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The use of Age at Death in Field Epidemiology: Review of Data from the Seven Countries Study

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Abstract

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Abstract

Age at death (AD) is an old demographic metric recently re-evaluated. In field epidemiology it has been never used because in this case the study population must be extinct or nearly extinct. The research group of the Seven Countries Study of Cardiovascular Diseases was able to reach a follow-up that in most cases corresponds to the extinction of cohorts allowing to study the problem of AD. A review of published material, with focus on 7 selected detailed examples, describes and comments findings dealing with determinants of AD at individual levels, comparison of AD across different causes of death, ecological comparison across different cohorts and possible determinants of differences.

Keywords: *Age at death, determinants, field epidemiology, Seven Countries Study*

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1. Introduction

Age at death (AD) is an old metric recently re-evaluated [1, 2, 3, 4]and mainly used by demographers. It consists in a single number corresponding to the age when death occurs, expressed in years. There are some research areas that traditionally used AD. Many investigations are run by demographers who use AD as an important parameter to study the increasing longevity, exploiting the official national mortality registers and possibly try to find explanations [5, 6, 7, 8, 9, 10, 11, 12]. AD represents a descriptive parameter associated with the occurrence of sudden and unexpected death among infants, although the age limits are rather different and not comparable across the various studies[13, 14, 15, 16, 17, 18, 19, 20, 21, 22]. The same applies to research dealing with sudden and unexpected deaths among athletes and more in general associated with leisure sporting activity, and in this case AD is only a descriptive parameter [23, 24, 25, 26, 27, 28, 29, 30]. Finally, in forensic medicine AD has become an unknown target to be estimated using sophisticated technologies [31, 32, 33, 34, 35, 36, 37, 38].

Outside the above-mentioned research areas, AD can theoretically be useful in epidemiological population studies based on samples or cohorts (field epidemiology) examined once or in multiple occasions and followed-up for long periods of time in order to reach the extinction of the cohort or at least its quasi-extinction (when survivors are less than 10%). Otherwise, its meaning and interpretation are rather weak and distorting. Although survival models (such as Cox Proportional Hazards, Weibull models, or Kaplan-Meier estimation) are designed specifically for continuous time-to-event data, they were not applied to model AD itself in these studies. The primary reason is that the cohorts under study are fully extinct (or nearly extinct), meaning there is no right-censoring, which simplifies the analysis of AD to ordinary least squares (OLS) linear regression. Simple linear regression is therefore feasible and appropriate due to the extinct nature of the cohorts, rather than survival analysis. In one of the original papers (reference [46]; Paper 1 in the Tabulation), a Cox proportional hazards model was indeed applied to all-cause mortality (using the same covariates) and reached rather similar findings. On the other hand, studies suitable for the use of AD in the area of field epidemiology seem extremely rare since population studies reaching this goal are extremely difficult and expensive to run and perhaps do not exist except some exceptions. When asking for AD in popular medical or health sciences bibliographic platforms [39, 40] the only available publications are related to the typologies mentioned above [5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38].

The research group of the Seven Countries Study of Cardiovascular Diseases (SCS) had the opportunity to extend the follow-up of their cohorts for long periods of time reaching in many cases 60 years, and at the same time observing the extinction of the cohorts. This allowed to compute at individual and ecological levels the AD and to use it for comparing duration of life as a whole and to look at possible determinants of AD. Moreover, it was used to compare different causes of death in order to describe the natural history of different diseases. Due to this lucky circumstance, we reviewed here a selected series of papers from the SCS reporting, summarizing and commenting some relevant data on AD only among those published so far [41, 42, 43, 44, 45, 46, 47].

2. Material and Methods

The SCS was started in 1958, with the enrollment of 16 cohorts of middle-aged men (ages 40-59, total 12,763) in seven countries,

i.e. USA, Finland, the Netherlands, Italy, two former Yugoslavia republics, (Croatia and Serbia), Greece, and Japan characterized by apparent contrasting eating habits. They included 10 rural communities, 1 fishing community, 4 varied occupational groups, 1 demographic sample from a Dutch town.

The entry examination included the collection of family and social data, lifestyle behaviors including smoking, physical activity habits, a series of anthropometric measurements, a few biochemical and biophysical measurements, diagnoses of major diseases obtained by a complex medical examination, recording of a resting and post-exercise electrocardiogram and resting spirometry measurements. A complex dietary survey was run in subsamples of each cohort, allowing the recording of many food-groups and the chemical measurement of basic nutrients in portions of food taken at home of the participants. Follow-up included at least 2 quinquennial field re-examinations, dedicated procedures to find data on incidence of major cardiovascular diseases, collection and coding of mortality data up to year 60 of follow-up in 10 cohorts (when practically extinct), and shorter follow-up in the other six. Mortality data were coded following defined rules and using the 8th Revision of the WHO International Classification of Diseases [48].

The main purpose of the study was to find whether there were true differences in the occurrence of major cardiovascular diseases (CVD) and mainly coronary heart diseases (CHD) across the various cohorts and to investigate whether such differences could be explained by different life-style and mainly dietary habits. Major information on the study can be found in 5 monographs and several hundreds of papers.

The use of AD started in 2017-2028, first applied to the Italian Rural Areas (IRA), then extended to other cohorts. Analyses involving AD in the SCS are many but only those selected and systematically reviewed are quoted here [41, 42, 43, 44, 45, 46, 47]. The analyses included different approaches: 1) estimates of AD at individual level, derived from all-cause mortality accompanied by multivariate models where AD represents the dependent variable, and various personal characteristics and risk factors play the role of possible determinants and predictors; 2) in some cases, the end-point was made by AD for some major cardiovascular types of mortality; 3) in other analysis, estimates of mean levels of AD were computed for single cohorts or countries to examine possible differences and to explain them, in an ecologic approach, by overall cohort characteristics.

3. Results

Findings are reported in a few Tables that are self-explanatory being provided with selected numbers and words and dealing with 7 examples derived from quoted references [41, 42, 43, 44, 45, 46, 47]. In this case the six Tables stand individually in place of the traditional narrative Results chapter.

Table 1. Examples of AD in the Italian Rural Areas of the SCS (Paper 1).

PAPER 1	
Paper	**Aging Clin Exp Res [46]** **Determinants of AD in Italian areas**
Population	Italian Rural Areas of the SCS. Entry denominator: 1712 men aged 40-59 years
End-point and follow-up	All-cause mortality during 61 years in practically extinct cohorts
Models	Multiple linear regression with AD as end-point (dependent variable) and 35 independent variables measured at entry dealing with family and social data, lifestyle behaviors, anthropometric measurements, classical risk factors, clinical signs, major prevalent diseases
Variables directly related to AD in a significant way ($p < 0.05$)	Age, socio-economic status, marital status, vigorous physical activity, never smoking, Intermediate and Mediterranean Diets (versus not-Mediterranean Diet), subscapular skinfold, arm circumference, vital capacity
Variables inversely related to AD in a significant way ($P < 0.05$)	Mother early death, current smoker, not-Mediterranean Diet, shoulder/pelvis shape, laterality/linearity index, systolic blood pressure, serum cholesterol, corneal arcus, xanthelasma, cardiovascular diseases, cancer, diabetes, chronic bronchitis
Notes and conclusions	Many of the available possible determinants of AD do coexist in the same model despite the existence of some correlations among them. They represent several types of determinants and each of them contributes with a small number of gained or lost years that, when combined together, may result in many years difference in AD

Table 2. Examples of AD in the Italian Rural Areas of the SCS (Paper 2).

<table>
<tr><th colspan="2">PAPER 2</th></tr>
<tr><td>Paper</td><td>Aging Clin Exp Res [41]
AD in different causes of death</td></tr>
<tr><td>Population</td><td>Italian Rural Areas of the SCS.
Entry denominator: 1712 men aged 40-59 years</td></tr>
<tr><td>End-point and follow-up</td><td>All-cause mortality in 50 years of follow-up (survivors = 2.5%, quasi extinct cohort)</td></tr>
<tr><td>Models</td><td>Proportions of different causes of death and median of AD</td></tr>
<tr><td>Notes and Conclusions

There is a great variation of median AD across some major causes of death. The most important finding is the large difference in AD across the 3 major Cardiovascular diseases, that is Coronary heart Disease, Heart Disease of Uncertain Etiology and Stroke that has suggested, together with other characteristics, that we are in front of 3 different diseases that should not be combined together in statistical analysis.

The contribution to overall AD is particularly heavy on the side of Coronary Heart Disease due to its relatively low level and the large proportion of cases classified in this way.</td><td>Cause of death % over all causes and median AD

<table>
<tr><th>Causes of death</th><th>% over all causes</th><th>Median of AD</th></tr>
<tr><td>Coronary heart disease</td><td>19.1</td><td>75</td></tr>
<tr><td>Heart disease of uncertain etiology</td><td>9.7</td><td>80</td></tr>
<tr><td>Stroke</td><td>13.5</td><td>76</td></tr>
<tr><td>Peripheral artery disease</td><td>1.4</td><td>80</td></tr>
<tr><td>Other cardiovascular diseases</td><td>2.1</td><td>68</td></tr>
<tr><td>Lung cancer</td><td>4.6</td><td>76</td></tr>
<tr><td>Other cancers</td><td>23.0</td><td>74</td></tr>
<tr><td>Chronic bronchitis</td><td>3.4</td><td>71</td></tr>
<tr><td>Infectious diseases</td><td>1.1</td><td>65</td></tr>
<tr><td>Violent deaths</td><td>4.8</td><td>70</td></tr>
<tr><td>Senility and cause unknown</td><td>7.4</td><td>86</td></tr>
<tr><td>Other causes</td><td>10.4</td><td>72</td></tr>
<tr><td>All causes</td><td>100.0</td><td>76</td></tr>
</table>
</td></tr>
</table>

Table 3. Examples of AD in cohorts of the SCS.

PAPER 3	
Paper	**Aging Clin Exp Res [42]** **All-cause death in 10 cohorts of the SCS**
Populations	7047 men aged 40-59 year in 10 cohorts of 5 European countries (Finland, the Netherlands, Italy, Serbia, Greece)
End-point and follow-up	All-cause mortality and AD during 50 years of follow-up with 3% of survivors (almost extinct cohorts)
Tested determinants	38 variables of different nature (including 3 references): family, social, lifestyle behaviors, risk factors, some major prevalent diseases, identification of countries
Models	Several multiple linear regressions with the last one computed with a stepwise approach, AD as dependent variable, and 38 variables as possible determinants
Variables directly and significantly related with AD with p<0.05	Age, socio-economic status, moderate and vigorous physical activity (versus sedentary habits), never smokers (versus smokers), arm circumference, subscapular skinfold, forced expiratory volume
Variables inversely and significantly related with AD with p<0.05	Father early death, current smoker, laterality/linearity index, systolic blood pressure, serum cholesterol, major cardiovascular diseases, diabetes, chronic bronchitis
Special risk factor	Body mass index, analyzed in classes, significantly related with AD and showing a parabolic relationship with lower AD at extremes of the curve
Notes and Comments	Large differences of AD across cohorts ranging from 72.4 years in East Finland to 77.9 in Crete (Greece)
PAPER 4	
Paper	**Aging Clin Exp Res [47]** **Determinants of AD in multiple cohorts and countries during 60 years**
Populations	10 cohorts from 6 countries (USA, Finland, the Netherlands, Italy, Greece, Japan) with 9043 men aged 40-59 years
End-point and follow-up	AD in all-cause mortality with a follow-up of 60 years and 0.8% survivors (practically extinct cohorts)
Tested determinants	12 major mainly cardiovascular diseases (CVD) risk factors, including lifestyle behaviors, classical risk factors, prevalence of CVD and silent ECG abnormalities
Models	Multiple linear regression with individual AD as end-point (dependent variable) and 12 possible determinants as independent variables adjusted for dummy variables identifying the 6 countries
Variables directly and significantly related with AD with p<0.05	Age, vigorous physical activity (versus sedentary habits), ex-smokers and never-smokers (versus smokers).
Variables inversely and significantly related with AD with p<0.05	Systolic blood pressure, heart rate, serum cholesterol, prevalence of major cardiovascular diseases, silent ECG abnormalities
Special risk factor	Body mass index significant if handled in a quadratic shape (parabolic) with low AD at both extremes of the curve
Variation across cohorts	Mean AD ranging from 71.8 in East Finland to 80.5 in Crete (Greece)
Notes and comments	An example of AD measured after 60 years of follow-up

Table 4. Example of AD in cohorts of elderly men of the SCS.

PAPER 5	
Paper	**Aging Clin Exp Res [45]** **AD in elderly European cohorts**
Populations	2457 elderly men aged 65-84 years, survivors in 4 countries (Finland, the Netherlands, Italy, Serbia) after 25 years of follow-up.
End-point and follow-up	AD after the subsequent 25 years of follow-up with 7% of survivors (almost extinct cohorts). Levels of AD ranging 80.6 in Finland to 83.3 in Italy
Tested determinants	18 risk factors, including major prevalent diseases and dummy variables identifying countries
Models	Multiple linear regression with AD as dependent variable and the above determinants as predictors
Variables directly and significantly related with AD with p<0.05	Age, never-smokers (versus current smokers), HDL cholesterol
Variables inversely and significantly related with AD with p<0.05	Smokers (versus never-smokers), heart rate, major ECG abnormalities, Coronary Heart Disease, Heart Diseases of Uncertain Etiology, Stroke, Chronic bronchitis, Cancer
Special risk factor	Body mass index significant if handled in a quadratic shape (parabolic) with low AD at the extremes of the curve
Comorbidity index	Created on the basis of major prevalent diseases and defined by the number of conditions for each individual (from 0 to 4). At baseline 69.5% of men had at least one major prevalent disease
Model 2	Multiple linear regression with AD as end-point (dependent variable), individual comorbidity index as independent variables plus other risk factors as confounding variables
Findings	A clear decreasing gradient of AD as a function of comorbidity index with a loss of AD from 1.87 to 6.39 years across the extreme levels
Notes and Comments	Findings focus on co-morbidity index in the elderly

Table 5. Example of AD for fatal cardiovascular diseases in cohorts of the SCS.

PAPER 6	
Paper	**Acta Cardiol [40]** **AD in fatal Cardiovascular Diseases (CVD)**
Populations	10628 men aged 40-59 years in a 45-year follow-up of 13 cohorts of 7 countries (USA, Finland, the Netherlands, Italy, Serbia, Greece, Japan)
End-point and follow-up	Major fatal CVD: Coronary Heart Disease (CHD), Heart Diseases of Uncertain Etiology (HDUE), Stroke (STR) during 45 years with 7% of survivors (quasi extinct cohorts)
Average AD findings	In the pool of all cohorts: AD for CHD=73.5; HDUE=70.1; STR=75.3. Differences across all possible comparisons highly significant
Notes and Comments	In the single countries, findings coherent with the above picture.

Table 6. Example of AD in ecological analysis of cohorts of the SCS.

PAPER 7	
Paper	**Eur J Prev Cardiol [44]** **Ecological analysis**
Populations	12763 men aged 40-59 in 16 cohorts of the Seven Countries Study, from 7 countries (USA, Finland, the Netherlands, Italy, Croatia (former Yugoslavia), Serbia (former Yugoslavia), Greece, Japan
End-point and follow-up	Mean AD in each cohort during a follow-up of 50 years with 3% survivors (quasi extinct cohorts)
Possible determinants	Mean dietary Inflammation Index of 16 cohorts computed from 19 food groups and several nutrients
Model	Linear correlation coefficient
Findings	R=0.51 with p=0.044
Notes and Comments	A significant association of Dietary Inflammation Index with AD

4. Discussion

OLS regression relies on the assumption of normally distributed residuals for valid inference and confidence intervals. However, age at death in adult cohorts is typically left-skewed. In the early phases of our work in this area, multiple linear regression was the primary choice, and alternative modeling approaches (such as generalized linear models) were not formally evaluated. Simply, some unpublished tests using the natural log of age at death did not yield results that differed substantively from those using the basic format for age at death. Furthermore, in our long-term (many decades) experience in this field, we have never found a single biological or medical variable that could be classified as strictly "normally distributed," and real, robust alternatives for these extinct cohort scenarios are limited. Actually, in Paper 1 (reference [46]) presented in Table 1, we added a Cox proportional hazards model using the same covariates and all-cause mortality (instead of age at death) and reached rather similar findings.

Regarding the regression models, the independent variables include baseline age (40–59 years) as a predictor for Age at Death (AD). Since individuals must survive to the baseline age to be included in the cohort, a structural selection effect (left truncation) is present where baseline age sets a hard lower bound on the age at death. This is an inevitable limitation in longitudinal studies of this nature, as measuring risk factors in newborns and following them until the end of their lifespan is practically unfeasible. To address and adjust for this, baseline age (at entry) was systematically

added as a covariate in the models to adjust the estimates for the baseline spread of age at the time of the entry examination, thereby accounting for potential age-at-entry effects.

Beyond the abovementioned technical notes, it is worth adding some details that were too cumbersome to be included in the tables of results. In particular, the comorbidity index mentioned in Table 4 (Paper 5) was defined by the number of baseline conditions for each individual (ranging from 0 to 4). It was constructed using 7 major prevalent diseases: coronary heart disease, heart diseases of uncertain etiology, peripheral artery disease, stroke, diabetes, chronic bronchitis and allied conditions, and cancer. While there were 7 candidate conditions, no individual carried more than 4 of them simultaneously. Each condition was weighted equally (assigned a score of 1 if present, and 0 if absent) and added up to form the final index.

Moreover, the last example (Table 6, Paper 7) deals with an ecological analysis of 16 cohorts, and therefore the interpretation of these findings requires caution. While the Dietary Inflammation Index was significantly associated with cohort-mean age at death at the cohort level, there is a risk of the ecological fallacy. A correlation observed at the cohort level does not necessarily imply that individuals with higher dietary inflammation die younger within those cohorts, and individual-level associations may differ from cohort-level patterns. Readers should thus be cautioned against drawing direct individual-level inferences from these aggregate ecological correlations.

5. Conclusions

This review confirms that AD is a useful metric to be applied in field-epidemiology data. It is mandatory that the study population-cohorts have reached the extinction or nearly extinction which represents an exception for most studies. On the other hands, AD represents a kind of summary dealing with the individual history of health and disease. Moreover, it is associated in direct or inverse way, with a large number of personal characteristics-risk factors including some of those which tested on single fatal or not-fatal morbid condition. This fact is likely bound to the large numbers and to the fact that AD represents, at the best, the pool of all possible morbid conditions.

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