RESEARCH REPORT

Patterns of mortality and their changes in France (1968–99): insights into the structure of diseases leading to death and epidemiological transition in an industrialised country

J Coste, E Bernardin, E Jouglà

J Epidemiol Community Health 2006;**60**:945–955. doi: 10.1136/jech.2005.044339

See end of article for authors' affiliations

Correspondence to: J Coste, Département de Biostatistique, Pavillon Saint-Jacques, Hôpital Cochin, 27 rue du Faubourg Saint-Jacques, 75674 Paris Cedex 14, France; coste@cochin.univ-paris5.fr

Accepted 3 March 2006

Background: Epidemiological transition theory is based on a succession of specific "patterns" of causes of death in human societies. However, the reality and consistency of patterns of causes of death in a population at a given moment has never been formally and statistically evaluated.

Methods: Correlation analyses and principal component analysis were used to explore the correlation between age and sex cause-specific death rates and to identify consistent patterns of mortality in France for two periods: 1968–79 and 1988–99.

Results: Cause-specific death rates in France from 1988 to 1999 were found to be strongly and consistently correlated across space and time. The analysis outlines four specific patterns: mortality of 45–84-year olds, mostly by neoplasms, cardiovascular and digestive diseases; mortality of the oldest old (>84 years); mortality of 25–64-year-old men, notably by HIV infection; and mortality by injury and poisoning of 15–44-year olds. These patterns, which cover 96% of the total mortality during the period, differ from those for the period 1968–79 when respiratory diseases and conditions affecting children aged <1 year shaped mortality. They also differ substantially from those predicted by classical epidemiological transition theory.

Conclusion: This study provides evidence for an evolutionary structure of patterns of mortality in contemporary France and therefore suggests using the concept of epidemiological transition in a less simplistic way than is commonly the case. It also shows much stronger interrelationships between diseases leading to death than is usually believed and suggests that current categorisations of cause-specific mortality in populations need reconsideration.

Approaching death remains the largest demographic driver of healthcare utilisation and costs.¹ A comprehensive assessment of patterns of cause-specific mortality and their trends is therefore essential for public health planning while most countries are undergoing profound demographic and epidemiological transformations.^{2–3} In 1971, Omran formulated the theory of "epidemiological transition" to explain worldwide changes in time and causes of human death: while developing and modernising, human societies experience a "shift in mortality and disease patterns", transiting from a first "age of pestilence and famine" in which mortality is high and fluctuating owing to epidemics of infectious diseases and food crises, to a second "age of receding pandemics" and attains a third "age of degenerative and man-made diseases" in which chronic diseases (cardiovascular diseases, diabetes, cancer, etc) and accidents predominate as causes of death.⁴ This theory, which was initially based on informal comparisons over time of the weight of broad causes of death (rank order, contribution to all-cause mortality) in six countries (Ceylon, Chile, England, Japan, Sweden and Wales), was further revised by its author and his followers, notably to account for the epidemiological changes of the 70s–80s. In particular, a fourth "age of delayed degenerative diseases" and a fifth "age of emergent and re-emergent infections" were added.^{5–9} After its endorsement by the World Health Organization (WHO) and by the US National Research Council, the epidemiological transition theory became increasingly popular to a point where it shapes many scientists' and public health professionals' conceptions of changes in causes of death with time. However, criticisms of the simplistic determinism (modernisation) and oversimplicity of the theory, which does not fit with observations

in many countries, accumulated during the 90s (summarised in Carolina and Gustavo¹⁰ and Caselli *et al*¹¹). Only one formal analysis of epidemiological transition in the long term, using detailed mortality datasets and multivariate descriptive methods, has been reported.¹² We used a similar approach to evaluate the reality of a short-term structure of causes of death—that is, whether, in a population at a given time, causes of death consistently assemble to form a specific "pattern" (or a set of few patterns). This fundamental assumption of the epidemiological transition theory has never been formally and statistically investigated. We used correlation analyses and principal component analysis (PCA) of age and sex cause-specific death rates to explore their correlation and to identify patterns of mortality in France for two periods: 1968–79 and 1988–99.

METHODS

Death certification

The health system in France follows the WHO guidelines on death certification. Death certification (compulsory with 100% coverage) uses the international medical certificate, which allows the underlying and, since 1968, two contributory causes of death and an immediate cause of death to be recorded. Causes are further coded according to the International Classification of Diseases (ICD): between 1968 and 78, the eighth revision was used¹³ and, between 1979 and 99, the ninth revision.¹⁴ These classifications are sufficiently similar (identical structure and headings and few different

Abbreviations: ICD, International Classification of Diseases; PCA, principal component analysis; WHO, World Health Organization

diseases) to allow comparisons of data coded with the two systems by broad categories.¹⁴

Cause-specific death rates

Cause-specific death rates were computed for

- the 17 headings (groups of diseases) of the ICD or the 46 diseases on the European shortlist of causes of death,¹⁵
- those diseases either recorded as an underlying cause or as “any” cause (immediate, underlying or contributory cause),
- sex and age category (<1, 1–14, 15–24, 25–44, 45–64, 65–84 and >84 years),
- each week of the two 12-year study periods, 1968–79 and 1988–99 (time units, each $n = 626$), and for each district of France (spatial units, $n = 348$) for the period 1988–99. The two study periods (1968–79 and 1988–99) were chosen long enough to provide sufficient time units (two or three times the number of rates, see later) and as distant as possible to observe differences between them.

Denominators of the rates (populations at risk of death) were obtained for each week (time unit) and district (spatial unit) from the Institut National de la Statistique et des Études, the French national demographic institute, which continuously updates population data in France.

Statistical analysis

Changes in age and sex cause-specific rates of death between 1968–79 and 1988–99 were assessed not only from the differences in rates between the two periods but also from the differences in ranks—this allows the general decrease in mortality over the whole study period to be taken into account. Correlation analyses and PCA were used to show patterns of death consistent across time (weeks) and space (districts). Firstly, correlation matrices (Pearson's coefficients) of sex and age cause-specific mortality were constructed for time units (for both the 1968–79 and the 1988–99 periods) and space units (for the period 1988–99). These matrices were further studied by PCA, an exploratory factor analysis method that allows identification of unobservable latent factors that underlie or structure a set of variables (here, sex and age cause-specific mortality). PCA includes three successive steps¹⁶:

1. Condensation of the data by the computation of principal components. Principal components are linear functions of observed correlated variables (death rates) generated in a sequential manner. The first component is the linear function of the original variables, the variance of which is the maximum over all possible linear functions. Each following component is the linear combination uncorrelated with the preceding principal components and having the largest possible variance. Principal components are usually computed using correlation matrices (or standardised variables) to avoid unit scale effects and ensure that variables are on an equal footing. In this case, the coefficients defining these linear functions, referred to as the loadings, are interpretable as correlation coefficients between principal components and original variables and are used to identify the nature of the principal components (loadings > 0.40 usually indicate substantial correlation).
2. Extraction of principal components or selection of the number of components to retain. These components correspond to the underlying latent variables or factors. The number of factors to extract was determined using a previously described methodology.¹⁷
3. Rotation of retained components to facilitate the interpretation. Usually, many of the principal components

computed are difficult to interpret and a second linear transformation of the principal components is therefore useful. This transformation is referred to as a rotation. Rotations are often carried out to obtain a simple structure—that is, to obtain, as with the varimax method used in this study, rotated components with variables that have loadings near either 0 or 1 (in which case the given variable participates in the definition of a single factor).

To avoid uninformative statistical fluctuations and limit the number of variables considered in the correlation matrices and PCA (<150), low death rates (<10 per 100 000) were grouped together, for each sex and age category, in a residual cause-of-death category. The primary analysis considered rates formed using the underlying cause categorised according to the 17 ICD headings. Secondary analyses were carried out using rates formed “any” causes (underlying, immediate or contributory) and those using a more detailed list of 46 diseases for the underlying cause of death to evaluate the sensitivity of results to classification rules.

RESULTS

Over 13 million deaths (about 530 000/year) and their causes (underlying, immediate or contributory) were considered in the analysis. Table 1 shows the top 50 list of age and sex cause-specific death rates (underlying cause, coded using ICD headings) for the period 1988–99 and changes relative to the period 1968–79. Several rates increased massively between 1968–79 and 1988–99 (diseases of the nervous system, mental disorders, diseases of the skin, disease of the musculoskeletal system for 65–84-year olds and especially >84-year olds), whereas many others decreased sharply or even disappeared from the top 50 (notably those about children <1 year). Ill-defined conditions remained stable overall (about 15% in both periods).

The correlation between death rates was high (Pearson's $r > 0.40$), both for time and spatial units (eg, table 2 shows extracts of the correlation matrix of 1988–99 rates for time units, upper right corner, and spatial units, lower left corner). Noticeably, the highest levels of correlation included rates of males and females for a same disease and age category (eg, diseases of the circulatory system in 65–84-year olds) and also both rates across age categories for individual diseases (eg, diseases of the circulatory system in 45–64-year olds and 65–84-year olds) and rates of different diseases (eg, diseases of the circulatory system, diseases of the respiratory system and diseases of the digestive system in 65–84-year olds).

These correlated rates assemble consistently in PCA to form four main factors or patterns of mortality (tables 3 and 4). For the period 1988–99, these patterns can be labelled “mortality between ages 45 and 84 years, mostly by neoplasms, cardiovascular and digestive diseases”; “mortality of the oldest old (>84 years old)”; “mortality by infectious diseases, neoplasms, mental and nervous system disorders, cardiovascular, respiratory, urogenital system and digestive disease”; “mortality of 25–64-year-old men” and “mortality by injury between ages 15 and 44 years”. These patterns explain 31–39% of the total variance of rates, but cover 96% of all mortality during the period (as most of the top-ranked death rates are constituents of these four patterns).

Four main patterns of mortality were also observed during the period 1968–79 (table 5), but they were not the same as those for the period 1988–99: “mortality between ages 45 and 84 years, mostly by respiratory and cardiovascular diseases”; “mortality of children aged <1 year”; “mortality of those aged >64 years, mostly by neoplasms, nervous diseases and mental disorders”; and “mortality by injury at all ages”. These patterns explain 40% of the variance of the rates, but they cover only 85% of all mortality during the period.

Table 1 Top 50 annual age and sex cause-specific death rates in France for the period 1988–99, classified according to the 17 headings of the International Classification of Diseases, and changes since the period 1968–79

ICD heading of underlying cause of death for age and sex group	Rank 1988–99	Change in rank relative to 1968–79*†	Rate per 100 000 (1988–99)	Change in rate (%) relative to 1968–79*
Diseases of the circulatory system, male, >84 years	1	0	6478.18	–29
Diseases of the circulatory system, female, >84 years	2	0	5949.67	–23
Neoplasms, male, >84 years	3	2	3028.39	26
Diseases of the respiratory system, male, >84 years	4	3	2158.65	–5
Neoplasms, female, >84 years	5	5	1524.97	4
Neoplasms, male, 65–84 years	6	5	1503.01	3
Diseases of the circulatory system, male, 65–84 years	7	–1	1413.66	–41
Symptoms, signs, and ill-defined conditions, female, >84 years	8	–4	1320.30	–54
Diseases of the respiratory system, female, >84 years	9	0	1315.20	–14
Symptoms, signs, and ill-defined conditions, male, >84 years	10	–7	1218.82	–62
Diseases of the circulatory system, female, 65–84 years	11	–3	912.32	–47
Injury and poisoning, male, >84 years	12	1	899.31	–11
Injury and poisoning, female, >84 years	13	–1	794.07	–33
Neoplasms, female, 65–84 years	14	0	669.14	–8
Diseases of the digestive system, male, >84 years	15	1	656.33	8
Diseases of the digestive system, female, >84 years	16	2	590.02	21
Mental disorders, female, >84 years	17	26	555.94	293
Endocrine, nutritional, metabolic diseases, and immunity disorders, female, >84 years	18	1	529.34	10
Endocrine, nutritional, metabolic diseases, and immunity disorders, male, >84 years	19	2	490.22	9
Mental disorders, male, >84 years	20	28	440.95	256
Diseases of the urogenital system, male, >84 years	21	–6	440.29	–37
Neoplasms, male, 45–64 years	22	0	428.20	1
Diseases of the respiratory system, male, 65–84 years	23	–3	348.48	0
Diseases of the nervous system and sense organs, male, >84 years	24	3	321.43	–3
Diseases of the nervous system and sense organs, female, >84 years	25	3	264.77	–12
Infectious and parasitic diseases, male, >84 years	26	11	251.40	34
Diseases of the urogenital system, female, >84 years	27	9	231.12	21
Symptoms, signs and ill-defined conditions, male, <1 year	28	5	223.89	–8
Injury and poisoning, male, 65–84 years	29	2	218.42	–17
Certain conditions originating in the perinatal period, male, <1 year	30	–13	208.47	–63
Diseases of the digestive system, male, 65–84 years	31	–6	201.02	–44
Infectious and parasitic diseases, female, >84 years	32	14	192.38	46
Neoplasms, female, 45–64 years	33	2	191.89	–14
Diseases of the circulatory system, male, 45–64 years	34	–8	190.47	–45
Certain conditions originating in the perinatal period, female, <1 year	35	–12	158.47	–62
Symptoms, signs and ill-defined conditions, male, 65–84 years	36	–12	156.63	–60
Diseases of the respiratory system, female, 65–84 years	37	–3	155.59	–34
Symptoms, signs and ill-defined conditions, female, <1 year	38	1	152.17	–16
Congenital anomalies, male, <1 year	39	–9	139.13	–53
Injury and poisoning, female, 65–84 years	40	–2	128.90	–31
Diseases of the skin and subcutaneous tissue, male, >84 years	41	18	128.63	72
Congenital anomalies, female, <1 year	42	–10	119.13	–52
Diseases of the digestive system, female, 65–84 years	43	–3	117.51	–33
Diseases of the blood and blood-forming organs, male, >84 years	44	19	112.47	80
Symptoms, signs, and ill-defined conditions, female, 65–84 years	45	–16	111.85	–62
Injury and poisoning, male, 45–64 years	46	–4	100.87	–30
Diseases of the nervous system and sense organs, male, 65–84 years	47	3	99.37	–14
Diseases of the musculoskeletal system and connective tissue, female, >84 years	48	20	92.78	97
Diseases of the skin and subcutaneous tissue, female, >84 years	49	23	92.05	102
Injury and poisoning, male, 25–44 years	50	3	87.83	–14

ICD, International Classification of Diseases.

*Rate for the period 1988–99 minus the rate for the period 1968–79 divided by the rate for the period 1968–79.

†Rank for the period 1988–99 minus the rank for the period 1968–79.

The correlations, patterns and trends for over 30 years observed with rates formed using “any” causes—that is, also using immediate and contributory causes (data not shown, available from the authors)—and those using a more detailed list of 46 diseases for the underlying cause of death were very similar (data not shown, available from the authors); this implies that the results are robust. Furthermore, analysis carried out with the detailed list indicated that the third pattern during the period 1988–99 was mainly shaped by HIV infection in men and that the fourth pattern was shaped by injuries and poisoning (other than suicide), falls and traffic accidents.

DISCUSSION

The limitations of death certification are well known.^{18 19} There are various reasons for inaccuracies of death certificate

information, including antemortem diagnosis errors, medical records being unavailable at the time of certification, misunderstanding of the certification process due to the inadequate training of doctors, and errors and inaccuracy when coding causes using the ICD. This classification reflects the prevailing medical knowledge (and caveats) and diagnostic habits, and also changes repeatedly. These phenomena impair long-term comparisons. In particular, there were major ICD changes in France in 1968 (when ICD-8 was implemented) and 2000 (when ICD-10 was implemented), which obliged us to carry out simple longitudinal comparisons of restricted lists of diseases or groups of diseases little affected by nosological and diagnostic changes during the relatively short 30-year period from 1968 to 1999 (unlike other successive ICD revisions, there were few differences between ICD-8 and ICD-9). Despite these limitations, our

Table 2 Extract of the correlation matrix* of age and sex cause-specific death rates

	Neoplasms, male, 45–64 years	Neoplasms, male, 65–84 years	Neoplasms, female, 45–64 years	Neoplasms, female, 65–84 years	Diseases of the circulatory system, male, 45–64 years	Diseases of the circulatory system, male, 65–84 years	Diseases of the circulatory system, female, 45–64 years	Diseases of the circulatory system, female, 65–84 years	Diseases of the respiratory system, male, 45–64 years	Diseases of the respiratory system, male, 65–84 years	Diseases of the digestive system, male, 45–64 years	Diseases of the digestive system, male, 65–84 years	Neoplasms, male, >84 years	Diseases of the circulatory system, male, >84 years	Diseases of the respiratory system, male, >84 years	Diseases of the digestive system, male, >84 years
Neoplasms, male, 45–64 years																
Neoplasms, male, 65–84 years	0.68															
Neoplasms, female, 45–64 years	0.38	0.66														
Neoplasms, female, 65–84 years	0.38	0.61	0.68													
Diseases of the circulatory system, male, 45–64 years	0.73	0.38	0.21	0.68												
Diseases of the circulatory system, male, 65–84 years	0.59	0.52	0.32	0.32	0.73											
Diseases of the circulatory system, female, 45–64 years	0.60	0.38	0.24	0.24	0.72	0.79										
Diseases of the circulatory system, female, 65–84 years	0.57	0.38	0.24	0.24	0.72	0.69	0.65									
Diseases of the respiratory system, male, 45–64 years	0.67	0.42	0.20	0.20	0.62	0.69	0.86	0.65								
Diseases of the respiratory system, male, 65–84 years	0.84	0.55	0.32	0.32	0.71	0.57	0.49	0.55	0.55							
Diseases of the digestive system, male, 45–64 years	0.61	0.57	0.37	0.37	0.50	0.55	0.39	0.39	0.51	0.65						
Diseases of the digestive system, male, 65–84 years	0.38	0.48	0.33	0.33	0.20	0.29	0.21	0.21	0.26	0.35	0.61					
Neoplasms, male, >84 years	0.38	0.36	0.20	0.20	0.40	0.59	0.39	0.39	0.28	0.36	0.28	0.28	0.15	0.46	0.45	0.34
Diseases of the circulatory system, male, >84 years	0.27	0.25	0.13	0.13	0.34	0.51	0.35	0.35	0.20	0.23	0.27	0.19	0.58	0.70	0.77	0.50
Diseases of the respiratory system, male, >84 years	0.37	0.37	0.17	0.17	0.27	0.37	0.33	0.33	0.46	0.32	0.32	0.37	0.43	0.50	0.78	0.48
Diseases of the digestive system, male, >84 years	0.28	0.15	0.13	0.13	0.26	0.25	0.21	0.21	0.20	0.23	0.23	0.35	0.30	0.35	0.31	0.42

Upper right corner, time units; lower left corner, spatial units.

*Pearson's correlation coefficient between selected rates in lines and columns are shown in cells.

Bold characters indicate high correlation ($r > 0.40$).

Table 3 Principal component analysis results for age and sex cause-specific death rates classified according to the 17 headings of the International Classification of Diseases 8–9: period 1988–99, time units*

Age and sex-specific mortality	Factor 1	Factor 2	Factor 3	Factor 4
Infectious and parasitic diseases				
Male, <1 year				
Male, 25–44 years			0.76	
Male, 45–64 years			0.65	
Male, 65–84 years	0.54			
Male, >84 years				
Female, <1 year				
Female, 65–84 years	0.52			
Female, >84 years				
Neoplasms				
Male, 25–44 years				
Male, 45–64 years	0.67	–0.59		
Male, 65–84 years	0.74			
Male, >84 years		0.49		
Female, 25–44 years				
Female, 45–64 years	0.54	–0.42		
Female, 65–84 years	0.68			
Female, >84 years				
Endocrine, nutritional and metabolic diseases and immunity disorders				
Male, 45–64 years				
Male, 65–84 years	0.47	0.44		
Male, >84 years		0.51		
Female, 65–84 years	0.72			
Female, >84 years		0.64		
Diseases of the blood and blood-forming organs				
Male, 65–84 years				
Male, >84 years				
Female, 65–84 years				
Female, >84 years				
Mental disorders				
Male, 45–64 years	0.43			
Male, 65–84 years	0.73			
Male, >84 years		0.64		
Female, 65–84 years	0.72			
Female, >84 years		0.80		
Diseases of the nervous system and sense organs				
Male, <1 year				
Male, 45–64 years				
Male, 65–84 years	0.40	0.53		
Male, >84 years		0.74		
Female, <1 year				
Female, 65–84 years		0.68		
Female, >84 years		0.83		
Diseases of the circulatory system				
Male, <1 year				
Male, 25–44 years	0.43			
Male, 45–64 years	0.78	–0.45		
Male, 65–84 years	0.91			
Male, >84 years	0.78	0.46		
Female, 45–64 years	0.74			
Female, 65–84 years	0.89			
Female, >84 years	0.88			
Diseases of the respiratory system				
Male, <1 year	0.46			
Male, 45–64 years	0.76			
Male, 65–84 years	0.77	0.42		
Male, >84 years	0.61	0.66		
Female, 45–64 years	0.56			
Female, 65–84 years	0.75	0.42		
Female, >84 years	0.62	0.64		
Diseases of the digestive system				
Male, 25–44 years				
Male, 45–64 years	0.66			
Male, 65–84 years	0.77			
Male, >84 years	0.46			
Female, 45–64 years	0.52			
Female, 65–84 years	0.72			
Female, >84 years	0.61			
Diseases of the urogenital system				
Male, 65–84 years	0.65			
Male, >84 years	0.53			
Female, 65–84 years	0.49			
Female, >84 years	0.42			
Diseases of the skin and subcutaneous tissue				
Male, 65–84 years				
Male, >84 years				
Female, 65–84 years				

Table 3 Continued

Age and sex-specific mortality	Factor 1	Factor 2	Factor 3	Factor 4
Female, >84 years				
Diseases of the musculoskeletal system and connective tissue				
Male, 65–84 years				
Male, >84 years				
Female, 65–84 years	0.51			
Female, >84 years				
Congenital anomalies				
Male, <1 year				
Female, <1 year				
Certain conditions originating in the perinatal period				
Male, <1 year				
Female, <1 year				
Symptoms, signs and ill-defined conditions				
Male, <1 year	0.65	–0.50		
Male, 25–44 years				
Male, 45–64 years				
Male, 65–84 years	0.74			
Male, >84 years	0.68	0.41		
Female, <1 year	0.62	–0.47		
Female, 45–64 years				
Female, 65–84 years	0.82			
Female, >84 years	0.72	0.48		
Injury and poisoning				
Male, <1 year				
Male, 1–14 years		–0.53		
Male, 15–24 years		–0.65		0.47
Male, 25–44 years		–0.58		0.44
Male, 45–64 years	0.40	–0.49		
Male, 65–84 years	0.60			
Male, >84 years	0.47			
Female, <1 year				
Female, 15–24 years		–0.41		0.40
Female, 25–44 years				
Female, 45–64 years		–0.41		
Female, 65–84 years	0.74			
Female, >84 years	0.76			
“Residual”				
Male, <1 year				
Male, 1–14 years	0.52			
Male, 15–24 years	0.40			
Male, 25–44 years			0.42	
Male, 45–64 years				
Male, 65–84 years				
Male, >84 years				
Female, <1 year				
Female, 1–14 years	0.44			
Female, 15–24 years				
Female, 25–44 years			0.53	
Female, 45–64 years	0.58			
Female, 65–84 years				
Female, >84 years				

*Only rates that are substantially correlated with factors (loading>0.40) and help interpret these factors are indicated.

Bold figures indicate a very high correlation between the rates and factors (loading>0.75).

study nevertheless provides evidence for the coexistence of four main patterns of mortality in contemporary France and for the evolutionary nature of these patterns. Interestingly, patterns reflecting the “age of degenerative and man-made diseases”; the “age of delayed degenerative diseases”; and the “age of emergent and re-emergent infections” of Omran’s classical presentation of the epidemiological transition theory were observed simultaneously. Also, we found that the recession of infectious (including epidemic) diseases was only partial, and even in more recent times these diseases remain causes of death in the elderly population. Although our findings are only from one country (France) and may be criticised for a lack of representativeness and generalisability, they generally confirm the conclusions of a previous analysis conducted in The Netherlands¹² and suggest that the concept of epidemiological transition, the empirical foundations of which (shift of communicable diseases to non-communicable

diseases while populations are ageing) cannot be contested, at least for Western Europe and North America, must be used much less simplistically and deterministically than is sometimes the case.²⁰ Rather than “succeeding ages” of the epidemiological transition, our results suggest “succeeding patterns of mortality” or, even more accurately, an “evolutionary structure of patterns” within which patterns strengthen or weaken or vary as causes of deaths in the population change. In the case of France, two main patterns of death clearly strengthened in this structure during the past 30 years: (a) death by neoplasms, cardiovascular and digestive diseases of those aged between 45 years and 84 years and (b) death of the oldest from all causes (replacing patterns of deaths from respiratory and cardiovascular diseases, and deaths from neoplasms, nervous diseases and mental disorders in the elderly people, respectively). Over the same period, mortality among young

Table 4 Principal component analysis results for age and sex cause-specific death rates classified according to the 17 headings of the International Classification of Diseases 8–9: period 1988–99, spatial units*

Age and sex-specific mortality	Factor 1	Factor 2	Factor 3	Factor 4
Infectious and parasitic diseases				
Male, <1 year				
Male, 25–44 years	–0.42	0.56		
Male, 45–64 years		0.50		
Male, 65–84 years				
Male, >84 years				
Female, <1 year				
Female, 65–84 years				
Female, >84 years				
Neoplasms				
Male, 25–44 years	0.51			
Male, 45–64 years	0.84			
Male, 65–84 years	0.64			
Male, >84 years	0.50		0.42	
Female, 25–44 years				
Female, 45–64 years	0.60			
Female, 65–84 years	0.41			
Female, >84 years			0.46	
Endocrine, nutritional and metabolic diseases and immunity disorders				
Male, 45–64 years	0.57			
Male, 65–84 years				
Male, >84 years				
Female, 65–84 years	0.56			
Female, >84 years				
Diseases of the blood and blood-forming organs				
Male, 65–84 years				
Male, >84 years				
Female, 65–84 years				
Female, >84 years				
Mental disorders				
Male, 45–64 years	0.67			
Male, 65–84 years	0.54			
Male, >84 years				
Female, 65–84 years	0.46			
Female, >84 years		–0.43		
Diseases of the nervous system and sense organs				
Male, <1 year				
Male, 45–64 years	0.47			
Male, 65–84 years				
Male, >84 years				
Female, <1 year				
Female, 65–84 years			0.41	
Female, >84 years			0.45	
Diseases of the circulatory system				
Male, <1 year	0.54			
Male, 25–44 years	0.76			
Male, 45–64 years	0.74			
Male, 65–84 years	0.56			
Male, >84 years				
Female, 45–64 years	0.67			
Female, 65–84 years	0.75			
Female, >84 years	0.47		0.43	
Diseases of the respiratory system				
Male, <1 year				
Male, 45–64 years	0.71			
Male, 65–84 years	0.67			
Male, >84 years	0.57			
Female, 45–64 years	0.54			
Female, 65–84 years	0.56			
Female, >84 years			0.49	
Diseases of the digestive system				
Male, 25–44 years	0.61			
Male, 45–64 years	0.82			
Male, 65–84 years	0.72			
Male, >84 years	0.42			
Female, 45–64 years	0.71			
Female, 65–84 years	0.64			
Female, >84 years	0.41			
Diseases of the urogenital system				
Male, 65–84 years	0.42			
Male, >84 years	0.42			
Female, 65–84 years	0.48			
Female, >84 years			0.51	
Diseases of the skin and subcutaneous tissue				
Male, 65–84 years				
Male, >84 years				
Female, 65–84 years	0.42			

Table 4 Continued

Age and sex-specific mortality	Factor 1	Factor 2	Factor 3	Factor 4
Female, >84 years				
Diseases of the musculoskeletal system and connective tissue				
Male, 65–84 years				
Male, >84 years				
Female, 65–84 years				
Female, >84 years				
Congenital anomalies				
Male, <1 year				
Female, <1 year				
Certain conditions originating in the perinatal period				
Male, <1 year				
Female, <1 year				
Symptoms, signs and ill-defined conditions				
Male, <1 year				
Male, 25–44 years		0.64		
Male, 45–64 years		0.78		
Male, 65–84 years		0.76		
Male, >84 years		0.44		0.52
Female, <1 year				
Female, 65–84 years		0.70		
Female, >84 years		0.42	0.43	0.55
Injury and poisoning				
Male, <1 year				
Male, 1–14 years				
Male, 15–24 years				0.76
Male, 25–44 years				0.75
Male, 45–64 years	0.50		–0.41	0.45
Male, 65–84 years	0.47			
Male, >84 years	0.41			
Female, <1 year				
Female, 15–24 years				0.53
Female, 25–44 years				0.50
Female, 45–64 years				
Female, 65–84 years	0.42			
Female, >84 years				
“Residual”				
Male, <1 year				
Male, 1–14 years				
Male, 15–24 years		0.42		
Male, 25–44 years	0.59			
Male, 45–64 years	0.48			
Male, 65–84 years				
Male, >84 years				
Female, <1 year				
Female, 1–14 years				
Female, 15–24 years				
Female, 25–44 years		0.57		
Female, 45–64 years	0.51	0.50		
Female, 65–84 years				
Female, >84 years				

*Only rates that are substantially correlated with factors (loading>0.40), and help interpret these factors are indicated.

Bold figures indicate a very high correlation between the rates and factors (loading>0.75).

men (notably due to HIV infection) replaced that of young children as the third pattern, and mortality due to injuries remained stable as the fourth.

Our study also shows very strong and consistent correlations between several cause-specific death rates. Although diagnostic and coding habit artefacts cannot be completely excluded, this correlation suggests an interdependency—association or competition—of several diseases as the leading causes of death. This result, not described previously, was predicted by the historian Mirko Grmek²¹ who elaborated the concept of pathocenosis in the 60s: the idea is that as for species of an ecosystem, frequencies of diseases of the “pathocenosis” (here, those diseases leading to death) depend on endogenous (eg, sex and age) and ecological factors (eg, diet, smoking and traffic), but also on the frequencies of other diseases (many diseases are competitive and some mutually exclusive in humans). Consequently, they tend towards a state of equilibrium, at least in the short term. We indeed observed this tendency towards equilibrium over

the three decades of our study, with the mortality structure clearly strengthening along two main patterns (see earlier).

Finally, these findings may be relevant to mortality surveillance. Considering structures or patterns of mortality and changes among them rather than the trends for (many) individual causes of death may indeed give simpler and more robust predictions of effect of diseases leading to death, and the needs of populations in the future. Our findings suggest that cause-specific mortality should be assessed in populations as a multidimensional phenomenon. Identifying its main patterns and components may help in the construction of composite measures of this phenomenon with higher validity than the groupings currently used (eg, by WHO²²), which are often derived from oversimplified epidemiological transition theories.

ACKNOWLEDGEMENTS

We thank Mrs F Laurent (INSERM CépIdC) for help in data handling and Professor G Salem and Dr JC Salomon for helpful comments on a

Table 5 Principal component analysis results for age and sex cause-specific death rates classified according to the 17 headings of the International Classification of Diseases 8–9: period 1968–79, time units*

Age and sex-specific mortality	Factor 1	Factor 2	Factor 3	Factor 4
Infectious and parasitic diseases				
Male, <1 year				
Male, 45–64 years	0.76			
Male, 65–84 years	0.61			
Male, >84 years				
Female, <1 year				
Female, 45–64 years				
Female, 65–84 years				
Female, >84 years				
Neoplasms				
Male, <1 year				
Male, 25–44 years				
Male, 45–64 years				
Male, 65–84 years		0.70		
Male, >84 years		0.46		
Female, 25–44 years	0.40			
Female, 45–64 years	0.50			
Female, 65–84 years	0.49			
Female, >84 years				
Endocrine, nutritional and metabolic diseases, and immunity disorders				
Male, <1 year				
Male, 45–64 years	0.49			
Male, 65–84 years	0.42	0.50		
Male, >84 years		0.41		
Female, <1 year				
Female, 45–64 years	0.69			
Female, 65–84 years	0.55	0.41		
Female, >84 years		0.54		
Diseases of the blood and blood-forming organs				
Male, <1 year				
Male, 65–84 years		0.44		
Male, >84 years				
Female, 65–84 years		0.43		
Female, >84 years				
Mental disorders				
Male, 45–64 years	0.53			
Male, 65–84 years	0.65			
Male, >84 years				
Female, 65–84 years	0.44			
Female, >84 years				
Diseases of the nervous system and sense organs				
Male, <1 year	0.44			
Male, 45–64 years	0.59			
Male, 65–84 years	0.61			0.44
Male, >84 years				
Female, <1 year	0.43			
Female, 45–64 years	0.56			
Female, 65–84 years	0.70			0.40
Female, >84 years				0.47
Diseases of the circulatory system				
Male, <1 year				
Male, 25–44 years	0.55			
Male, 45–64 years	0.89			
Male, 65–84 years	0.87			
Male, >84 years	0.69	0.48		
Female, <1 year				
Male, 25–44 years	0.46			
Female, 45–64 years	0.88			
Female, 65–84 years	0.86			
Female, >84 years	0.63	0.56		
Diseases of the respiratory system				
Male, <1 year	0.80			
Male, 45–64 years	0.73			
Male, 65–84 years	0.73	0.41		
Male, >84 years	0.70	0.55		
Female, <1 year	0.78			
Female, 45–64 years	0.70			
Female, 65–84 years	0.79			
Female, >84 years	0.74	0.49		
Diseases of the digestive system				
Male, <1 year				
Male, 25–44 years				
Male, 45–64 years	0.63			
Male, 65–84 years	0.55			
Male, >84 years				
Female, <1 year				
Female, 25–44 years				

Table 5 Continued

Age and sex-specific mortality	Factor 1	Factor 2	Factor 3	Factor 4
Female, 45–64 years	0.44			
Female, 65–84 years				
Female, >84 years		0.47		
Diseases of the urogenital system				
Male, 45–64 years	0.60			
Male, 65–84 years	0.50			
Male, >84 years				
Female, 65–84 years		0.54		
Female, >84 years		0.62		
Diseases of the skin and subcutaneous tissue				
Male, 65–84 years				
Male, >84 years				
Female, 65–84 years				
Female, >84 years				
Diseases of the musculoskeletal system and connective tissue				
Female, 65–84 years				
Female, >84 years				
Congenital anomalies				
Male, <1 year				
Female, <1 year	0.43			
Certain conditions originating in the perinatal period				
Male, <1 year	0.64	-0.60		
Female, <1 year	0.63	-0.59		
Symptoms, signs and ill-defined conditions				
Male, <1 year		0.58		
Male, 25–44 years				
Male, 45–64 years	0.83			
Male, 65–84 years	0.93			
Male, >84 years	0.89			
Female, <1 year		0.53		
Female, 45–64 years	0.79			
Female, 65–84 years	0.93			
Female, >84 years	0.91			
Injury and poisoning				
Male, <1 year				
Male, 1–14 years		-0.54		
Male, 15–24 years			0.63	
Male, 25–44 years		-0.57	0.54	
Male, 45–64 years	0.44	-0.53		
Male, 65–84 years			0.47	
Male, >84 years				
Female, <1 year				
Female, 1–14 years		-0.52		
Female, 15–24 years			0.57	
Female, 25–44 years			0.42	
Female, 45–64 years	0.53			
Female, 65–84 years	0.48	0.42		
Female, >84 years				
“Residual”				
Male, <1 year				
Male, 1–14 years	0.66			
Male, 15–24 years				
Male, 25–44 years	0.78			
Male, 45–64 years				
Male, 65–84 years				
Male, >84 years				
Female, <1 year				
Female, 1–14 years	0.68			
Female, 15–24 years				
Female, 25–44 years	0.80			
Female, 45–64 years	0.56			
Female, 65–84 years		0.45		
Female, >84 years				

*Only rates that are substantially correlated with factors (loading>0.40), and help interpret these factors are indicated.

Bold figures indicate a very high correlation between the rates and factors (loading>0.75).

Female, >84 years.

What is already known on this topic

- The popular and widely used epidemiological transition theory is based on a succession of specific “patterns” of causes of death in human societies.
- However, the reality and consistency of patterns of causes of death in a population at a given moment has never been formally evaluated.

What this study adds

- Our study provides evidence for an evolutionary structure of patterns of mortality in contemporary France and therefore suggests using the concept of epidemiological transition in a less simplistic way than is commonly the case.

Policy implications

- Our study also shows much stronger interrelationships between diseases leading to death than is usually believed and suggests that current categorisations of cause-specific mortality in populations need reconsideration.

previous draft of the manuscript. We also thank the reviewers for their useful comments.

Authors' affiliations

J Coste, E Bernardin, Université Paris-Descartes, Faculté de Médecine, AP-HP, Hôpital Cochin, Paris, France
E Jouglu, INSERM CépîDc, Le Vésinet, France

Competing interests: None.

REFERENCES

- 1 Seshamani M, Gray AM. A longitudinal study of the effects of age and time to death on hospital costs. *J Health Econ* 2004;**23**:217–35.
- 2 Tuljapourkar S, Li N, Boe C. A universal pattern of mortality decline in the G7 countries. *Nature* 2000;**405**:789–92.
- 3 McMichael AJ, McKee M, Shkolnikov V, et al. Mortality trends and setbacks: global convergence or divergence? *Lancet* 2004;**363**:1155–9.
- 4 Omran AR. The epidemiologic transition. A theory of the epidemiology of population change. *Milbank Mem Fund Q* 1971;**49**:509–38.
- 5 Olshansky SJ, Ault AB. The fourth stage of the epidemiologic transition: the age of delayed degenerative diseases. *Milbank Q* 1986;**64**:355–91.
- 6 Rogers RG, Hackenberg R. Extending epidemiologic transition theory: a new stage. *Soc Biol* 1987;**34**:234–43.
- 7 Omran AR. The epidemiologic transition theory revisited thirty years later. *World Health Stat Q* 1998;**51**:99–119.
- 8 Olshansky SJ, Carnes B, Rogers RG, et al. Emerging infectious diseases: the fifth stage of the epidemiologic transition? *World Health Stat Q* 1998;**51**:207–17.
- 9 Olshansky SJ, Carnes B, Rogers RG, et al. Infectious diseases, new and ancient threats to world health. *Popul Bull* 1997;**52**:1–52.
- 10 Carolina MS, Gustavo LF. Epidemiological transition: model or illusion? A look at the problem of health in Mexico. *Soc Sci Med* 2003;**57**:539–50.
- 11 Caselli G, Mesle F, Vallin J. Epidemiologic transition theory exceptions. *Genus* 2002;**58**:9–52.
- 12 Wolleswinkel-van den Bosch JH, Looman CW, Van Poppel FW, et al. Cause-specific mortality trends in The Netherlands, 1875–1992: a formal analysis of the epidemiologic transition. *Int J Epidemiol* 1997;**26**:772–81.
- 13 World Health Organization. *International classification of diseases*, 8th revision. Geneva: WHO, 1967.
- 14 World Health Organization. *International classification of diseases*, 9th revision. Geneva: WHO, 1977.
- 15 EUROSTAT. *Health statistics. Atlas on mortality in the European Union (data 1994–96)*. Luxembourg: European Communities, 2002.
- 16 Jackson JE. *A user's guide to principal components*. New York: Wiley, 1991.
- 17 Coste J, Bouee S, Ecosse E, et al. Methodological issues in determining the dimensionality of composite health measures using principal component analysis: case illustration and suggestions for practice. *Qual Life Res* 2005;**14**:641–54.
- 18 Comstock GW, Markush RE. Further comments on problems in death certification. *Am J Epidemiol* 1986;**124**:180–81.
- 19 Jouglu E, Pavillon G, Rossollin F, et al. Improvement of the quality and comparability of causes-of-death statistics inside the European Community. EUROSTAT Task Force on “uses of death statistics”. *Rev Epidemiol Sante Publique* 1998;**46**:447–56.
- 20 Caldwell JC. Population health in transition. *Bull World Health Organ* 2001;**79**:159–60.
- 21 Grmek MD. Préliminaires d'une étude des maladies. *Ann ESC* 1969;**24**:1437–83.
- 22 Murray CJ, Lopez AD. Mortality by cause for eight regions of the world: Global Burden of Disease Study. *Lancet* 1997;**349**:1269–76.

International Forum on Quality & Safety in Health Care

18–20 April 2007, Palau de Congressos, Barcelona.

Why attend?

- Join over 1000 healthcare professionals from over 40 countries worldwide
 - Learn from experienced leaders and improvement experts
 - Gain new skills and tools for creating change in your organisation
 - Take home practical solutions for improvement methods
- <http://www.quality.bmj.com>