Is it possible to measure life expectancy at 110 in France?

France Meslé[1], Jacques Vallin[2], Jean-Marie Robine[3], Guy Desplanques[4], and Amandine Cournil[5]

[1] INED, 133 Boulevard Davout, 75980 Paris Cedex 20, France.
E-Mail: mesle@ined.fr
[2] INED, 133 Boulevard Davout, 75980 Paris Cedex 20, France.
E-Mail: vallin@ined.fr
[3] INSERM, Equipe Démographie, et Santé Centre Val d'Aurelle - Parc Euromédecine, 34094 Montpellier Cedex 5, France.
E-Mail: robine@valdorel.fnclcc.fr
[4] INSEE, 18 bd Pinard, 75014 Paris, France.
E-Mail: guy.desplanques@insee.fr
[5] INSERM, Démographie et Santé, Université de Montpellier I et CRLC, Val d' Aurelle, 34298 Montpellier Cedex 5, France.
E-Mail: acournil@ish-lyon.cnrs.fr

Abstract. The observed curve of life expectancy by age seems to be coherent at the oldest ages until about age 107, when the extinct generation method is used. Beyond that age, however, improbably large fluctuations call into question any results directly derived from vital statistics, which appear to suggest that life expectancy at 110 is higher than life expectancy at 107 (2.29 years versus 1.73). A careful study of validation of age at death of all French supposed supercentenarians, undertaken in the framework of the International Database on Longevity (IDL), has established a life expectancy at 110 of 1.76 years, which is a much more realistic figure, if still slightly overestimated. The authors also show that it is possible to improve estimates directly derived from vital statistics by simple intuitive correction of some obvious defects. While such an approach still results in an obvious overestimation of life expectancy at 110 (2.0 years), estimation becomes more accurate each time new cohorts enter the field of computation.

The central question concerning mortality at very advanced ages is the following: Does mortality increase with age in an exponential manner until the complete disappearance of a given cohort; or does it slow down, halt, or even start to decline? Biostatisticians have shown

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that, for some species, in particular flies, mortality ceases to rise beyond a certain age, and then it begins to decrease. One must be careful, of course, when transferring this phenomenon to humans, but some authors have raised the issue (Vaupel et al., 1998).

To answer this central question, we must first have the necessary tools that will allow us to develop an accurate measurement of survival at very advanced ages. For example, is it possible today to estimate life expectancy at 110? Difficult practical questions must be resolved before we can answer this question. First, it is well known that, at very advanced ages, exact age is often misreported for different reasons, including overestimation of age. Furthermore, since very old individuals are very rare, the numbers of deaths are very small, and random mistakes made at the stage of coding can have a crucial impact. It is particularly important to make sure that ages at death have been rigorously checked. This problem has been discussed in the chapter devoted to French supercentenarians.

A second problem arises when we want to compute mortality rates. The problem of age accuracy is even greater for population data than for death registration. First, ages of individuals recorded by censuses are usually much less accurate than ages at death registered by the civil registration system. In particular, overestimation of age is very frequent among very old people. Furthermore, censuses are usually separated by long periods of time, and, due to the uncertainty of ages given by censuses, the age-specific annual population estimates, which could serve as a denominator for calculating mortality rates, are very unreliable. It would be quite unrealistic to compute mortality rates in that classical way. Fortunately, very old ages are also ages at which migration is rare; it is then quite possible to calculate mortality rates using the extinct cohorts method (Vincent, 1951), as its basic assumption seems perfectly acceptable (Meslé and Vallin, 2002).

In the first section of this chapter, we will try to arrive at an estimate of life expectancy at the age of 110 by using only the deaths for which exact age has been carefully substantiated, as reported in the chapter on French supercentenarians. However, in a second section we shall investigate to what extent it would be possible to approach the same results by using the death counts directly derived from the civil registration system using simple intuitive corrections.

1 An estimation of life expectancy at 110?

Let us try to compute life expectancy at 110 on the basis of deaths for which the age of the deceased has been precisely validated, as reported in the chapter on French supercentenarians.

We will thus take into account the 49 verified deaths confirmed by the RNIPP (Répertoire national d'identification des personnes physiques, or National Identification Register of Private Individuals)[6], plus the 20 verified deaths of people on the list of names not found in the RNIPP. Figure 1 represents these 69 deaths on a Lexis diagram, by year of birth and calendar year.

1.1 Fifty deaths which can be used for calculations

We will, however, have to limit our analysis to a reduced fraction of this set. Since, as we have already mentioned, reliable population estimates at advanced ages as of January 1st of each year are not available, the only way to calculate the probability of dying is by applying the extinct generations method (Vincent,1951; Meslé and Vallin, 2002). Using this method obviously means working with generations that are presumably extinct, or, in other words, that have no survivors. If we were to assume that the death of Jeanne Calment marks, for the time being, the extreme limit of life; and if we were to select only cohorts that are absolutely extinct, this would mean limiting our study to cohorts born from 1866 to 1881, since our database ends in 2004. In that case, our database would include only 19 deaths, a figure that is too small to be reasonably used for calculations. However, other than the case of Jeanne Calment, no deaths beyond the exact age of 116 have ever been recorded. In 2004, the most recent cohort to have reached the age of 116 was born in 1888[7]. If we consider it quite unlikely that any deaths might still occur among these cohorts, we may extend our field of analysis to the 50 deaths observed among the cohorts born between 1866 and 1888.

[6] Since the chapter on French supercentenarians was written, an additional eight ages at death were verified, and we can take into account here 49 deaths provided by the RNIPP, instead of 41.

[7] More precisely, only those who were born very early in 1888 could approach age 116 in 2004. The more recent cohort which has completely reached age 116 in 2004, is the 1887 cohort. However, Jeanne Brémond, who died at age 115, is also a unique case, and it is very unlikely that a similar case could occur in the 1888 cohort in the year 2004. On the other hand, it is very useful for the purposes of computation to include the cohort 1888, which produced nine verified supercentenarians.

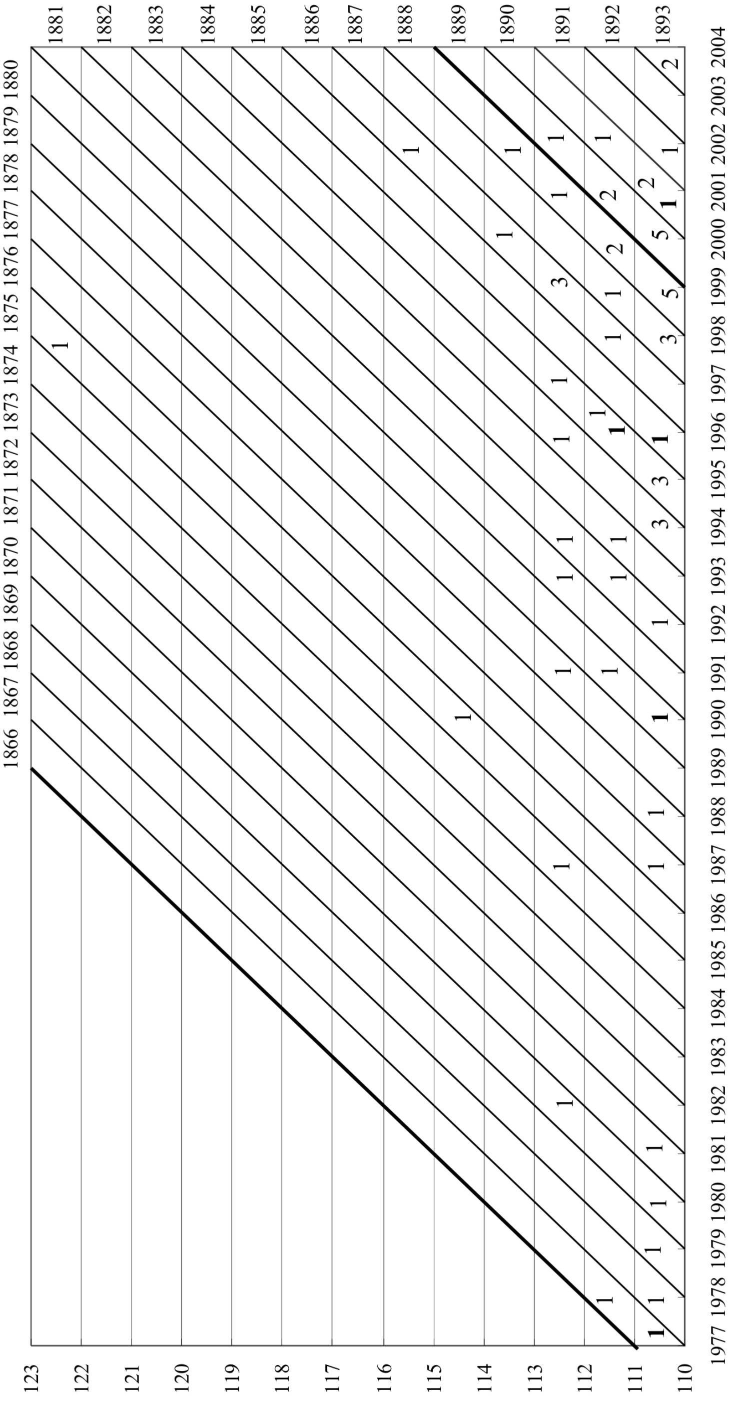

Fig. 1. Representation on a Lexis diagram of deaths at age 110 and over observed in cohorts born from 1866 to 1893

Given the Jeanne Calment precedent, it could be that some individuals born before 1888 may still be alive; nonetheless, the probability of finding such persons is so low that it may be disregarded. This means taking the limited risk of underestimating the life expectancy of these cohorts, but the fact that we still have another 50 deaths to work with reduces the distortions tied to small numbers. On the other hand, we cannot extend the sample any further, and we cannot, unfortunately, take into account the 15 deaths recorded in the later cohorts (beginning in 1889).

An underlying assumption of the extinct generations method is that there are no international migrations at such advanced ages. As demonstrated elsewhere (Meslé and Vallin, 2002), this assumption is perfectly realistic on the scale of a country such as France, since practically the only reason to migrate at that age would be a move to a specialized institution, and it is most improbable that a person who is still in France at the age of 110 would be transferred to an institution abroad, and vice versa.

1.2 Nearly 1.5 years of life expectancy at 110?

According to this extinct generation method, it is possible to determine for each cohort the number of survivors at each birthday by cumulating the number of deaths at each age, starting from the oldest age at death. This was done in Table 1 for the 1866-1888 cohorts.

The cumulated deaths figure directly yields the number of survivors on each birthday. If we establish a ratio between the deaths at each age to the number of survivors on the previous birthday, we obtain the probability of dying (between two birthdays) and we can calculate life expectancy in the same way as with a traditional life table.

Thus, we obtain for all the cohorts born between 1866 and 1888 a life expectancy at 110 of 1.68 years. Of course, the case of Jeanne Calment weighs a great deal in this small database. Given that it is very unlikely that there will be another similar case in the near future, life expectancy estimates at 110 may be expected to decline over time. If we do not include the death of Jeanne Calment at age 122, life expectancy at 110 for the same group of cohorts drops to 1.46 years. Jeanne Calment's case thus raises this life expectancy by 0.2 years. This can clearly be seen in Table 1: at 116, life expectancy suddenly increases to 6.5 years, which corresponds to the number of years of life left to the sole survivor of this group of cohorts, Jeanne Calment. This fact shows the limits of this type of probabilistic calculation, since, when only one survivor remains, life expectancy is no longer an 'expectancy' but the actual number of years subsequently lived by the survivor in question; when this duration is quite long, as in Jeanne Calment's case, it weighs heavily on previous calculations, since they concern very small numbers. In no way does this situation call into question the credibility of Jeanne Calment's dates of birth and death, but the exceptionality of Jeanne Calment's case makes rather obvious that the very small universe of French supercentenarians is much too small to be the true statistical universe of Jeanne Calment, which should include all the supercentenarians of the world, since she is the most extreme case in the world. Consequently, it makes sense to compute French life expectancy at 110 without including Jeanne Calment. In the absence of any other bias, the result underestimates the truth much less than including Jeanne Calment overestimates it.

The sample we have examined includes only four males, which means that we cannot offer separate results for men. We can, however, calculate that the life expectancy of females is 1.76 years for the 1866-1888 cohorts, but 1.52 if we exclude Jeanne Calment.

Of course, these estimates are quite relative, first because they are based on a small number of cases, but also because it is most probable that, despite our efforts, the set of supercentenarian deaths used here does not exactly correspond to reality. In particular, none of our information for the years prior to 1987 (1977-1986) comes from the RNIPP; our only source for that period is the initial list of supercentenarians, and we know that it is incomplete. It is quite likely that the list covers mainly the more exceptional cases, and that persons who died right after their 110th birthday are given less importance in the list than persons who died at an older age.

If this were the case, the mean age at death of the real group of supercentenarians would be slightly younger than the one observed. This is a second reason to think that our result without Jeanne Calment is much closer to the reality than the one with Jeanne Calment. It could even be an overestimation. Let us conclude that French female life expectancy at 110 might be very close to 1.5 years.

2 Return to vital statistics

This result may be compared with vital statistics estimates, even if they are biased; indeed, it is important to situate the estimate of life expectancy at 110 in the context of age-specific life expectancy trends after 100. In order to do this, one must first concretely determine the impact of these biases, up to what age these data can be used, and which kind of adjustment hypotheses would be needed.

Table 1. Cumulative number of deaths in the extinct generations and calculation of probabilities of dying and life expectancies

Age	1866-1888				1866-1888 without Jeanne Calment			
	Deaths	Cumulated deaths	Probabilities	Life expectancy	Deaths	Cumulated deaths	Probabilities	Life expectancy
110	24	50	0.48	1.68	24	49	0.49	1.46
111	10	26	0.38	1.77	10	25	0.4	1.38
112	11	16	0.69	1.56	11	15	0.73	0.97
113	2	5	0.4	2.9	2	4	0.5	1.25
114	1	3	0.33	3.5	1	2	0.5	1
115	1	2	0.5	4	1	1	1	0.5
116	0	1	0	6.5	0	0		
117	0	1	0	5.5	0	0		
118	0	1	0	4.5	0	0		
119	0	1	0	3.5	0	0		
120	0	1	0	2.5	0	0		
121	0	1	0	1.5	0	0		
122	1	1	1	0.5	0	0		
123		0				0		

2.1 Life expectancy after 100, according to vital statistics

We applied the extinct generations method to recalculate life expectancy at 100 on the basis of the entire set of deaths recorded by vital statistics for the 1868-1888 cohorts[8]. This set of cohorts is slightly smaller than those referred to in the chapter devoted to French supercentenarians since, in this database, the first cohort to have reached the age of 100 was born in 1868, and not in 1866.

Since there are only very few men among those reaching the age of 110, it seemed preferable to limit our study to the female sex. The curve titled "crude vital statistics" in Figure 2 shows the trend of female life expectancy after 100, resulting from the application of the extinct generations method to crude death data obtained from vital statistics.

The life expectancy estimates based on this data are clearly quite satisfactory until the age of 108. From 2.0 years at the age of 100, it gradually declines to 1.7 years at 108. Of course, the fact that the decline is gradual does not necessarily exclude the possibility that the life expectancy of centenarians may be overestimated, but it does lend some credibility to vital statistics data until that age. On the other hand, it is clear that the life expectancy trends beyond 108 are not acceptable. Such an increase, from 1.7 years at 108 to 3.8 years at 117, cannot be seriously considered realistic. This improbable increase is the obvious result of the overestimation of very advanced ages at death. We have already mentioned (in the chapter devoted to French supercentenarians) that this database includes the recent death of a woman aged 120, and of another at 124; these women were not known personalities like Jeanne Calment and do not belong to the group of French supercentenarians whose age at death has been duly checked. We therefore assumed that, in these cases, the reported ages at death were incorrect, and withdrew these two deaths from the database and made new calculations. The result is the curve at the bottom of Figure 2 (indicated as "vital stats corr1"). The impact of this simple adjustment was considerable, leading to a reversal of the life expectancy trend after the age of 111, and to a life expectancy of 0.5 years at 117.

However, as may be expected, such a simple adjustment does not really solve the problem, because the life expectancy curve still shows an improbable upswing between 108 and 110. In addition, although the withdrawal of the two deaths at 120 and 124 was correct, one error nonetheless remains due to the fact that vital statistics do not include

[8] Since available vital statistics concern deaths observed between 1968 and 2003 (see chapter on French supercentenarians), the first cohort covered was born in 1868, and the last one, covered until age 115, was born in 1888.

Jeanne Calment's death; if we add the latter to vital statistics data, we get the two curves drawn in fine print in Figure 2, which are no more acceptable than those resulting from crude data. The first (crude vital statistics + Jeanne Calment) is the most unrealistic of all. The second (vital stats corr1 + Jeanne Calment) provides a relatively stable life expectancy between 110 and 117, but there remains the sudden and improbable increase between 108 and 110.

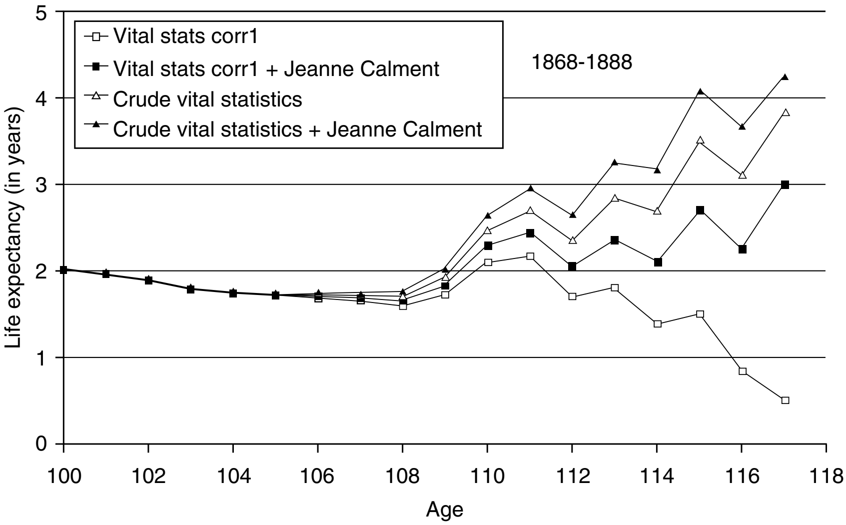

Fig. 2. Life expectancy by age, after 100, according to vital statistics

2.2 Can the artefact produced by INSEE rule on reported age be eliminated?

This sudden upswing is linked to another source of errors which has undermined the reliability of vital statistics: the problem that, prior to 1988, INSEE (Institut National de la Statistique et des Études Économiques, or National Institute for Statistics and Economic Studies) did not accept any ages at death above 109 (see the chapter on French supercentenarians). At first, we assumed that INSEE randomly distributed those deaths over other ages at death. However, if we take a closer look at the probabilities of dying per year of age beyond 100, we observe an unexpected rise at 108 and 109, followed by wide random fluctuations at more advanced ages due to the increasing smallness of the concerned population (Figure 3).

In fact, what happened was that INSEE's exclusion rule did not apply to ages, but to cohorts. In a given year of observation a, all deaths reported as pertaining to a cohort preceding a - 110 were considered unbelievable. The abnormally high level of the death probabilities at 108 and 109 leads us to think that these deaths were attributed to the a - 109 cohort, without changing the day and month of birth. Depending on whether the death occurred before or after the birthday, the result was an excess of deaths at either 108 or 109.

On the basis of this assumption, we tried to estimate the excess number of deaths classified at those two ages, and distribute them over older ages. In order to determine the excess number of deaths classified under ages 108-109, we examined the figures by age, and according to their position before or after birthdays, for the 1968-1987 period. Our observations indicate that, in 25 cases, the deaths occurred the year of the person's 108th birthday, after the birthday had been celebrated. However, the figure rises to 32 cases for those who celebrated their 108th birthday the previous year, when we would instead have expected the figure to drop drastically, since at those ages mortality is very high. At age 109, by contrast, the figure of 14 deaths of persons who had celebrated their 109th birthday the same year is probably too high, although we cannot compare it to the number of persons who celebrated their 109th birthday the previous year, since these were rejected by INSEE as being impossible. We examined the pace of decline in the number of deaths observed by age and cohort at immediately preceding ages, and concluded that nine excess deaths had been classified among the 32 deaths at 108, while only three excess deaths had been included among the 14 that occurred at age 109. The 12 deaths which had been wrongly included among deaths at ages 108-109 were then distributed among older ages[9], in proportion to the deaths observed after 1987 among the 1868-1888 cohorts.

In terms of probability of dying (see Figure 3), this adjustment obviously does not solve all problems, but it does reinsert the probability of dying at 108 and 109 in the continuity of the mortality increase with age before age 108, even if the probabilities of dying after 109 still fluctuate in a very unlikely manner. Such fluctuations make impossible any conclusion on the slope of the mortality curve after age 111, but our correction suggests a plateau from ages 108 to 111 that is not refuted by the general trends shown for successive years.

[9] In fact, at ages 110 and 111 only to avoid reinforcing the already existing bias of aging the oldest old.

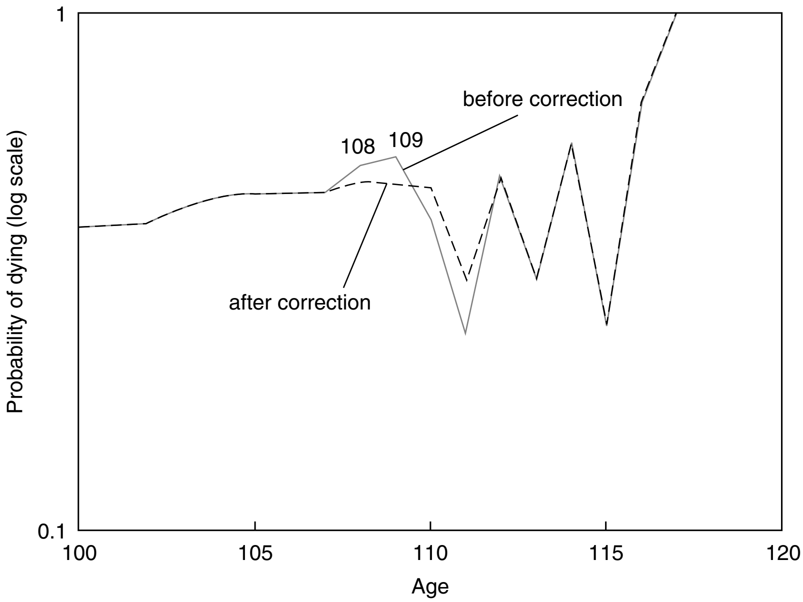

Fig. 3. Female age-specific probability of dying after 100, according to vital statistics, for the cohorts born from 1868 to 1888. Solid line: crude data + Jeanne Calment. Dotted line: after distribution of excess deaths at 108-109

In terms of life expectancy, the adjustment slightly improves results after age 108. The improvement can be seen in Figure 4 if we compare either the two curves including Jeanne Calment, or the two curves in which Jeanne Calment is not added to vital statistics figures. In both cases, life expectancy levels from ages 109 to 111 are considerably reduced and seem much more realistic. Thus, after the double adjustment of vital statistics data (withdrawal of two deaths at 120 and 124, and redistribution of the excess deaths at 108 and 109 to higher ages), life expectancy at 110 is 2.01 years if we add Jeanne Calment to vital statistics data, and 1.86 years without her. These values are closer to those determined on the sole basis of validated deaths (1.76 with Jeanne Calment and 1.52 without) than those given by crude vital statistics (2.29 and 2.10). However, these values still clearly overestimate life expectancy at 110 and beyond. The two simple intuitive corrections made improve the curve of life expectancy by age after 100, but not enough to erase completely the abnormal increase between ages 108 and 111.

This means that a more general overestimation of oldest ages is at work than the two most obvious ones that we eliminated.

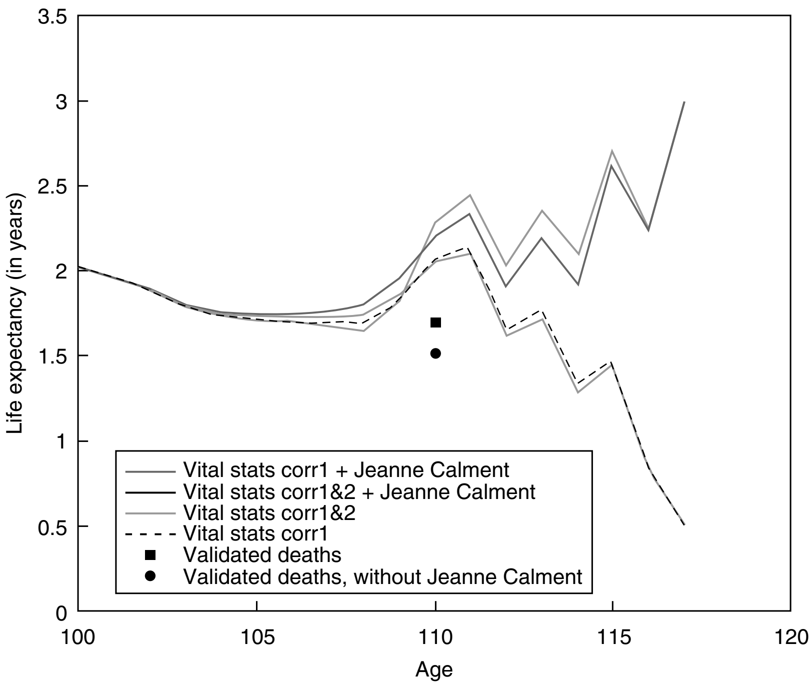

Fig. 4. Age-specific life expectancy after 100 according to vital statistics, depending on various adjustments (1868-1888 cohorts) and life expectancy at 110 according to validated data (1866-1888 cohorts). Females

It is interesting to note that, after age 112, the result obtained from the adjusted vital statistics data is lower than that obtained from the validated deaths with Jeanne Calment included, while it is higher when she is not included. The reason is that Jeanne Calment's relative weight is higher in the smaller group of 16 validated female deaths from the 1866-1888 cohorts than in the group of 26[10] from vital statistics of cohorts born in 1868-1888 (see Figure 5). However, the fact that vital statistics provide a larger number of cases holds another advantage, namely, that of reducing the fluctuations of life expectancy after 110.

[10] The 27 recorded deaths, minus the two eliminated deaths at 120 and 124, plus Jeanne Calment.

This phenomenon is particularly visible here, when Jeanne Calment is not included in the calculation.

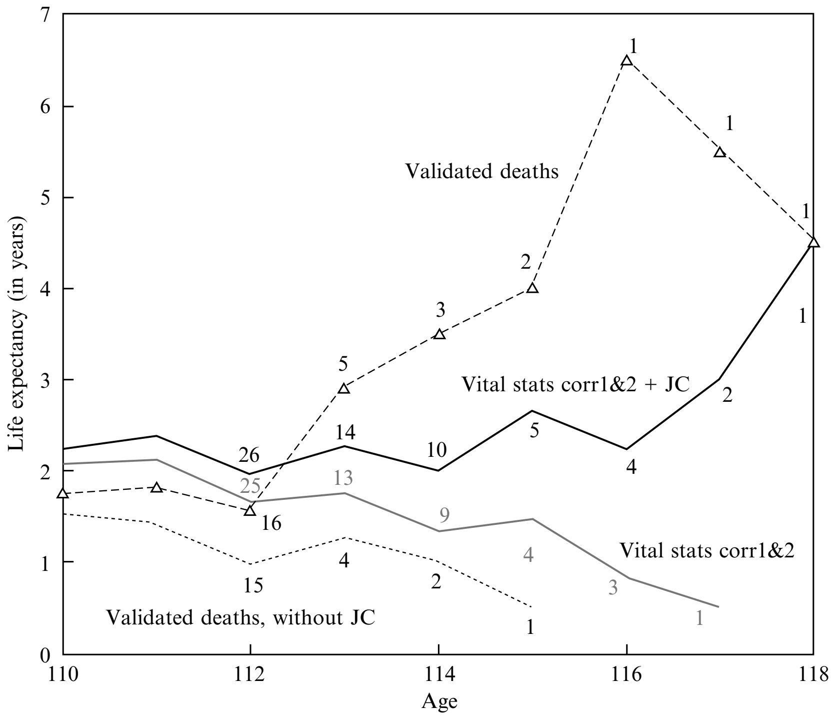

Fig. 5. Life expectancy by age over 110, according to vital statistics (1868-1888 cohorts) and according to validated data (1866-1888 cohorts). Females. (Numbers stand for population on which the computation relies)

2.3 Hope for future improvement of estimation based on vital statistics

Thus, with some caution and several adjustments, it is possible today to obtain an approximate measure of French life expectancy at rather advanced ages on the basis of vital statistics. This measure will probably be improved during the upcoming decades since we can expect a massive increase in the number of observations. As it is, each time the number of generations available to apply the extinct generation method increases, the estimation of life expectancy at 110 gets closer to the results derived from validated cases, even when the correction at ages 108-109 is not made. At the same time, the curve of life expectancy by ages over 100 become less and less abnormal (Figure 6). When our first attempt was published (Meslé et al, 2000), vital statistics gave a life expectancy at 110 of 2.82 years for 1868-1882 cohorts. Four years later, it was 2.36 for 1868-1886 cohorts. It is now 2.10[11] for 1868-1888 cohorts. In short, each time we added two new cohorts, estimation is three months shorter.

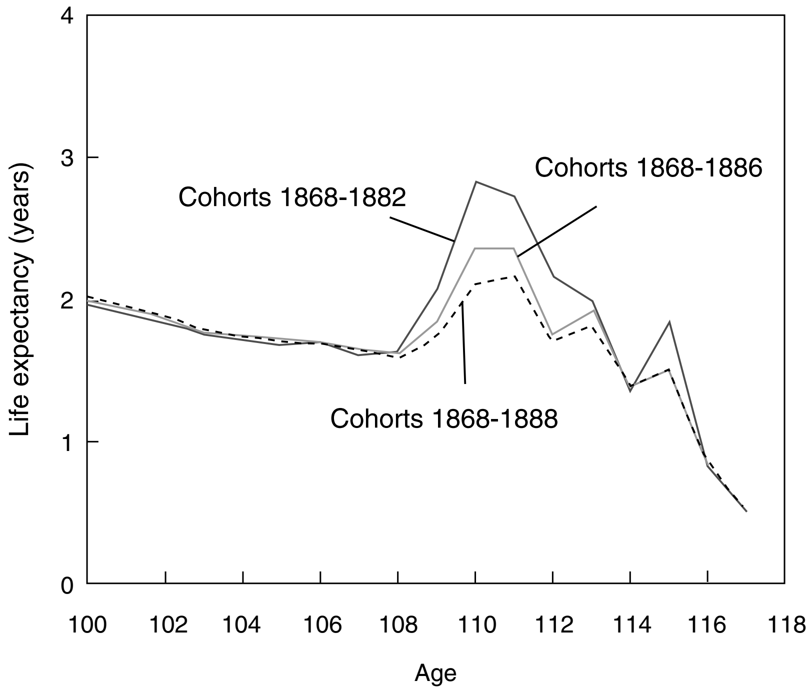

Fig. 6. Life expectancy by age over 100, according to vital statistics for three groups of cohorts. Females. (Not taking in account the two deaths at spurious ages 120 and 124)

[11] In 2000, we hadn't made the second adjustment of the vital statistics data, which consisted of the redistribution of excess deaths at 108-109 years. For this reason, we can only compare life expectancies calculated before this redistribution (2.82 in 2000, 2.36 in 2004, and 2.10 today), but the difference between results is necessarily homothetic.

This does not mean that it is unnecessary to build a complete and validated database—quite the contrary. Experiments based on vital statistics have shown that no procedure produces a life expectancy at 110 in perfect harmony with trends observed at younger ages. With or without Jeanne Calment, life expectancy at 110 is always found to be higher than life expectancy at 107. Of course, we may optimistically assume that beyond a certain age (and why not 107?), mortality ceases to increase with age and instead begins to decline, but for the time being, neither our calculations based on vital statistics, nor those based on verified deaths, can serve as evidence of such a phenomenon. On the contrary, the computation of validated data clearly calls this finding into question, since life expectancy is only very slightly higher at age 110 than at age 107 when Jeanne Calment is included (1.76 against 1.73), and significantly lower when she is not (1.52 versus 1.68). Furthermore, when Jeanne Calment is excluded, validated data show a downward trend after age 110 until the last age for which computation is possible (115). Only a complete and verified database covering a large sample of deaths could possibly confirm or disprove the finding that, at some very old age, life expectancy really ceases to decline. At this stage, we can only insist once again on the importance, in the context of the constitution of the International Database on Longevity (IDL), of updating the French database on deaths of supercentenarians whose ages at death have been duly verified.

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