawa and the gap between mainland Japan and Okinawa.

In further publications, Suzuki et al. [22–24] demonstrated the effect of hereditary, family antecedents and genetic factors to explain the exceptional longevity in Okinawa. Nevertheless, many authors consider nutrition to be the main reason for Okinawa's lower mortality rate, highlighting the beneficial role of the 'fish–rice–soy' trilogy. Matsuzaki [25] mentioned among other reasons that the longevity in Okinawa may be linked to the consumption of meat, little salt and important physical activity in daily life, mostly in agriculture. Takahashi [21] explained that Okinawa has developed completely differently historically and culturally from Japan. For example, Okinawan people eat meat, mostly pork – their remoteness from mainland Japan kept them untouched by Buddhist precepts not to kill animals. According to these authors, such diet plays a positive role in preventing arterio-cerebral disease that has been one of the main causes of mortality in Japan but much less frequent in Okinawa. Other researchers, such as Akisaka et al. [26] and Chan et al. [27], also discussed the energy and nutrient intakes of Okinawan centenarians and even enlarged the spectrum of plausible nutritional factors favouring longevity. Sho [28] explained that the concept that 'food is medicine' and a high regard for medical practice are also intrinsic to Okinawan culture. Okinawan food culture is intimately linked with a highly developed social structure and network. The same conclusions emerged from the survey of nonagenarians carried out by the Prefecture of Okinawa in 1995. These results showed that the health of nonagenarians was marked by few degenerative diseases and a high level of immunization. The reasons for this exceptional situation put forward by the surveyed persons themselves were a mild climate, excellent intergenerational relations and a high regard for the oldest in the society.

Okamoto and Yagyu [29] studied the geographical distribution of centenarians in prefectures of Japan and conducted a multivariate analysis based on aggregated data. Their results showed that the factors most often associated with a high proportion of centenarians were mild climate, higher income level, the proportion of people working in the service sector for aged people and the relative number of places available in homes for the elderly. Using a similar approach, Cockerham et al. [30, 31] also found a positive correlation between the level of socio-economic development of Japanese prefectures – as measured by average per capita income – and the life expectancy of their population. Nevertheless, it turns out that Okinawa prefecture has the highest level of longevity but the lowest income. According to these authors, nutritional factors and lifestyles specific to Okinawa were to be taken into consideration to better understand the exceptional longevity of this region, despite its less favourable economic situation.

Similarly, several researchers emphasized the important role of lifestyle habits and sleep health among factors contributing to longevity in Okinawa [32–35]. Physical exercise, daily activities and bone density were predictors of longevity in Okinawa

 

[36]. Others suggested that the explanatory factors include preventive public health measures, improved dietary habits, reduced stressors and the adoption of healthier lifestyles. The favourable socio-biological environment [37], both the cultural climate and social practices [38] observed in Okinawa, are probably related to cultural habits. Accordingly, the traditional lifestyle observed in Okinawa undoubtedly helps to explain this exceptional longevity.

### The first signs of Okinawa's declining primacy

Okinawa's life expectancy advantage over the population of Japan as a whole peaked in 1985. Although it declined thereafter, Okinawa's first place among Japan's 47 prefectures was maintained, but only until the last decade of the 20th century (Ministry of Health and Welfare). Even in the context of the gradual decline of Okinawa's advantage over Japan as a whole, the enthusiasm of researchers to explain the primacy of Okinawa did not subside, even long after the turn of the century.

An analysis of regional differences in age-specific mortality rates based on the same regional life tables was conducted by Kaneko [20]. When comparing standardised mortality rates for Okinawa compared to Japan as a whole, he highlighted the relatively higher mortality in the age-groups 15–19, 25–29 and 30–34 for men, and in the age-groups 15–19 and 20–24 for women, but without comments. Moreover, Takahashi [21] detailed the difference between the contributions of each age-group to the exceptional level of longevity but did not highlight the unfavourable situation of the younger generations aged 15–34 from 1975 to 1990, and 35–49 for the year 1990 that mainly concerned men.

A survey on the exceptional longevity in Okinawa carried out by the prefecture in 1995 highlighted the changes in mortality of middle-aged people. The report [39] made a distinction between two generational groups, stating: 'However, some survey results offered warning signals concerning future longevity in this prefecture. Setting the middle-age bracket at 50 to 55 years of age, the death rate was found to be lower for older generations and higher for younger generations when compared to the national average. The reasons for this were an increased disease in adulthood, such as cancer, heart disease, and cerebra-vascular disease, all caused by westernisation of lifestyle and diet, as well as an increase in death by traffic accidents, etc. among the younger generations. To counteract this trend, it is important to provide health education to the generations born after the war'.

### The so-called 'shock 26'

At the end of 2002, published data on regional mortality based on the 19th complete Japanese life table – including the updated ranking of Japanese prefectures according to male and female life expectancy – caused confusion. By its male life expectancy, the prefecture of Okinawa was situated in the 26th place, compared to the 4th place in 1995. Even if the female life expectancy remained in first place, this information came as a shock to the people and authorities of Okinawa and is known as 'shock 26'. It was considered to be the collapse of the myth of longevity, with important impact even on the food industry, which largely advertised on its basis [40]. On 3 September 2003, Oomura published in the *Asahi* newspaper an article with the 'shock 26' [41], presenting the results of a health survey carried out soon after the 'shock 26', as well as comments made by Suzuki and B. Willcox. The latter researchers believed that 'automobilization' – involving a lack of physical exercise – disrupted eating habits, and higher alcohol consumption are the main causes of the slower improvement in longevity in Okinawa compared with Japan.

Among the first publications after the 'shock 26' article, a chapter of a book published by the *Okinawa Times* [42] questioned the exceptional longevity in Okinawa. It addressed the changes in eating habits and health in Okinawa, the importance of stress in everyday life and the increase of the number of suicides. Even though little demographic data is added to illustrate these findings, this book remains interesting insofar as its publication itself showed a certain awareness of the difference between reality and the image that Okinawa generally held as being the island with the highest longevity worldwide. Miyagi et al. [12] examined why the longevity indicators in Okinawa were once the highest in Japan, and what the reasons were for their recent decline with an increase of the three leading causes of death in 2000 compared to their 1990 levels. They mentioned briefly that mortality rates of men in Okinawa were higher than the nationwide figures. for ages 20–49 but did

 

not investigate further in the comparison between generations.

Despite the negative impact of the 'shock 26', investigations into the exceptional longevity on Okinawa and its explanation continued to flourish over the following decades. The familial transmission of longevity was already brought to light by Suzuki et al. in 1983 [22], whereas Willcox et al. confirmed in 2006 [43] the heredity of longevity, proving that siblings of Okinawan centenarians share lifelong mortality advantages. The progress in analysis of genes and genome sequencing allowed researchers to seek longevity genes. The first paper on this topic by Willcox et al. [43] concluded that based on genetic studies on the Okinawan population, Okinawans are a genetically distinct group, but 'despite the observation that there is substantial genetic contribution to human longevity, little is known about what specific genetic effects are involved'. Nevertheless, in further research, they showed that the gene FOXO3 is strongly associated with human longevity [44]. A further study investigated who the Okinawans are in terms of ancestry and genome diversity and analysed implications for the genetic study of human longevity from a geographically isolated population [45]. After the 'shock 26', a large part of research interest still focused on the traditional diet of Okinawan centenarians and more specifically on the impact of calorie restriction [46] that people in Okinawa – in a mild form but prolonged over about half of their adult lives – have undergone [47]. Considering the longer life expectancy, and the higher prevalence of centenarians in Okinawa, these arguments have been used to support the hypothesis of the positive effect of calorie restriction for increasing lifespan in humans. However, no long-term epidemiologic analysis has been conducted on traditional dietary patterns, energy balance and potential calorie restriction phenotypes for the specific cohort of Okinawans who are purported to have had a calorically restricted diet [48].

## Data sources for demographic analysis

The data sources available to investigate the trends in exceptional longevity in Okinawa are the following: (i) annual lists of centenarians (*Zenkoku Koureisha Meibo*), (ii) official statistics from population censuses and vital registration and (iii) regional life tables at the level of the 47 prefectures, including Okinawa.

### *Annual list of centenarians*

Since 1963, a list of people aged 99 and over has been published by the Ministry of Health, Labour and Welfare in September each year for the whole of Japan, but Okinawa is only included since 1975. The choice of these dates is linked to the fiscal year that starts on April 1st and ends on March 31st of the following year. As explained by Robine et al. [13], these lists may be used to estimate the number of centenarians on October 1st, considering that some oldest in the population listed will die in September before October 1st and that some others are only 99 years old and will hopefully celebrate their 100th birthday before March 31st. Accordingly, the ministry in charge of annually releasing these figures introduces some necessary corrections for annually disseminating the total number of centenarians.

### *Population censuses and vital statistics*

Population censuses have been taken every 5 years since 1920 – with one exception in 1947 – to ascertain the population situation of the country. The census in 2020 was the 21st by order. During the US occupation, census data were collected in Okinawa by the Ryukyu Islands' U.S. Military Government in 1950 and the Government of the Ryukyu Islands thereafter. Since 1975, the censuses in Okinawa have been part of the general population censuses of Japan.

### *Regional life tables*

The Ministry of Health, Labour and Welfare prepares and disseminates a set of complete life tables for the 47 Japanese prefectures every 5-year period. The 14th complete life table computed in 1975 included for the first time Okinawa. The 23rd complete life table was recently released for 2020. The regional life tables are based on deaths recorded for 5 years and the population enumerated at census mid-period. The Japanese Mortality Database [49] proposes a structure similar to the one displayed in the Human Mortality Database [50]. On its website, all data are disseminated since 1975, and these are similar to those produced by the Ministry of Health, Labour and Welfare [51].

## The number of centenarians

The number of centenarians in Okinawa increased almost exponentially from 1975 to 2000 and continued to grow linearly thereafter (Fig. 1). From 29 centenarians identified in 1975, it grew to 889 in

 

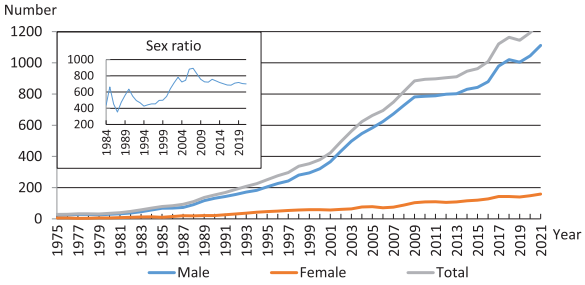


**Fig. 1** *Number of centenarians in Okinawa by gender and sex ratio (1975–2021) (number of female centenarians per 100 male centenarians).*

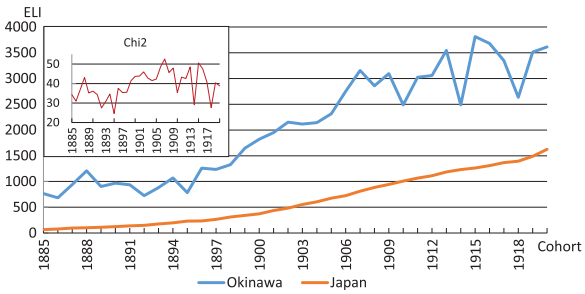


**Fig. 2** *Life expectancy in Okinawa compared to Japan (1975–2020).*

2009 and peaked at 1271 in 2021 according to the Japanese Mortality Database [49]. A clear increase appears also in sex ratio, growing from 400 women per 100 men in the mid-1980s to more than 800 in 2006, and thereafter declining slowly. Such a high level is unique worldwide, showing that Okinawa is characterized by exceptionally high female longevity.

### Evolution of longevity in Okinawa compared with Japan

Despite the fact that Okinawa was under US occupation after WWII, the origins and history of its population are interconnected with the one of mainland Japan, as are the current socio-political, cultural and economic environments, including the health-care and social protection systems. Japan is the leading country in terms of life expectancy, and Okinawan longevity may be seen as a particular facet of Japanese longevity. The following Figures present longevity indicators of Okinawa compared to the ones of Japan as a whole.

As shown in Fig. 2, the life expectancy at birth has always been higher in Okinawa compared to Japan as a whole, and both have grown rapidly during the last 45 years. However, the relative increase in Okinawa has not been as high as in Japan as a whole, resulting in the convergence in female life expectancy. Concerning the male life expectancy, a crossover is observed and the fall in the ranking among the 47 Japanese prefectures was brought to public attention by the 'shock 26'.

The exceptional longevity of the Okinawan population can also be seen through the proportion of centenarians in the total population. The situation in Okinawa is exceptional also in this regard. In 2003, Okinawa passed the threshold of 40 centenarians per 100,000 population, compared to just over 15 for Japan. However, the prevalence of centenarians often appears to be a biased indicator of longevity level, as the number of centenarians is related to a population that has undergone large fluctuations over the past century due to fertility and mortality, as well as important migratory flows. Therefore, for the purposes of comparison, it is preferable to use another indicator – the extreme longevity index (ELI), which gives the probability for a newborn in a given birth cohort to reach the age of 100 [52]. This longevity index only considers centenarians born in the studied population, regardless of whether they are alive or dead. Centenarians who emigrated from their place of birth and celebrated their 100th birthday elsewhere in the world are considered in the calculation if their existence is known. On the other hand, all centenarians born outside the studied population are excluded. Thus, the longevity index cannot be overestimated, and only a slight underestimation may be expected insofar as not all centenarians who died abroad are identified (82 centenarians who died in Hawaii are included in the calculation of the longevity index).

The ELI (Fig. 3) calculated for cohorts born more than 100 years ago – from 1875 to 1921 – shows a somewhat similar situation, with earlier cohorts having faster ELI growth in Okinawa, but Japan having higher growth in later cohorts. The $chi^2$ distance between two curves increases for cohorts born in 1910 and decreases for the younger cohorts.

### Mortality rates by age and gender

As shown in Fig. 3, the ELI for the Okinawan population has been higher than in Japan in all observed birth cohorts, with a particularly big difference appearing for cohorts born at the turn of the century. The ratio of death rates in Okinawa

 

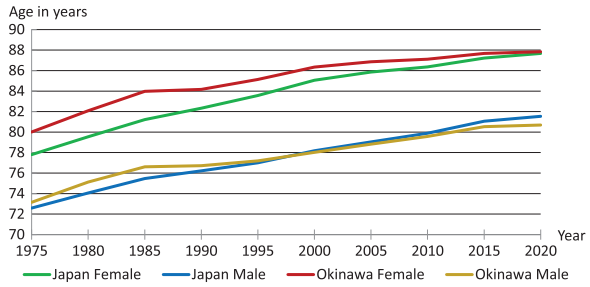


**Fig. 3** *Extreme longevity index (ELI) by birth cohort, compared between Okinawa and Japan (1885–1920). ELI is the probability for a newborn to become centenarian. ELI is computed based on the number of persons who reached 100 years and the number of newborn by year of birth extracted from the Japanese Mortality Database [49]. The chi$^2$ distance is computed between figures from Okinawa and Japan.*

compared to Japan shows that since the mid-1980s, death rates in Okinawa have increased at a faster rate than in Japan for all ages and for both sexes (Table 1). Moreover, the death rate of people under age 70 has already been higher in Okinawa than in Japan as a whole for several decades.

An appropriate approach to assess the mortality differences between Okinawa and Japan is to use the sex-specific mortality ratios by 5-year age-groups for each complete life table from 1975 to 2020 for Okinawa and Japan (Table 1). Traditionally, any demographic change may be addressed under three different perspectives: by age-group (starting at age 50), by period (from 1975 to 2020) or by birth cohorts that may be obtained by difference between period and age. The means of these ratios by age-group and by period are presented in Table 1. In both cases, a U-curve is found with a maximum advantage for Okinawa at the period from 1985 to 1990 and at ages 80–89 years. The worse situation for Okinawa is observed for the more recent years close to 2020 and for the youngest age-group of 50–54 years.

To better understand how each cohort, by gender, has contributed to the decline of longevity in Okinawa compared to Japan as a whole, the data has been organized by birth cohorts, and the average ratio was computed for each of 5-year birth cohort. In Fig. 4, a clear difference appears between the generations. The generations born in Okinawa before WWII had a favourable situation compared to their peers

**Table 1.** *Ratio between death rates in Okinawa compared to Japan by age and gender (1975–2020).*

| | 1975 | 1980 | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Male** | | | | | | | | | | | |
| 50–54 | 1.028 | 0.987 | 0.867 | 0.975 | 1.077 | 1.104 | 1.287 | 1.298 | 1.396 | 1.391 | 1.141 |
| 55–59 | 0.894 | 0.969 | 0.906 | 0.934 | 0.975 | 1.019 | 1.060 | 1.272 | 1.242 | 1.341 | 1.061 |
| 60–64 | 1.008 | 0.899 | 0.982 | 0.920 | 0.912 | 0.962 | 0.984 | 1.113 | 1.261 | 1.266 | 1.031 |
| 65–69 | 0.860 | 0.889 | 0.847 | 0.894 | 0.942 | 0.932 | 0.990 | 1.028 | 1.063 | 1.157 | 0.960 |
| 70–74 | 0.872 | 0.800 | 0.856 | 0.853 | 0.880 | 0.950 | 0.952 | 0.983 | 1.000 | 1.021 | 0.917 |
| 75–79 | 0.770 | 0.796 | 0.786 | 0.857 | 0.819 | 0.924 | 0.894 | 0.931 | 0.943 | 0.974 | 0.869 |
| 80–84 | 0.783 | 0.782 | 0.767 | 0.809 | 0.843 | 0.902 | 0.886 | 0.892 | 0.944 | 0.948 | 0.856 |
| 85–89 | 0.832 | 0.814 | 0.982 | 0.825 | 0.838 | 0.892 | 0.883 | 0.893 | 0.927 | 0.944 | 0.883 |
| Mean | 0.881 | 0.867 | 0.874 | 0.883 | 0.911 | 0.961 | 0.992 | 1.051 | 1.097 | 1.130 | |
| **Female** | | | | | | | | | | | |
| 50–54 | 0.897 | 0.845 | 0.859 | 0.930 | 1.032 | 1.043 | 1.074 | 1.152 | 1.194 | 1.195 | 1.022 |
| 55–59 | 0.877 | 0.833 | 0.877 | 0.877 | 0.882 | 0.939 | 1.045 | 1.031 | 1.183 | 1.177 | 0.972 |
| 60–64 | 0.805 | 0.791 | 0.841 | 0.869 | 0.888 | 0.958 | 1.105 | 0.987 | 1.115 | 1.193 | 0.955 |
| 65–69 | 0.736 | 0.751 | 0.743 | 0.782 | 0.829 | 0.934 | 0.973 | 0.982 | 0.958 | 1.082 | 0.877 |
| 70–74 | 0.672 | 0.685 | 0.711 | 0.741 | 0.844 | 0.886 | 0.904 | 0.984 | 0.932 | 0.994 | 0.835 |
| 75–79 | 0.706 | 0.687 | 0.704 | 0.723 | 0.767 | 0.863 | 0.896 | 0.874 | 0.960 | 0.961 | 0.814 |
| 80–84 | 0.684 | 0.690 | 0.708 | 0.727 | 0.759 | 0.798 | 0.823 | 0.872 | 0.883 | 0.926 | 0.787 |
| 85–89 | 0.763 | 0.743 | 0.734 | 0.735 | 0.755 | 0.806 | 0.814 | 0.850 | 0.882 | 0.931 | 0.801 |
| Mean | 0.768 | 0.753 | 0.772 | 0.798 | 0.844 | 0.903 | 0.954 | 0.967 | 1.013 | 1.057 | |

*Source*: Japanese Mortality Database [49].

 

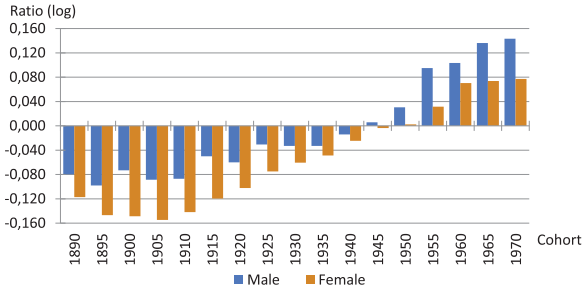


**Fig. 4** *Average ratio, in logarithm, between death rates in Okinawa and Japan, by sex and year of birth.*

born elsewhere in Japan, and the advantage was the biggest for generations born in Okinawa at the turn of the 20th century and for women compared to men. This situation gradually disappeared for cohorts born in the 1940s and turned in the opposite direction thereafter. Cohorts born after the 1950s in Okinawa had higher mortality rates compared to Japan as a whole. Moreover, this gap increased by each subsequent birth cohort, and the mortality disadvantage is more evident among men.

### Two groups of generations born before or after WWII

Between the relative under-mortality of the older generations and the obvious excess mortality of the younger generations, the difference is enormous – almost a factor of two. Therefore, any explanation suggested must be able to account for the enormous difference between these two groups of generations. Which factors – whether identical or different over generations – or regions of Japan might be associated with the excess mortality of young people, on the one hand, and the under-mortality of older people, on the other? In the following section, we discuss the various factors cited in the scientific literature, maintaining the generational approach.

The investigations conducted by Kaneko [20] and Takahashi [21], as well as the results of the survey of longevity in Okinawa [39], already highlighted the changes in mortality for middle-aged people before the 'shock 26'. The increasing prevalence of adulthood cancer, heart disease and cerebrovascular disease was pointed out, all these caused by the westernization of lifestyle and diet. As reported by Ryall, a *Daily Telegraph* correspondent in Tokyo, 'an influx of foreign influences, ranging from fast food to less exercise, the stress of modern life, as well as a loss of the traditional sense of "ikigai" are all to blame' [53]. In the same press article, Suzuki – the initiator of the Living Centenarian Study and the best scientist to consult on changes that occurred in Okinawa during the last half century – reacted as follows to the announcement of the 'shock 26': 'The life expectancy of the people of Okinawa is coming down quite rapidly, and we believe the problem is that younger people have failed to follow in the footsteps of earlier generations' [53]. In traditional Okinawa, the family and community were always very important, and the people had little stress. Today, many Okinawans have recently adopted the 'hurry hurry approach' to life that is more associated with the mainland Japanese lifestyle [53]. Clearly, most of these changes affected various aspects of the lifestyle and are part of the process of westernization of the Okinawan society that is closely linked to Okinawa's own history, and particularly to the US occupation between 1945 and 1972. The following reaction, also reported in the media, is indicative of the impact of the American dream on the Okinawan people: 'I thought the Americans were the greatest people on earth, an entirely different species. They drove big cars, the whole family dressed well, and they would go to the beach with their parasols. They'd have barbecues. I still remember the smell of grilled meat' [54].

### The excess mortality of the younger generations

The relative decline of longevity compared to Japan is mostly due to the post-WWII generations. Lifestyle westernization in Okinawa under US occupation certainly had its effect on the unfavourable trend in the mortality of these younger generations. Nevertheless, such lifestyle changes can generally only be seen over a relatively long period of time and are often difficult to measure. Moreover, these likely affect similarly the entire population, including older people. Two important questions emerge: (i) Which aspects of westernization have the highest impact, and (ii) why are only the post-WWII generations affected?

The analysis carried out by Todoriki et al. [55] is unequivocal. In 1945, in a country devastated by war, the population lived mainly on food rations distributed by the US Civil Administration of the Ryukyu Islands. In this context, the biggest change was the sudden replacement of sweet potatoes by rice, a radical change that was unique in Japan. From 1960 onwards, when the population

 

benefited from economic growth with increased purchasing power and the lifting of controls by the US Administration, there was an increase in imports of foodstuffs from the American food industry with high energy density foods that contributed to an overall increase in caloric intake. The generations most affected by this nutritional transition were undoubtedly the children. The widespread distribution of American style 'lunch boxes' to schoolchildren has certainly greatly amplified the situation that very quickly resulted in growing obesity among the post-WWII generations. As would be expected with such a rapid nutrition transition, younger Okinawans growing up during the post-WWII period have been facing higher risk for morbidity and mortality when compared to other areas of Japan that have been less affected by these large dietary and lifestyle shifts. Indeed, Okinawa currently suffers from the highest obesity rates in Japan, and metabolic syndrome has become a significant burden [56]. Such lifestyle shift has gradually taken place with overeating, inactivity and obesity emerging as major public health challenges [55]. As a direct result of these changes, the frequency of main causes of death traditionally low in Okinawa increased compared to mainland Japan with an increase of the prevalence of type 2 diabetes, acute myocardial infarction, chronic liver disease and cirrhosis, diabetes mellitus and suicide. Trends in age-specific death rates by these causes show that the survival lead of Okinawa compared with the Japanese nationwide situation disappeared gradually as the share of cohorts born before WWII decreased in the total population [57].

### The under-mortality of the older generations

In this context of major and harmful nutritional transition, how can we explain the obvious under-mortality of generations born before WWII? One hypothesis might be that the older generations were already 'prepared for' exceptional longevity before WWII by their traditional lifestyle that might favour longer life. Being able to maintain this lifestyle despite the context of the US occupation, they could resist the westernization. However, the life tables available before WWII did not show any significant longevity advantage for men and women in Okinawa compared to the rest of Japan. Considering that the life table computed in 1956 during the US occupation was hardly comparable to the one available in Japan, the first after-war life table computed simultaneously in Okinawa and Japan was done in 1975, and that was the first time when the under-mortality of the older generations appeared.

According to the initial work of Kagawa [15] and Suzuki [22] as well as the numerous studies carried out within the Okinawa Centenarian Program, different longevity factors have been highlighted, but still, it is difficult to estimate the real contribution of each of these factors. Nevertheless, none of these – considered separately – can explain the enormous survival advantage of older people in Okinawa compared to their Japanese peers but also compared to the younger generations. Among other results, an association between the FOXO3 gene and exceptional longevity has been found [44], but it would be necessary to understand why the generations belonging to the same genetic pool and born after WWII did not benefit from it.

Clearly, according to the literature, the main factor that could have favoured longevity in Okinawa is calorie restriction – a hypothesis that has been largely investigated [46, 47, 58] – but there are still arguments against the fact that calorie restriction may really be beneficial for the lifespan of human beings [59, 60]. Incidentally, if calorie restriction can be considered a factor in longevity, it is important to consider that the nutrition pathway of the Okinawa population included some significant famines. In 1923, the great Kanto earthquake and the worldwide effects of the Great Depression caused a chronic economic recession which severely affected the lives of Okinawans. Food became scarce, and Okinawans were forced to process and eat a toxic plant in the cycad family to survive [61]. Later, WWII events brought a new famine, which culminated in the Battle of Okinawa from 1 April to 22 June 1945, and a severe shortage of food was still present after the war. To help the population, the US Administration distributed rationed food for several years. During these difficult periods, can we speak of a voluntary calorie restriction that would respect the basic nutrients essential to live? Is it conceivable that this forced calorie restriction could be a kind of dietary hormesis which, in response to a mild stress due to a temporary food shortage, would enable the body to unlock new strategies that would allow it to live longer and in good health? The nutritional change after WWII (rather than a progressive transition) is part of the timeframe modelled on the US occupation that had an impact on all generations

 

but especially on those born during that period, whereas the loss of the traditional way of living was gradual and did not affect the old generations so strongly.

### The validity of age of centenarians in Okinawa

Although the considerable nutritional changes of the lifestyle are very likely responsible for the reversed longevity gap for the post-WWII generations in Okinawa compared to Japan as a whole, it is hardly plausible that they explain the entire huge difference between Okinawa's younger and older generations compared to their peers in mainland Japan.

In 1991, Coale [62] – a world-renowned demographer – warned that 'data on ages listed in censuses, surveys, or registers of a population must be scrutinized critically, even when there are reasons to suppose that the data are accurate. Accuracy of most of the data does not mean that all data are accurate; as William Brass said, all data are guilty until proven innocent'. In centenarian studies, age validation is an important initial task to be carefully performed, as so many alleged centenarians have been unvalidated [63]. In the New England Centenarian Study, Perls et al. [64] compared the declared age at census with the birth certificate of each centenarian and found some errors. Theoretically, four types of errors on age may be considered. The first one is strictly linked to hazard, and reported age may be considered distributed randomly around the real age following a Gaussian distribution. For the second type, reported ages are also randomly distributed but probably include an unconscious but systematic tendency for overestimation. The third situation would correspond to a clear willingness to exaggerate age to get some benefit. In the specific situation of Japan, a fourth type of possible error might be of an exactly 12-year difference compared to real age corresponding to the repeating sequence of the twelve zodiac animal signs [65].

In the case of Okinawa, the question was raised already two decades ago [52]. Briefly, it may be summarized as the following: In Japan, the age of a person is identified based on the Koseki, the family registry that includes the individual birth records of all family members. During the Battle of Okinawa, most Kosekis on the island were destroyed. Temporary Kosekis were reissued, not only as family and civil status registers but also for the distribution of food rations and to fix the list of Okinawans who would be asked to help the American army. Nishihara [66] conducted an in-depth analysis of the circumstances of the reconstruction of the Koseki in Okinawa and concluded that this reconstruction had been done within a very difficult context due to the loss of documents destroyed during the war but also due to the poor coordination between the US Administration in Okinawa and Japan thereafter. He highlighted several problems encountered when reissuing Koseki, including false declarations of age. Matsuzaki [25] also addressed the reliability of information extracted from the Koseki and mentioned that he found several errors in date of birth. These statements indicate a fairly high risk that the age data recorded in reconstructed Koseki – not being based on original documents of birth – may have differed somewhat from the person's actual age which would confirm Okinawa's status as a Longevity Blue Zone [67]. The above-mentioned arguments questioning the validity of extreme ages of Okinawans have been refuted by Willcox et al. [68] and Robine et al. [69]. Their contra-arguments are based on the fact that some age heaping, the absence of too extreme age at death or exceptionally high proportions of centenarians aged 110+ compared with 105+ and 105+ compared with 100 as well as unusual sex ratio of centenarians were not found. These indicators supported the existence of an exceptional population longevity in Okinawa, as all observed figures ranged within reasonable values. However, these arguments – even if necessary – are not direct proof that all data are correct, and these are not sufficient for the validation of exceptional population longevity. Even if individual age validation is quite difficult in Japan because of limited access to original individual data sources, cross-checking individual data from independent data sources is crucial for identifying a statistically significant number of alleged centenarians [70].

### A plea for further investigations

Future scientific investigations are needed on both groups of generations identified in this review: the post-WWII generations who exhibit an excess mortality compared to their peers in mainland Japan, and the older generations for whom, oppositely, lower mortality rates are observed.

For the younger generations, the Okinawa Prefectural Government launched after the 'shock 26' some projects with the goal of recapturing the

 

title of highest average life expectancy for both men and women by 2040. More recently, a cooperation agreement was signed with the Okinawa Labour Bureau to promote an effective policy for improving the health of working-age individuals (ages 20–64) [71]. In this context, more in-depth scientific investigations are expected to understand the underlying factors responsible for the excess mortality and to support such policies that are essential to sustain the wellbeing of the population of Okinawa in the future.

For the older generations, some arguments show that possible age misreporting and age exaggeration may occur. Japanese sources – and more specifically the Koseki – are in general highly reliable [13, 72] but mainly due to the peculiarities of the reconstruction of the Koseki in Okinawa after WWII, some errors in age might have occurred. In fact, the longevity indicators may be affected even by relatively few errors in age. Such errors cause rather more over- than underestimation of longevity. Preston et al. [73] demonstrated that, in the presence of age misreporting, there is always underestimation of mortality rates at old ages. Our investigations do not put into question the various findings on determinants of the exceptional longevity in Okinawa. The apparent advantage of Okinawa's population longevity for generations born before WWII is so remarkable that – even in the event of possible misreporting of ages – the situation in Okinawa remains exceptional, which would confirm Okinawa's status as a Blue Zone. Still, a reconsideration of the reliability of the population longevity on the island is expected, and this should start with an in-depth demographic analysis based on individual and genealogical data.

### Author contributions

Michel Poulain initiated the research, prepared a first draft of this review and presented it as oral communication during the Key Symposium held in Okinawa in May 2023. Anne Herm contributed to the demographic analysis and the writing of this review and ensured the final validation of the text.

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The authors declare no conflicts of interest.

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Data derived from public domain resources.

### References

1 Taeuber IB. The population of the Ryukyu Islands. *Popul Index.* 1955;**21**(4):233–63.
2 Leaf A. Every day is a gift when you are over 100. *Nat Geo.* 1973;**143**(1):92–119.
3 Yanagishita M, Guralnik JM. Changing mortality patterns that led life expectancy in Japan to surpass Sweden's: 1972–1982. *Demography.* 1988;**25**(4):611–24.
4 Kagawa Y, Ishiguro M, Okuno M, Tsukiji H, Terakado M, Iwamuro S, et al. Area of longevity in Japan in 1976. *Jpn J Nutr.* 1976;**34**:163–72
5 Sanabe E, Ajitomi I, Terukina M, Iju H, Suzuki M, Suzuki J, et al. A social and medical survey on centenarians in Okinawa. *Okinawa J Pub Health.* 1977;**9**:98–106.
6 Mazess RB, Forman S. Longevity and age exaggeration in Vilcabamba, Ecuador. *J Gerontol.* 1979;**34**(1):94–98. https://doi.org/10.1093/geronj/34.1.94
7 Thoms WJ. *Human longevity, its facts and its fictions.* London: John Murray; 1873.
8 Leaf A. Statement regarding the purported longevous peoples of Vilcabamba. In: Wershow HJ, editor. *Controversial issues in gerontology.* New York: Springer; 1981. p. 25–26.
9 Jeune B, Kannisto V. Emergence of centenarians and supercentenarians. In: Robine JM, Vaupel JW, Jeune B, Allard M, editors. *Longevity: to the limits and beyond.* Berlin: Springer; 1997. p. 77–89.
10 Poulain M. Validating centenarian's age: a challenge for researchers and scholars. *Global Ageing.* 2006;**4**(1):16–26.
11 Saito Y. Supercentenarians in Japan. In: H Maier, Gampe J, Jeune B, Robine JM, Vaupel JW, editors. *Supercentenarians demographic research monographs.* Heidelberg: Springer; 2010. p. 74–99.
12 Miyagi SA, Iwama NB, Kawabata TC, Hasegawa KC. Longevity and diet in Okinawa, Japan: the past, present and future. *Asia Pac J Public Health.* 2003;**15**:S3–S9.
13 Robine JM, Saïto Y. Survival beyond age 100. Acceleration of the evolution in Japan. *Popul Dev Rev.* 2003;**29**:208–28.
14 Kannisto V. *Development of oldest-old mortality, 1950–1990: evidence from 28 developed countries [Monographs on population aging].* Odense, Denmark: University Press of Southern Denmark; 1994.
15 Kagawa Y. Impact of westernization on the nutrition of Japanese: changes in physique, cancer, longevity, and centenarians. *Prev Med.* 1978;**7**(2):205–17.
16 Okinawa Centenarian Study. Okinawa Rersearch Center for Longevity Science (ORCLS). Accessed 14 Oct 2023. http://www.orcls.org.
17 Kono S, Takahashi S. *Mortality trends in Japan: why has the Japanese life expectancy kept on increasing?* Tokyo: Institute of Population Problems; 1989.
18 Horiuchi S, Wilmoth JR. Deceleration in the age pattern of mortality at older age. *Demography.* 1998;**35**(4):391–412.
19 Wilmoth JR. Is the pace of Japanese mortality decline converging toward international trends? *Popul Dev Rev.* 1998;**24**(3):593–600.
20 Kaneko T. Trends in regional differences in age-specific mortality rates. *Jinko Mondai Kenkyu.* 1987;**184**:39–51.

 

21 Takahashi S. *Health and mortality differentials among the elderly in Japan: a regional analysis with special emphasis on Okinawa [Working Paper Series]*. Tokyo: Institute of Population Problems; 1993.
22 Suzuki M, Mori H, Akamatsu T, Komi K, Uechi K, Sakiyama K, et al. Recherche sur la prédisposition génétique dans les enquêtes sur les antécédents familiaux des centenaires. *Jpn J Geriatr.* 1983;**20**:107.
23 Suzuki M, Mori H, Sekiguchi S. Une étude sur la prédisposition génétique à la super-longévité. Enquête sur les antécédents familiaux et modèle HLA. *Jpn J Intern Med.* 1984;**73**:284.
24 Suzuki M, Mori H, Asoto T, Sakugawa H, Ishii T, Hosoda Y. Medical research upon centenarians in Okinawa—case controlled study of family history as hereditary influence on longevity. *Jpn J Geriatr.* 1985;**22**:457–67.
25 Matsuzaki T. Examination of centenarians and factors affecting longevity in Japan. In: Hishinuma S, editor. *Why do the Japanese live long?* Tokyo: Dobun; 1988. p. 120–23.
26 Akisaka M, Asato L, Chan YC, Suzuki M, Uezato T, Yamamoto S. Energy, and nutrient intakes of Okinawan centenarians. *J Nutr Sci Vitaminol (Tokyo).* 1996;**42**(3):241–48.
27 Chan YC, Suzuki M, Yamamoto S. Dietary, anthropometric, hematological and biochemical assessment of the nutritional status of centenarians and elderly people in Okinawa, Japan. *J Am Coll Nutr.* 1997;**16**(3):229–35.
28 Sho H. History and characteristics of Okinawa longevity food. *Asia Pac J Clin Nutr.* 2001;**10**(2):159–64.
29 Okamoto K, Yagyu K. Geographication of centenarians and its related factors in Japan. *Jpn J Hyg.* 1998;**53**:529–35.
30 Cockerham WC, Hattori H, Yamori Y. The social gradient in life expectancy: the contrary case of Okinawa. *Soc Sci Med.* 2000;**51**(1):115–22.
31 Cockerham WC, Yamori Y. Okinawa: an exception to the social gradient of life expectancy in Japan. *Asia Pac J Clin Nutr.* 2001;**10**(2):154–58.
32 Tanaka H, Taira K, Uezu E. The examination of sleep health and life habits of the elderly individuals: the survey of long-live prefecture Okinawa. *Jpn J Mental Health.* 1999;**45**:63–68.
33 Uezu E, Taira K, Tanaka M, Arakawa C, Togushi H, Yamamoto Y, et al. Survey of sleep-health and lifestyle of the elderly in Okinawa. *Psychiatry Clin Neurosci.* 2000;**54**:311–13.
34 Arakawa M, Tanaka H, Toguchi H, Shirakawa S, Taira K. Comparative study on sleep health and lifestyle of the elderly in the urban areas and suburbs of Okinawa. *Psychiatry Clin Neurosci.* 2002;**56**:245–46.
35 Taira K, Tanaka H, Arakawa M, Nagahama N, Uza M, Shirakaw S. Sleep health and lifestyle of elderly people in Ogimi, a village of longevity. *Psychiatry Clin Neurosci.* 2002;**56**(3):243–44.
36 Akisaka M, Suzuki M. The bone density and activities of daily living in Okinawa centenarians. *Hong Kong J Gerontol.* 1996;**10**:453–57.
37 Sakihara S. *A study on relationship between socio-biological environments and life span in Okinawa*. Okinawa: University of Ryukyus, Faculty of Medicine, Department of Health Sociology; 1999.
38 Suzuki M. Cultural climate and social custom for longevity region, Okinawa. *Jpn J Geriatr.* 2001;**38**(2):163–65.
39 Prefecture of Okinawa. *Proclamation of Okinawa as world region of longevity*. Okinawa: Okinawa Prefectural Governmen; 1995. Accessed 15 Oct 2023 at http://www.pref.okinawa.jp/syakaihosho/VI-e.html
40 Toyokawa S, Takagi T. The collapse of the 'myth of longevity' and the construction of alternatives: the case of the Okinawan health food industry. *J Org Discourse.* 2020;**1**(1):22–29.
41 Oomura J. Okinawa crisis: chojyuken no '26 choc' ["choc 26" of long-life prefecture]. Press articles published on 3 and 10 September 2003, in Asahi shinbum.
42 Okinawa times editor. Okinawa ga chouju de nakunaru hi [Le jour où Okinawa ne sera plus une region de longévité]. Tokyo: Iwanami shoten; 2004.
43 Willcox BJ, Willcox DC, He Q, Curb JD, Suzuki M. Siblings of Okinawan centenarians share lifelong mortality advantages. *J Gerontol A Biol Sci Med Sci.* 2006;**61**(4):345–54.
44 Willcox BJ, Donlon TA, He Q, Chen R, Grove JS, Yano K, et al. FOXO3A genotype is strongly associated with human longevity. *Proc Nat Acad Sci USA.* 2008;**105**(37):13987–92.
45 Bendjilali N, Hsueh WC, He Q, Willcox DC, Nievergelt CM, Donlon TA, et al. Who are the Okinawans? Ancestry, genome diversity, and implications for the genetic study of human longevity from a geographically isolated population. *J Gerontol A Biol Sci Med Sci.* 2014;**69**(12):1474–84.
46 Willcox BJ, Willcox DC. Caloric restriction, caloric restriction mimetics, and healthy aging in Okinawa: controversies and clinical implications. *Curr Opin Clin Nutr Metab Care.* 2014;**17**(1):51–58.
47 Willcox DC, Willcox BJ, Todoriki H, Curb JD, Suzuki M. Caloric restriction and human longevity: what can we learn from the Okinawans? *Biogerontology.* 2006;**7**(3):173–77.
48 Willcox BJ, Willcox DC, Todoriki H, Fujiyoshi A, Yano K, He Q, et al. Caloric restriction, the traditional Okinawan diet, and healthy aging: the diet of the world's longest-lived people and its potential impact on morbidity and life span. *Ann NY Acad Sci.* 2007;**1114**:434–55.
49 National Institute of Population and Social Security Research. *Japanese mortality database*. Tokyo: National Institute of Population and Social Security Research. Accessed 15 Oct 2023 http://www.ipss.go.jp/p-toukei/JMD/index-en.asp.
50 *Human mortality database*. Espoo: HMD. Accessed 15 Oct 2023 http://www.mortality.org.
51 Ministry of Health, Labour and Welfare. Complete life tables. Tokyo: National Institute of Population and Social Security Research. Assessed 15 Oct 2023 http://www.ipss.go.jp/p-toukei/JMD/index-en.asp.
52 Poulain M, Naito K. L'évolution de la longévité à Okinawa. *Cah Qué Démogr.* 2004;**33**(1):29–49.
53 Ryall J. What's behind Okinawa's falling life expectancy? DW News. 2022. Accessed on 15 Oct 2023 at https://p.dw.com/p/4CVyC
54 Onishi N. Love of U.S. food shortening Okinawans' lives/life expectancy among islands' young men takes a big dive. *New York Times.* 2004. Accessed 15 Oct 2023 at https://www.nytimes.com/2004/03/30/world/urasoe-journal-on-us-fast-food-more-okinawans-grow-super-sized.html
55 Todoriki H, Willcox DC, Willcox BJ. The effects of post-war dietary change on longevity and health in Okinawa. *Oki J Amer Studies.* 2004;**1**:55–64.
56 Tanaka H, Shimabukuro T, Shimabukuro M. High prevalence of metabolic syndrome among men in Okinawa. *J Atheroscler Thromb.* 2005;**12**(5):284–88.
57 Kuwae N. Trends in mortality rates by sex, age and cause of death in Okinawa prefecture—comparisons between Okinawa prefecture and the rest of the country between 1973 and 2009. *Okinawa Prefecture Sanitation and Environment Research Report (in Japanese).* 2010;**44**:71–82.


 

58 Rosenbaum MW, Willcox BJ, Willcox DC, Suzuki M. Okinawa: a naturally calorie restricted population. In: Everitt AV, Rattan SI, Couteur DG, Cabo R, editors. *Calorie restriction, aging and longevity*. Berlin: Springer; 2010. p. 43–53.
59 Le Bourg E. Dietary restriction studies in humans: focusing on obesity, forgetting longevity. *Gerontology*. 2012;**58**:126–28.
60 Le Bourg E. Somatotropic axis' role in ageing and longevity could depend on life-history strategies of species. In: Rattan SI, Sharma R, editors. *Hormones in ageing and longevity, healthy ageing and longevity*. Berlin: Springer; 2017. p. 21–33.
61 *The life of Okinawan citizens during the "Cycad Hell"*. London: Royal College of Art. http://rca.open.ed.jp/web_e/history/story/epoch4/sotetu_1.html
62 Coale AJ, Li S. The effect of age misreporting in China on the calculation of mortality rates at very high ages. *Demography*. 1991;**28**(2):293–301.
63 Poulain M. Exceptional longevity in Okinawa: a plea for in-depth validation. *Demographic Res*. 2011;**25**(7):245–84.
64 Perls T, Bochen M, Freemen L, Alpert L, Silver MH. Age validation in the New England centenarian study. In: Jeune B, Vaupel JW, editors. *Validation of exceptional longevity*. Vol. **6**. Odense: Monographs on Population Aging; 1999. p. 215–24.
65 Young RD, Desjardins B, McLaughin K, Poulain M, Perls T. Typologies of extreme longevity myths. *Curr Gerontol Geriatr Res*. 2010;**2010**:423087.
66 Nishihara J. Sengo Okinawa no Koseki Hosei [Lois en ce qui concerne les koseki à Okinawa d'après-guerre]. *Sociol Law*. 1977;**29**:90–100.
67 Poulain M, Herm A, Pes GM. The blue zones: Areas of exceptional longevity around the world. *Vienna Yearb Popul Res*. 2013;**11**:87–108. https://www.jstor.org/stable/43050798
68 Willcox DC, Willcox BJ, He Q, Wang NC, Suzuki M. They really are that old: a validation study of centenarian prevalence in Okinawa. *J Gerontol A Biol Sci Med Sci*. 2008;**63**(4):338–49.
69 Robine JM, Herrmann FR, Arai Y, Willcox DC, Gondo Y, Hirose N. et al. Accuracy of the centenarian numbers in Okinawa and the role of the Okinawan diet on longevity: responses to Le Bourg about the article "exploring the impact of climate on human longevity". *Exp Gerontol*. 2013;**48**(8):840–42.
70 Saito Y. Supercentenarians in Japan. In: Maier H et al. (eds.) *Supercentenarians*. Demographic Research Monographs. 2010: 74–99.
71 Okinawa teams up with local organizations to improve health of working age people, hopes to recapture longest average life expectancy title in Japan by 2040. *Ryukyu Shimpo*. 2021. Accessed Nov 30 2023 at. http://english.ryukyushimpo.jp/2021/03/23/33496/
72 Willcox BJ, Willcox DC, Suzuki M. *The Okinawa program: how the world's lived people achieve everlasting health and how you can too*. New York: Clarkson Potter Publishers; 2001.
73 Preston SH, Elo IT, Stewart Q. Effects of age misreporting on mortality estimates at older ages. *Popul Stud (Camb)*. 1999;**53**(2):165–77.

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