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Familial Determinants of Sardinian Longevity: A Genealogical Approach

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1. Introduction and theory

The oldest old have recently enjoyed a steady growth in life expectancy. The number of centenarians has approximately doubled every ten years since 1960, as a result of a growing number of over 80–year-olds in the population (Vaupel and Jeune, 1995; Wilmoth et al., 2000). Centenarians appear to be a unique model to investigate the biological and non-biological determinants of aging and longevity, as well as how these intertwine (Franceschi et al., 2000).

This paper is part of a multidisciplinary and multipurpose research project, "A demographic analysis of Sardinian Longevity"[1], an attempt to document and verify a remarkable pattern of low mortality among 80+ years old Sardinian males and to explore the underlying reasons (Caselli and Lipsi, submitted). A large number of exceptionally old men (aged 100+ and 105+) live in Sardinia and the sex ratio among centenarians is unexpectedly low, particularly in the inland municipalities of Nuoro province (Poulain et al., 2004; Poulain, in press; Caselli and Rasulo, submitted, Deiana et al. in press).

The Sardinian population on 2001 census was roughly 1,631.880, including 187 centenarians (53 men and 134 women), with a ratio of 1.2 centenarians per 10,000 inhabitants, compared with 1.0 for Italy and a centenarian female sex ratio - taking the number of women per man- of 2.5. Elsewhere, in Italy the centenarian sex ratio is slightly over 5 and in other low mortality countries it is from 5 to 7 (Robin et al, submitted). Furthermore, in certain pockets of Sardinia the sex ratio is even lower, at times only slightly over 1 (Poulain et. al, 2004).

The demographic history of Sardinia is quite striking. Cohorts born at the turn of the 20th century, that include the cohorts in this study, experienced a particularly interesting life-course**.**

These cohorts experienced the lowest infant (and especially neonatal) mortality rates recorded in Italy at that time and stillbirth rates lower than the national average (Pozzi, 2000; Astolfi and Zonta, 2002; Astolfi *et al.*, 2002), even though the maternal mean age at birth was the highest.

[1] AKEA 2 is the name of the survey of Sardinian centenarians: Demographic Analysis of Longevity. A Survey on Sardinian Centenarians, director James Vaupel, Max Planck Institute (financed by NIA, US, subcontract with Duke University n.03-SC-NIH-1027).

However, after age 2, risks of dying for Sardinian cohorts during childhood and youth were substantially higher compared with cohorts from other Italian regions. Exposure to malaria which was still endemic on the island cannot be ignored and deserves further attention (Tognotti, 1996).

Of further note is the genetic selection that occurred over the centuries thanks to malaria. This selection provoked glucose-6-phosphate deidrogenase (G6PD) deficiency, that for Sardinian centenarians is double that of the rest of the population. Recent research claims that the lack of this enzyme creates the conditions leading to this extraordinary longevity in Sardinia and to the exceptionally high number of male centenarians (Deiana *et al*., in press). Some preliminary data indicate that this mutation is present in 11,2 % female and 25% male centenarians[2].

Hence generations of centenarians have been able to tap into a great vital potential: struck down by malaria at young ages, the usual selection process was triggered with the elimination of the more fragile and the emergence of more robust individuals due to this genetic mutation.

Sardinia has often been the focus of genetic studies as the population presents a number of unique features due to their isolation over the centuries and that they stem from a single familial group stock (Cavalli Sforza *et al*. 1994; Cavalli Sforza, 2001)

Also of interest is the fact that men from these centenarian cohorts were caught up in the First World War and experienced higher probabilities of death (compared with neighbouring cohorts not directly involved in the war). Higher mortality persisted for many years after the conflict ended, as recent research has pointed out. Having undergone further selection due to high mortality at young-adult ages, at the threshold of old age these cohorts may contain a large number of particularly robust individuals (Barbi and Caselli, 2003).

Furthermore, little mobility occurred between the centenarians' place of birth and current residence. A positive correlation has been found between low mobility and low mortality (Caselli, 1995). Another feature, along with low mobility, is the relatively high number of centenarians, particularly aged 105 years, living in certain inland areas where environmental risk factors are lower (Sanna et al., 1995; Bertollini et al, 1997).

A point of further note regarding Sardinians and particularly those living inland is the considerable variation of the frequency of given surnames in the different areas of the region (Zei et al., 1986) and the prevalence of specific territorial surnames, assuming the practice of endogamy in the past (Murru Corriga, 1990). Higher infant and child mortality among births from consanguineous marriages has been clearly reported in the literature (Cavalli Sforza *et al,* 2004; Romeo and Goldoni, 2004). Thus, we might ask, why is it that Sardinian centenarians are found in highly endogamic communities? Does consanguinity generate a selection effect ? Do individuals born within an endogamically selected couple boast a greater vital potential ?

These and other considerations lead us to believe that Sardinian centenarians are an ideal population group to test the impact of different determinants on survivorship to exceptionally old ages.

Longevity is, broadly speaking, the outcome of various factors of a genetic or environmental nature (early life factors, life styles, education, occupation, place of residence, dietary habits, environment, etc.)[3]. The number of centenarians in developed societies is a fast growing segment of the population and has inspired research into the role played by genetics in longevity. There is still wide debate on many of the most relevant issues regarding familial longevity (Bouquet-Appel and Jacobi, 1990 and 1991). Some authors have dismissed the role of genetics in familial longevity and

[2] Cfr. AKEA Project on Demographic Analysis of Sardinian Longevity.

[3] Hereafter socio-economic, environmental, behavioural and cultural factors will be referred to as the environmental impact.

found that familial resemblance is minor and that social explanations are more relevant. Studies on homozygote twins show the genetic component of longevity at birth to be 50%, but that this drops to 30% at old age due to environmental impacts (Christensen and Vaupel, 1996; Yashin et al., 1999a, 1999b).

Conclusions regarding twins can not be extended to include other population groups. This would imply that they share the same genetic component and the same environment until they are adults when their paths separate (Clare and Lickinbill, 1985; Herskind et al., 1996). Even analyses of a population group where family clusters of longevity are pinpointed fail to isolate a genetic factor. Rather, similar life experiences or life styles, or even environmental factors, may provide the answer.

Inheritability could be surmised for a family cluster of longevity among a group of centenarians when a survival differential exists for individuals from the cluster at extreme ages. It would appear that at old old age environmental impacts that were crucial in generating earlier survival differences are cancelled out. This would imply increased homogeneity for the old old and would depend on shared genetic factors. (Vaupel et al. 1979; Yashin et al., 1985; Vaupel and Yashin, 1985; Vaupel et al., 1998; Barbi et al., 2003).

Demography could help provide insight into the role of inheritability on longevity, even in the absence of genetic variables. To do so what are needed are data to reconstruct family histories of the oldest old and, in this instance, centenarians from a distinct geographical area. Then an analysis can be performed of genealogies and family life histories, using features from individual trajectories to reconstruct the life history of each sibling.

A principal aim of this paper is to illustrate the various steps taken to reconstruct the centenarians' genealogies using a particularly thorough validation procedure. A second aim, using their genealogical trees, is to speculate on family relationships and the familial impacts on Sardinian centenarians.

2. Familial longevity: a genealogical approach

While much has been said and written on the question of longevity and inheritability, the question is still wide open.

The pioneering studies by Mary Beeton e Karl Pearson (1901) reveal a positive correlation between age at death of parents and their children, while Alexander Graham Bell (1918), who confirmed this correlation, claimed that the role of the male line is greater than that of the female line. However, this early work uses incomplete data and is not free of oversights. Later research questioned these findings. E. Javalisto (1951), for example, refuted the predominant paternal role. Barry H. Cohen (1964) raised the issue of incomplete data and errors in reconstructing genealogies. Alan E. Murphy (1978) confirmed the criticisms raised by Barry H. Cohen (1964) and Albert Jacquard (1982) posed the question whether longevity was in fact hereditary.

More recent research on twins (Christensen et al, 2000a and 2000b), such as those using group genealogies or selected population subgroups (Philippe, 1978; Desjardins, Bocquet-Appel and Jakobi, 1990, Mc Gue et al, 1993, Cournil, 1995-1996; Gavrilov and Gavrilova, 1997; Tallis and Leppard, 1997; Poulain et al., 1998) have lent fresh impetus to the question of longevity and inheritability and cast new light on our understanding of this issue (see Poulain et al. 1998 for an extensive review of the existing literature).

Fortunately, today, we can avail of reference populations who have reached the age 100, as well as know, in many cases, their place of birth and residence. For Sardinia, data are also available on

the past history of the family of origin, their parents, grandparents, great great grandparents, and siblings. Often, data can also be had regarding the extended family, uncles, aunts, grand uncles, grand aunts, etc.

Thanks to the availability of data from fairly wide-ranging and reliable samples and sources, family genealogies are reconstructed that can throw light on longevity and inheritability, on the relative impact of the male or female line as well as the role of events during early infancy. For Sardinian centenarians data can also be retraced regarding the composition and size of the family, for example, place of birth and residence, birth order and birth intervals, the month of birth, and age of parents at birth. These aspects have been shown to be of vital importance in longevity studies. There would appear to be, for instance, a link not only between the mother's age, but also that of the father at birth and the survival of the child (Gavrilov and Gavrilova, 1997 and 2000).

Sardinian centenarians are also exceptionally homogeneous regarding socio-occupational status, the men usually being either peasants or shepherds, and the women housewives, following an age old tradition handed down from parent to child. In view of the role of the socio-occupational variable in mortality studies, this is not a discriminator in the study of Sardinian centenarians.

The lack of mobility and frequent kinship among those born and bred in the various municipalities throughout Sardinia have been pointed out. Phenomena such as isonomy (Sanna et al., 2001) and endogamy (Sanna et al., 2004) are found. While interesting, they complicate the construction of genealogical trees. Exact relationships of kin are difficult to sort out as frequently the same surname or double barrelled surname[4] is used a leftover from the Spanish occupation. A baptismal certificate may, for example, record either the father's surname or the mother's surname, or even both. On the other hand, the birth certificate may only record the father's surname. On occasion, a child may have been given two or more names, not all of which appear on every certificate. Moreover, the name of a dead child is often passed on to another sibling.

To construct a genealogy is time consuming and despite this the data are not always complete. This is particularly the case with earlier dates where data are often incomplete or missing, compromising any continuity in the life history. At times perhaps a parent's or another forebear's age at death is missing. Nonetheless, as all the names and surnames are known in the genealogy, they remain important for the study of kinship and the role of consanguinity.

These limits somewhat undermine what is in fact a considerable wealth of material on Sardinian centenarians. We are dealing with as many as 207 centenarians (100 men and 107 women), that are certainly representative of a population that only some years previously numbered 310 centenarians (1 January 1997 to 15 September 2003). Moreover this research also reconstructs the family histories, at least first degree, of a considerable control group from a sample of survivors belonging to the 1906-1908, 1911-1913, 1920-1922 generations, born and resident in the same municipality and of the same sex as each centenarian (621 individuals). Two other controls were selected for each centenarian, of the same sex and generation, deceased at age 60-65 and 70-75, and their family histories constructed.

3. Data and age validation

Only a small proportion of the AKEA data collected will be used for the reasons referred to above. Selected genealogies are examined that typify certain traits of Sardinian centenarians and that highlight the wealth of the material available.

[4] In the early 700's female offspring in some parts of the region were often given their mother's surname, see note 12.

A number of time consuming steps are needed to construct a genealogy that also involves a meticulous check of a vast number of vital records. It is particularly crucial to establish first of all that the centenarian is in fact authentic.

The validation process was begun some years ago as part of the preliminary AKEA study and conducted by Michel Poulain (University of Louvain) and Gianni Pes (University of Sassari). The preliminary results have been submitted for publication (Poulain, in press). Thus this second phase was facilitated by their pioneering work, both with regard to the data available, experience in the field and the methodology tried and tested. Particularly important is the good relationship established between the AKEA team and employees of the municipal authorities.

From an initial 141 centenarians validated by AKEA 1, this has risen to 207 centenarians with AKEA 2, only some of whom were included in the first survey. For these further details were collected thanks to a control over a larger series of documents triggered by the fact that AKEA 2 addressed other aspects such as endogamy, the fertility of centenarian women, (age at first birth, birth intervals, number of children, etc.) and the survivorship of the centenarians' descendants.

Civil records and parish registers were used for the validation process and to build the genealogical trees.

Civil Records

1. Birth, death and marriage registers held in each municipality dating from 1866-1867. In parallel, parish registers are referred to confirm any information or to find information before 1866.

2. "Anagrafe", i.e., local population registers kept on a continuous basis in each municipality. The anagrafe is composed of a set of individual sheets; a computerised version is being processed.

For a complete age validation the following is required:

a) birth certificate;
b) marriage certificate(s);
c) widowhood certificate;
d) anagrafe sheet;
e) birth certificates of both parents, and
f) their marriage certificate, and
g) their death certificates;
h) birth certificates for all children of the case, and
i) their anagrafe sheets;
j) birth certificates siblings of the case, and
k) their anagrafe sheets.

Complete validation is achieved only when the cross checked data are congruent. That is:

- Full compatibility between birth and death registers and *anagrafe*, if the centenarian has died, and between the birth register and *anagrafe*, if he or she is living (date and place of birth, names given to the new-born, name of parents, age of father if given).
- Reasonable compatibility between the names in the various records. (In some cases, the names given to the new-born are slightly different from those in the death register).
- Full compatibility with the marriage register for parent's marriage (name of spouses, date and place of marriage, ages, checking for the plausibility of the age at marriage of both spouses).

- Coherence of all between-birth intervals for the centenarian and siblings, taking into consideration those who died in their first year of life. A repetition of the name given to siblings must be explained by the death of a previous sibling and considered in the age validation.
- Compatibility, if married, of ages given on the marriage certificate and on the birth certificates of all children.
- Check for isonomy in the village that could have resulted in an error when linking different events and calculating age.

Parish registers

The civil registration system was introduced in Italy after national unification and the first data on births, marriage and deaths of each Italian municipality date from 1862. For the previous years parish registers are used:

1. «Libri dei battesimi» (Baptismal registers)
2. «Libri dei matrimoni» (Marriage registers)
3. «Libri dei defunti» (Burial registers)
4. Status Animarum (a sort of parish population censuses).

Besides providing additional elements to confirm the age validation, these sources are useful to reconstruct the biographies of the centenarians' ancestors.

It is envisaged that the family trees for those aged 105 plus will be constructed using these parish registers. A total of 53 persons from 44 municipalities (Figure 1) from the 1997-2003 centenarian survey were identified (45 of whom validated using vital records). To date 11 genealogical trees have been built. This involved a year's work on the part of the historian involved[5].

4. Some characteristics of individuals aged 105 and over

Who and where are they?

The centenarians participating in the AKEA project were selected on the basis of their place of birth. The 53 centenarians aged 105 plus (17 % of the total) are distributed throughout 44 municipalities on the island (see Figure 1). No age errors occurred for the 44 validated, nor was there any discrepancy between vital records and parish registers for 11 centenarians.

Of these 53 centenarians, 33 are women and 20 are men. In the province of Cagliari, centenarian women number 39.4% of the total centenarian population, while only 9.1% in the province of Oristano (Table 1). Distribution for centenarian men is quite different between provinces: 50% live in Nuoro, 25% in Cagliari and the rest in Sassari and Oristano. The proportion of those aged 105+ in Nuoro over the total population is three times that recorded in the whole region. For women it is less than double than that of the region. As the distribution for men and women is different, subsequently the sex ratio changes, depending on the province in question (see table 2).

Of particular note are the two men aged 110 plus in Nuoro province.

[5] Dr. Marilena Secchi, University of Sassari

Table 1. Centenarians (age 105 plus) by sex and age from 1997 to 2003. Total population by sex at 2001 census and proportion of centenarians. Provinces and Sardinia

Provinces and region	105-107 years	108-109 years	110+ years	Total 105+years	Prov./region per 100	Total Population at 2001 Census	105 and over on population per 10.000
MEN							
Cagliari	3	2	-	5	25.0	371528	0,13
Nuoro	7	1	2	10	50.0	130223	0,77
Oristano	2	-	-	2	10.0	75296	0,27
Sassari	2	1	-	3	15.0	222191	0,14
Sardinia	14	4	2	20	100.0	799238	0,25
WOMEN							
Cagliari	11	2	-	13	39.4	388783	0,33
Nuoro	6	3	-	9	27.3	134636	0,67
Oristano	2	1	-	3	9.1	77786	0,39
Sassari	8	-	-	8	24.1	231437	0,35
Sardinia	27	6	-	33	100.0	832642	0,40
MEN AND WOMEN							
Cagliari	14	4	-	18 (*15*)	34.0	760311	0,24
Nuoro	13	4	2	19 (*16*)	35.8	264859	0,72
Oristano	4	1	-	5 (*5*)	9.4	153082	0,33
Sassari	10	1	-	11 (*8*)	20.8	453628	0,24
Sardinia	41	10	2	53 (*44*)	100.0	1631880	0,32
N.B. The number of municipalities are in brackets. Source: www.istat..it, and AKEA 2 project							

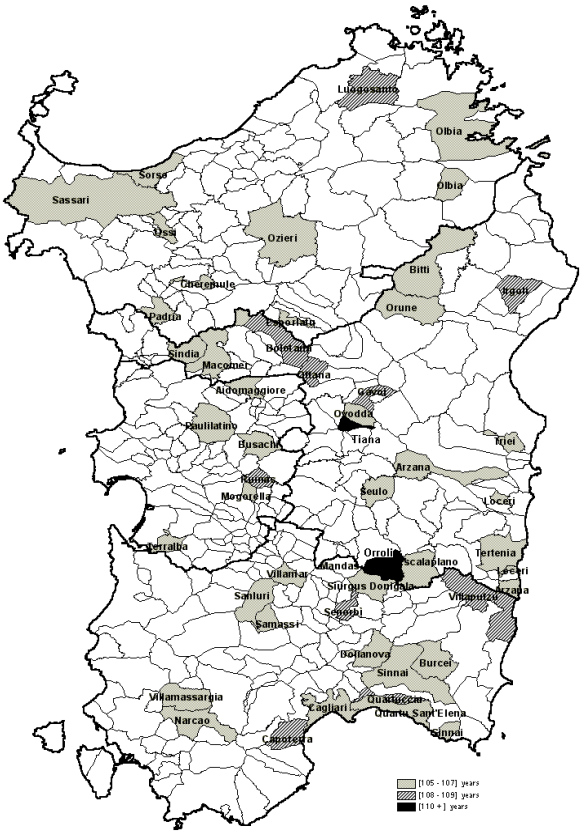

Figure 1. Geography of Sardinian centenarians aged 105 and over: 53 individuals located in 44 municipalities by age

Table 2. Women centenarians' (age 105 plus) sex ratio

Provinces and Region	Women	Men	Women/Men	Women	Men	Women/Men	Women	Men	Women/Men
	105-107 years			108+ years			105+ years		
Cagliari	11	3	3.7	2	2	1.0	13	5	2.6
Nuoro	6	7	0.9	3	3	1.0	9	10	0.9
Oristano	2	2	1.0	1	0	-	3	2	1.5
Sassari	8	2	4.0	0	1	--	8	3	2.7
Sardinia	27	14	1.9	6	6	1.0	33	20	1.7

Which genealogies?

Mention has already been made of how time consuming and difficult it is to build genealogies. While the vital records for all the individuals involved have been validated, to date 11 genealogies are complete, 6 men and 5 women, of whom 3 were born in province of Cagliari, 6 in the province of Nuoro and 2 in the province of Sassari. The priority selection criteria was naturally age. Obviously we began with the two individuals aged 110 plus, both males and both born in Nuoro province, Antono Todde in Tiana and Giovanni Efisio Emanuele Frau in Orroli. The same criteria applied to women and the oldest woman selected was aged 109 years lived in Cagliari. Privilege was given to those linked by kinship. Here, we are dealing with two cousins from Padria (Sassari province), one of whom, Antonietta Sebastiana Serra, died aged 106 and the other, Caterina Serra, still alive on 10th February 2004, aged 106.

That the information gathered was correct was checked both for the genealogies and the validation process for all centenarians in AKEA 1 and AKEA 2 and only one exception was found (Poulain et al., submitted). Both vital records and the parish registers were compared at all times. We found, for example, that the date of birth contained in the baptism certificate, usually celebrated sometime after the event, was the same as that on the birth certificate. The quality and completeness of the vital records available and the sheer amount of information contained in the parish registers guaranteed the accuracy of our work.

The availability of data was also ensured by the low mobility among the centenarians and their families. Of the 53 persons included in 15 instances did the province of birth differ from that of residence and even within the province any moves from the municipality of birth were quite few. Of the 11 genealogies completed, apart from 1 case, all the others were born and lived in the same municipality. The eleven validated super-centenarians all shared the same occupation: the 5 women were all housewives and the 6 men either peasants or shepherds.

5. Family genealogies: endogamy, exogamy, isonomy and inbreeding

Before coming to the three selected family genealogies, some results are provided that corroborate and further enrich the wealth of data available for Sardinia regarding endogamy, exogamy, isonomy and inbreeding.

The communities where the centenarians lived, were particularly isolated from the surrounding world, which was fairly typical of Sardinia until quite recently, and the object of research by anthropological geneticists and demographers (Moroni, 1972; Zei et al., 1983a, 1983b, 1986; Gatti, 1990).

In view of the possible impact of this isolation on the genetic structure and demography for two first municipalities: Padria (in the province of Sassari) and Orroli (in the province of Nuoro)

parish marriage records were examined to identify married names, place of residence, and any dispensations because of kindred, for two 25-year periods (1856-1880[6] e 1881-1905), so as to cover more or less two generations.

Early results, yet to be fully corroborated, are interesting. Of note is the fact that endogamy was quite common to both municipalities as well as intermarriage. Another interesting point is that both marriage partners are more often than not from the same municipality. "Non local"[7] partners are usually from neighbouring parishes, merely a few kilometres away. Moroni *et al* (1972) and Gatti (1990) found that between roughly 1850 and 1918 there was an increase in consanguineous marriages and the marriage distance between partners' residences narrowed.

Endogamic marriages were quite frequent in Orroli until recently, dropping from as high as 90% during the first period considered to 87% during the second. This was somewhat lower in Padria, but still fairly high at 82% between 1856 and 1880, and 87% between 1881 and 1905.

Nor can we exclude possible oversights on the part of the parish priest when indicating the place of origin of the "non-local" partner. This is particularly plausible for Padria where the greater variety of surnames among couples would suppose more frequent outside partners.[8].

There are 4-5 partners with the same surname in Padria, and an average of 8 in Orroli, and new surnames from "outside" the area are more frequent in Padria.

To measure precisely the extent to which a municipality was isolated, consanguinity was analysed using church marriage dispensations for close degree kindred. This was high for both municipalities but the time trends were different: in Orroli 10,45 of all marriages were consanguineous between 1856 and 1880, rising to 16,3% between 1881 and 1905 and in Padria, 16,7% and 11,6%, respectively.

Data regarding exogamy and consanguinity were somewhat surprising. Exogamy did not lead to a reduction in consanguineous marriages, nor *viceversa.* Indeed, exactly the opposite arose in the two municipalities observed.

Initial results for consanguinity are fairly contradictory. To clarify the situation a longer time span is needed and the analysis extended to include other communities. Some indirect measure of consanguinity should also be made by calculating marital isonomy (both random and not random).

When the source is reliable marriage dispensations allow a precise and accurate measure of consanguinity. One drawback however is that the analysis only concerns marriages where the degree of kinship is known, completely ignoring cases of distant kin relations which should not be overlooked in view of the genetic impact.

5. 1. Three genealogies under focus

Often the law of small numbers does not support the hypotheses made and, on the contrary,

[6] Excluding the years 1866-72 for Padria as records were suspended by the bishop.

[7] Marriages were usually celebrated in the bride's parish, confirmed by the fact that the "non local" is usually the groom, that somewhat detracts from the results obtained. Marriages for grooms from Orroli and Padria escaped our control. For a better overview of marriage exchanges neighbouring parishes should be included in the analysis or we should have a nominative source like a census or a status animarum, but unfortunately this is not the case of our communities.

[8] Nonetheless, parish priests were usually very careful filling out the marriage certificate, clearly stating the groom's origins and the parish of birth and residence when these did not coincide.

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points elsewhere. For this very reason, we have decided to present three familial genealogies that are representative of three different contexts.

First, we will deal with the family history of Antonio Todde, who died at the ripe old age of 112, in the same place of residence as he was born in, and where we can trace the history of longevity inherited from the maternal side of the family. There is a history of inter-marriage between maternal and paternal relations. The second genealogy, as we said, is that of a supercentenarian Giovanni Efisio Emanuele Frau, who died in 2003 at the age of 112. The third family genealogy reconstructed, that pinpoints the links between longevity and isonimy, belongs to two first cousins, Antonietta Sebastiana Serra and Caterina Serra.

One key factor was common to all four centenarians: each of them were related to someone who had reached 100 years old, either a family member or kin. Antonio Todde had a surviving sister aged 101 years and a first cousin who died aged 103 years. Giovanni Frau had a first cousin once removed who died aged 101 years, while the two Serra were first cousins.

Antonio Todde's genealogical tree

There are a number of reasons underlying our decision to present the family tree of Antonio Todde, born in Tiana in 1889 and who died there in 2002. The AKEA1 study corroborated that he was the oldest man in the world, and accepted as such in Guinness Book of World Records 2002 (2002). He is also the subject of a previous study that assessed various aspects of his biography, health and genetics (Deiana *et al*. 2002). This choice was further dictated to by the fact that he belonged to a family from a geographical zone with the highest number of known centenarians (Deiana *et al*., 1999). Moreover, he was male and represented the particularly high number of male centenarians found in Sardinia (Deiana et al., 1999).

Retracing the Todde family tree was also aided by the availability of documentary sources free of significant time gaps.

Civil status registers for the municipality of Tiana are complete for three series (births, marriages and deaths) from the year 1867. They are well preserved, easily accessible, in Italian and easy to read. For life events prior to 1867 we used original parish registers for Tiana, stored at the Historical Archive of the Diocese of Oristano, that are easily accessible, written in Castilian until 1820, then in Latin or Italian, and in Italian only after 1840.

The fact that the family comes from a small community facilitated drawing up the family tree, the population today not being much different from that at the end of the 1800's, and historically isolated with respect to the surrounding community. This enabled us to trace back five generations, covering a time span from the last twenty years of the 18th century up until today. Antonio Todde's family tree is presented in Figure 2 and shows the age at death of each of the "relatives" for whom this data is available. A distinction must be made between cases where this data was based on a linkage between birth and/or baptism certificates and death and/or burial certificates, and those where the age was taken from death or burial registers. With regard to the latter some approximation may have occurred. Experience, however, has proven that ages contained in the civil registers are usually fairly accurate, more so than parish registers, particularly more ancient ones.

Antonio Todde was born in a small village in the province of Nuoro, in the central mountain zone of the island, on 22 January 1889 and died there on 3 January 2002, at the age of 112 years and 346 days old. This information was obtained by putting together the data contained in the following records:

- Baptismal certificate n. 4, dated 23 January 1889 (only the date the baptism took place is shown). The certificate contains the names and surnames of his parents Francesco Maria Todde e Francesca Angela Deiana.
- Birth certificate n° 4, from the civil status register, dated 26 January 1889, referring to 22 January 1889 as the date of birth. The certificate includes the name of the father, as well as declaring, while that of the mother does not appear as both parents at that date had contracted a religious marriage only. The custom holding this to be the more important ceremony, often delaying the civil marriage ceremony, has also been found to be the case in other Italian regions of the time[9].
- Civil marriage certificate for Todde's parents, celebrated on 30 December 1908, 25 years after the religious ceremony, containing the legitimisation of their children born during their marriage and still alive.
- Marriage certificate n° 9 of Antonio Todde with Maria Antonia Madeddu, dated 15 September 1920, where the groom's age (31 years) is consistent with the date of birth, 22 January 1889. The paternity of the groom is correctly reported. Information regarding this marriage, with consistent dates, is noted in the margins of Antonio Todde's birth certificate.
- The birth certificates of five of the children born to the couple Todde Madeddu, spanning the years 1921-1933. In each of the certificates the age of the father is consistent with that deduced from the birth certificate.
- Death certificate n° 1-first part, reporting the death of Antonio Todde on 3 January 2002. This information, reporting the same dates, is also contained in the margins of Antonio Todde's birth certificate.
- The same procedure was followed for the other members of the family, although in some cases (particularly for the older generations) fewer documents were found than was the case for Antonio Todde.

An analysis of the family tree shows several cases of longevity among first degree relatives of Antonio Todde. His father died at the age of 88 and his mother at the ripe old age of 98. One sister died at the age of 98 and another is still living aged 101 years.

Another sister died immediately after birth, and a brother, the first-born, died before he was four. Considering that two other sibling deaths can be traced to violent causes at a young-adult age, overall, the family would appear to enjoy an unusual longevity.

To be noted in the family tree, as is the practice in Sardinia and among other populations, is the custom of giving the same name to a child who has died to a later child. In Antonio Todde's family tree, after the death of his fifth sister, Maria Agostina, the same name was given to a sister born later, the ninth, who is still living.

Of Antonio Todde's five children, four are still alive, aged between 70 and 82 years. The only child who died as a child (21 months' old) was a girl, and her death, going by family recollections, was due to a form of anaemia, probably talassemia, frequently found in Sardinia and more than plausible given that her father was a carrier, as shown by molecular tests (Deiana *et al*. 2002).

The AKEA 1 study also identified another centenarian who lived at Tiana where she died at the age of 103 years, subsequently found to be a cousin once removed of Antonio Todde on his

[9] The column containing the observations and margin notes alongside the main text of the birth certificate are especially useful, as they provide information on the individual referred to in the certificate. Mention is made to other events after birth, namely marriage and death, with reference to the date, the number of the certificate and the series it belongs to, thus facilitating the link between the various documents.

mother's side. This led to a further reconstruction of the maternal branch of Antonio Todde's family tree, and this cousin's ancestors were included.

The ages at death of Antonio Todde's grandparents and great-grandparents do not yield any exceptional cases of longevity among his paternal ancestors.

Among his mother's ancestors and collaterals, however, at least one instance of longevity (93 years) is found, a brother, father of the centenarian mentioned above. Moreover, her maternal grandfather died in 1924, aged 87 years, and a maternal great-grandfather died aged 75, a maternal great-great-grandmother died in 1874 aged 87 years, and a maternal great-grandfather died aged 75, that was quite old for the times, i.e., 1873.

A close look at the family tree shows that endogamic unions were frequent, as is to be expected among a family living in an area that has been isolated for centuries (Murru Corriga, 1890; Moroni *et al*, 1972). A direct consequence is the small variety of family names contained in the genealogy reconstructed, that is only to be partly attributed to the small size of the community. We were able to trace the descendancy of all the relatives with the surname Deiana from a single ancestor, Mattia. The same was not the case for the Todde family. This is despite the fact that 4 marriages involve a Deiana to a Todde. This data could presume a tendency towards consanguineous marriages, but available data are not sufficient to corroborate this. An obvious example of consanguinity is the marriage of the centenarian female cousin to a first degree cousin, also a first degree cousin of Antonio Todde.

Figure 2 here

Giovanni Efisio Emanuele Frau's family genealogy

The decision to include Giovanni Efisio Emanuele Frau's family genealogies was similar to that for Antonio Todde. He is to all purposes the only other real "fully-fledged" supercentenarian[10]. He, too, was included and his documentation validated first in AKEA 1, then in AKEA 2, and was born in an inland municipality in the province of Nuoro where he died aged 112 years, 5 months and 20 days.

Civil status registers for the municipality of Orroli, as well as those for Tiana, are complete for three series (births, marriages and deaths) from the year 1867. They are well preserved, easily accessible, in Italian and easy to read. For life events prior to 1867 we used the digitalised records of the parish registers stored at the Sassari Regional Archive[11].. These sources are accessible, written in Castilian until about 1820, then in Latin and they do not present important gaps, even if the older documents are occasionally damaged and quite difficult to read.

The parish records have been used also for the years after 1867 in order to increase the accurateness of the validation procedure.

As with Todde, information regarding him and that of his family was perfectly consistent in the various birth, death and marriage certificates. A similar validation procedure and construction of the family biographies were also conducted.

The reconstruction of Frau's family history was successful despite a number of gaps, such as

[10] In November 2003, after 15 September the cut-off date for our sample, another supercentenarian celebrated 110 years, but who died before his next birthday.

[11] The Records and Document Assets Editorial and Information Service of the Sardinian Region, has produced microfilms and digitalised images of the parish registers of almost all the Sardinian parishes. We would like to thank Maurizio Pirisi, director of the Sassari office, who placed at our disposal the documentation collected.

in the kinship network[12], thanks to the fact that Orroli was fairly isolated and closed to the outside world.

Frau was born on 29 December, 1890 in Orroli and died there on 19 June, 2003, at that moment the oldest man in Europe. He worked as a farmer all his life.

His father was 45 when he was born, and his mother 32.

Giovanni married at the age of 36 in 1927. He married Giuseppa Cavalleri who died aged 89, in 1995. They had eight children, and the last was born when Giovanni was 56. At the date of the survey six of his children were still alive: of the other two, one died at the age of 3, and the other aged 68.

Various cases of longevity are found in his family. Of his seven siblings, a sister died aged 95 years, one brother aged 90 and another aged 84.

Various cases of longevity[13] were found in the maternal branch of the family (five generations included). Giovanni's mother, Daniela Fortunata Orrù, born in 1859, died aged 87, and two aunts died at ages 82 and 79, respectively.

Giovanni's maternal grandparents were related: the parish marriage certificate contained a dispensation for "4th degree kindred", presumably cousins. It was thanks to this dispensation that kinship was traced. Merely tracing the biographies of the ascendants of the individuals in question did not reveal all the kindred relationships existing.

Going back in time, a case of longevity was found in Orrù's family: a maternal grand uncle, Gianuario Luigi, born on 26 February, 1815, died at the ripe old age of 88.

Interestingly enough, the other centenarian from Orroli is a relation of his: Elena Orrù, born in 1903 and who died in May 2004, at the age of 101.

Giovanni Frau and Elena Orrù's grandfathers were in fact brothers.

Elena Orrù's is Antonio's daughter (died age 72), who is Gianuario's son[14]. When Elena, the second last of 7 children, was born her father was 58 years old and 65 when the last son was born. Two of Elena's brothers died when they were over 80 years old: one aged 88 and the other aged 82.

Recently the Municipality of Orroli published on its web page a list of over 90 year olds living there on 1 March 2004. Of a total of 33, 20 were women and 13 men. Four of the women, including Elena aged 100, had the same surname, Orrù. No great emphasis shoud be given to this as it is the most frequent surname among the generations in question. Another woman, Ottanza, born in 1912, is a first degree cousin of Giovanni Frau. Ottanza is the daughter of Battista, Daniela Fortunata Orrù's niece, Giovanni Frau's mother. Daniela's brother, Tommaso, is Battista's father.

A single ascendant has not been traced for the other Orrùs, while the frequency of certain names at baptism would lead us to believe in their common ascendancy. Only a careful reconstruction of family trees, going back as far as possible, will reveal the existence, however

[12] For earlier periods, a correct identification of kinship in Orroli is complicated by the fact that at times in the early 700's female offspring were often given their mother's surname, already found elsewhere in Sardinia (Francalacci et al., 1996).

[13] Particular instances of longevity were not identified along the paternal line, apart from two paternal great-grandparents: a great grandfather born in 1770 who died aged 77 and a great grandmother born around 1775 who died aged 75, as stated on the death certificate but not corroborated. All other instances of longevity mentioned in this paragraph were validated.

[14] Focus was given only to Elena Orrù's direct ascendants. Antonio, for instance, is not Gianuario's only child. The analysis will be extended to include Antonio's other siblings and their descendants.

remote, of kinship.

Two pairs of siblings were also included in this list of 33 ninety-year olds in Orroli (two brothers, born in 1905 and 1911, and a sister and brother born in 1909 and 1911). Curiously, a grandparent of the two brothers is called Fortunata Orrù, but kinship with our centenarians has not been established. Perhaps other forms of kindred exist among the other over 90-year olds, that only further research will reveal.

Antonietta Sebastina Serra and Caterina Serra's family genealogies

The family history of these two cousins is fairly unique as a history of inter-family relationships between spouses are quite frequent going back as far as the 1700s.

The reconstruction of the family tree and the validation process for these two cousins, who borne and lived in Padria, were identical to those performed for Todde. For both the documentation used is well preserved and easily accessible.

Antonietta Sebastiana, who died at the age of 106 years, is the daughter of Caterina's mother's brother (still alive on 10° February, aged 106 years). Antonietta Sebastiana's mother's died giving birth at the age of 22, while the father died aged 67 years. Caterina's mother, however, died at the age of 93 (the 1877 generation), while her father died aged 73. Caterina's parents had the same surname, both being second cousins, confirmed by a dispensation for 4th degree kinship from the bishop, contained in the parish marriage register.

The cousins' parents come from large families. The grandfather, married a woman who was 28 years younger than he was, and had 10 children, three of whom died, respectively aged 93, 93 and 88 years. Caterina's mother, who died at the age of 93, was born when her father was already 65 years old and his wife 37.

The grandparents common to both cousins died at the age of 87 (the grandfather) and 85 years (the grandmother). They both came from long-living families. The paternal grandfather of both cousins had a maternal grandmother who died when she was 88, who had the same surname as the mother, although no clear kindred between the two was revealed. In any case longevity runs in the family branch shared by Antonietta Sebastiana and Caterina, but Caterina's family history also contains another curiosity. As we saw, she was born when her father was already almost 70; Caterina then married her cousin, the son of her maternal grandfather's nephew, that is the son of the grandfather's brother. Another peculiarity is that Caterina's paternal grandfather has the same surname as the rest of the family, although once again no direct kindred between the two families was established. The only conclusion is that four generations of ascendants of Caterina's family have the same surname.

In point of fact, Antonietta Sebastiana and Caterina's family tree, from the mid-1700's until today, only contains three surnames of three families, each of which has a history of long-living.

6. Some conclusions

The clustering of exceptional survival within families suggests a familial component affecting mortality differences, especially at extreme old ages, but of course not all familial effects are genetic. That an exceptional number of persons in the same family reach extreme old ages does not necessarily imply the role of genetic factors in human longevity. Shared characteristics, such as life style, environment, etc. might also play a part.

An important aspect that emerged in this centenarian study is that longevity was found among ascendants of a particular branch of the family, and in most cases along the maternal line. This is still a provisional data but, should it apply to other validated cases, would provide empirical evidence of a genetic component in longevity.

A more thorough examination of the data available may provide better insight into the role played by endogamy and inbreeding. This may also yield further information regarding consanguinity among Sardinians who enjoy exceptionally long lives.

Early results from the family histories considered in this study would suggest that in the future what is urged is a long term analysis of certain communities, using all available data from the early 1800's, where there is a history of longevity. The individual and family histories of all the members of the community should be focused on to corroborate:

1) the presence of family clusters of longevity in the community or whether longevity is transversal across families;

2) the existence of longevity in the past.

Answers to these questions could help pinpoint the role of genetic and environmental factors in long living and verify the biodemographic existence of a longevity model common to sub-population groups.

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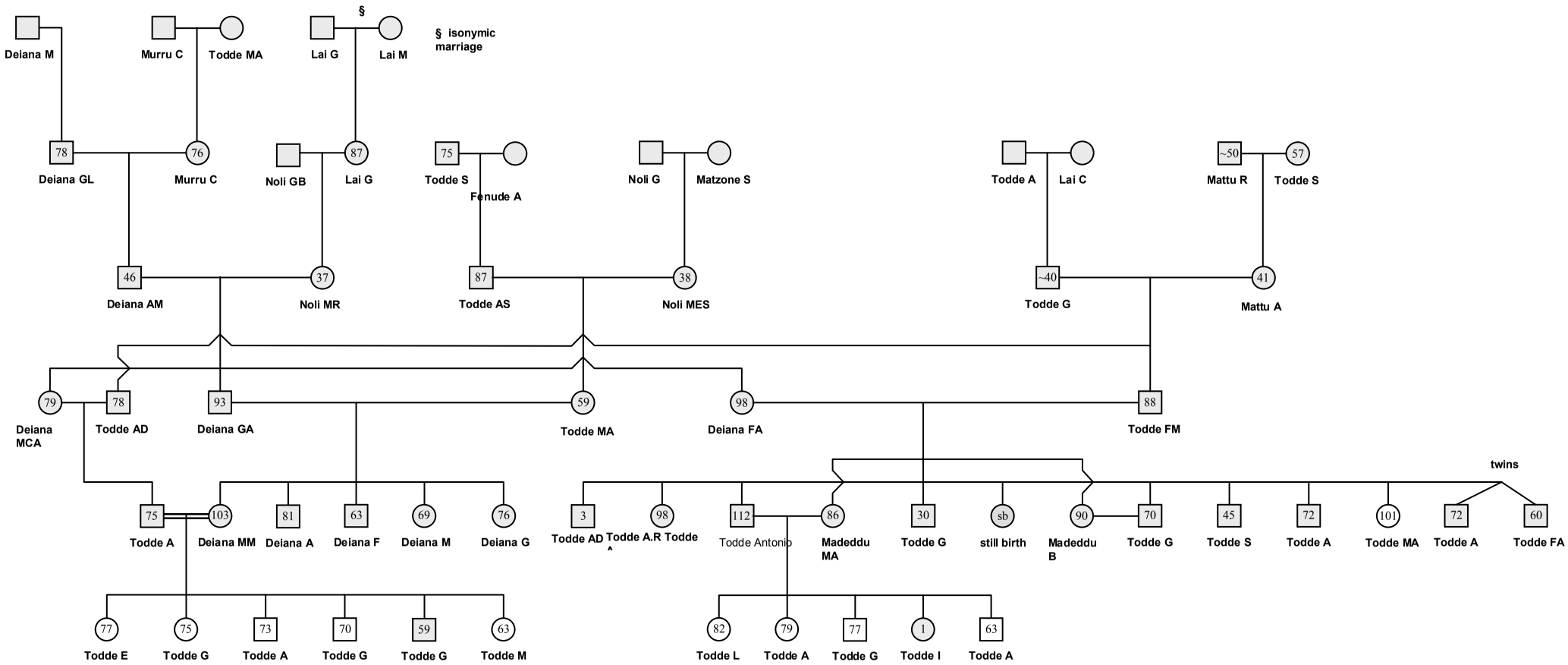

Figure 2. Family tree of Antonio Todde (1889-2002). The number inside the symbols (circle for women and square for men) represents the age in years at death (symbols grey) and the age reached (symbols white)