Competing Causes of Death: Quantifying the Probability of Dying from One Cause Before Another with Multiple Causes of Death

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Abstract

Throughout life, individuals are exposed to multiple risks, where the occurrence of one can prevent others. This is known as competing risks. In mortality analysis, this means dying from one cause prevents death from other diseases. Understanding competing risks is essential for assessing disease lethality, guiding clinical treatment decisions, and evaluating disease burden. However, comprehensive documentation of competing risks across multiple morbid conditions remains limited. In this study, we investigate whether multiple causes of death (MCD) data can be used to evaluate mortality competing risks across diseases. We conduct pairwise comparisons among the 10 leading groups of causes of death in Denmark, France, Spain, and the United States. Specifically, we use cumulative incidence functions to estimate the probability that one cause initiated the mortality process before another when both diseases were reported on the death certificate. We then validate this approach by comparing these probabilities with those derived from Danish register data, where exposure to both diseases is known. Analysis of MCD data reveals that individuals with neoplasms or diseases of the digestive system at the end of life are more likely to have these conditions listed as their underlying causes of death compared to other comorbidities present on the death certificate. The estimated probabilities from MCD data showed consistency across countries and aligned with the "true" probabilities from register data in terms of direction, i.e. identifying which cause is most likely to lead to death, but can differ significantly in magnitude.

Introduction

The prevalence of multimorbidity, the co-occurrence of two or more chronic conditions, has been increasing over time (Chowdhury et al. 2023; Køster-Rasmussen et al. 2025). Rising multimorbidity is reflected in causes of death statistics, with the majority of death certificates listing more than one cause as having contributed to a death (Désesquelles et al. 2010, 2016). There are two broad perspectives for analyzing multimorbidity and causes of death: (1) multiple conditions (or causes) jointly influence the risk of death, or (2) various conditions compete to become the single underlying (or leading) cause of death (UCD). Given the predominant focus on analyzing the UCD, both for identifying the condition that initiates the chain of events leading to death and for simplifying the analysis (we die once from one cause), mortality analyses tend to imply or favor a competing risk approach. By requiring the selection of a single UCD, cause of death reporting inherently creates a competing risk framework among diseases.

Understanding these competing risks is important for both clinical practice and public health. At the individual level, it can help medical practitioners determine whether an elderly patient is more likely to die from one condition before benefiting from treatment for another. It can also inform on treatment prioritization. At the population level, accounting for competing risks is crucial for accurately assessing the burden of specific causes of death and designing effective public health interventions. In demographic analysis, competing risk frameworks are commonly used to examine how changes in mortality from one cause affect mortality patterns for other causes. Literature provides many competing risk analyses. However, these analyses are often limited to comparing a few diseases at a time. Consequently, we lack a comprehensive overview of competing risks across multiple morbid conditions.

The World Health Organization (WHO) has made major efforts to provide international guidelines to select, report and codes causes of death, in the International Classification of Diseases (ICD). To make internationally comparable causes of death statistics, ACME decision tables have been developed and adopted in softwares for automated causes of death selection. These softwares reconstruct the morbid chain of event leading to death, from all causes reported on the death certificate, and produce an initiator (or UCD). In this sense, the analysis of multiple causes of death can provide information on competing causes of death and on the

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probability of one cause initiating the process leading to death before other conditions present at the end of life.

However, cause-of-death reporting and the selection of the UCD are known to vary across countries. Countries have different cause of death data processing strategies, as well as training of the death certifiers, which might lead to inconsistencies in UCD selection across countries. In this study, we aim to evaluate whether multiple causes of death (MCD) data can be used to measure competing risks between causes. To do so, we address two questions: (1) are competing risks estimated from MCD consistent across countries, and (2) are the competing risks evaluated from MCD representative of the "real" competing risks determined using patient data?

Data

MCD data for Denmark, France, Spain and the U.S. are used for the analysis, for the period 2016-2019. We use data from age 60 to 100+. Danish causes of death data come from the Danish Causes of Death registry, provided by Statistics Denmark. French data are prepared by the French National Institute for Health and Medical Research (INSERM), available through the French Health Registry (SNDS). Spanish data comes from the National Institute of Statistics. Causes of death data from the U.S. comes from the Multiple Causes of Death Data from the CDC(Centers for Disease Control and Prevention 2022). Exposures are taken from the Human Mortality Database (HMD 2025). For the MCD analysis, diseases are grouped into 10 major groups of causes, representing the 10 most common ICD-10 chapters: Infectious and parasitic diseases; neoplasm; endocrine, nutritional and metabolic diseases; mental and behavioral disorders; diseases of the nervous system; diseases of the circulatory system, diseases of the respiratory system, diseases of the digestive system; diseases of the genitourinary system; and external causes of death .

For the analysis of the “real” competing risk, we use the Danish Selected Chronic Diseases and Severe Mental Disorders register (Udvalgte kroniske sygdomme og svære psykiske lidelser), providing information on diagnosis, including year of diagnosis and age of patients, for specific diseases including type-2 diabetes, dementia (including Alzheimer’s disease) and chronic pulmonary obstructive diseases (COPD). The register is linked to the Danish Causes of Death registry to obtain information on causes of death.

Methods

We use the cumulative incidence function (CIF) to estimate the probability to die from one cause before another. The CIF measures the risk of failure from a specific event at a given time, accounting for competing events without assuming independence between them. As a standard survival analysis tool, the CIF mirrors multiple decrement life table functions. The probability of failure (*I*) from event *c* at time *t* is expressed as

$$I(c,t) = S(t-1) * h(c,t)$$

Where $S(t-1)$ is the overall survival function and $h(c,t)$ is the hazard function event *c* at time *t*. The CIF is then estimated by the sum of $I(c,t)$ over time. In a life table setting, the $I(c,t)$ can represent the life table deaths from cause *c* at age *x*, $d(c,x)$, such that

$$CIF(c) = \sum_x d(c,x) = \sum_x S(x) * q(c,x)$$

where $q(c,x)$ are the death probabilities from cause *c* at age *x*. The competing nature of the multiple decrement life tables is well documented in Preston, Heuveline, and Guillot (2001), where the authors of the demographic textbook shows that the death probabilities (but not the rates) are dependent probabilities.

To simplify the analysis, we do pairwise comparison between causes of death. We estimate the death rates using the death counts when both diseases being compared appear on the death certificates as numerator and the total population exposure as denominator. We then use these rates to estimate multiple decrement life table with only two decrements: one where disease *A* appears as the UCD with diseases *B* reported on the death certificate as non-UCD and one where disease *B* appears as the UCD with diseases *A* reported as non-UCD. The resulting probabilities vary between 0 and 1, with $CIF(A) + CIF(B) = 1$. If $CIF(A) = 0.5$, this means that there is an equal chance of dying of cause A before B than from B before A. If $CIF(A) > 0.5$, there is a higher chance of dying from cause A before B, with a value of 1 indicating that everyone dies of A before B.

If $CIF(A) < 0.5$, there is a lower chance of dying from cause A before B, with a value of 0 indicating that everyone dies of B before A.

We conduct a similar analysis using Danish register data, but in this case we know the true exposure, that is, we use the exposure from individuals who have both diseases. Additionally, in this second analysis, both diseases do not need to appear on the death certificate; but at least one must be present as the UCD.

Preliminary results

Figure 1 shows the probability of dying from cause A (y-axis) before cause B (x-axis), using MCD data in four countries. All tiles in purple represent a higher probability of dying from cause A (probability above 0.5) and all tiles in green represent a lower probability of dying from cause A (or higher probability of dying from cause B). The tiles in white means that there is roughly a 50-50 chance of dying of either cause. The causes are ranked from the highest probability to the lowest, highlighting the causes with the highest lethality and those with the lowest. The figure shows that, for people with neoplasm and other conditions on their death certificate, there is a higher probability of dying from neoplasms before any other conditions. There is also a higher probability of dying from diseases of the digestive system before any other conditions, except neoplasms. At the other end of the scale, there is a higher probability of dying from any other conditions before diseases of the genitourinary system and endocrine, nutritional and metabolic diseases.

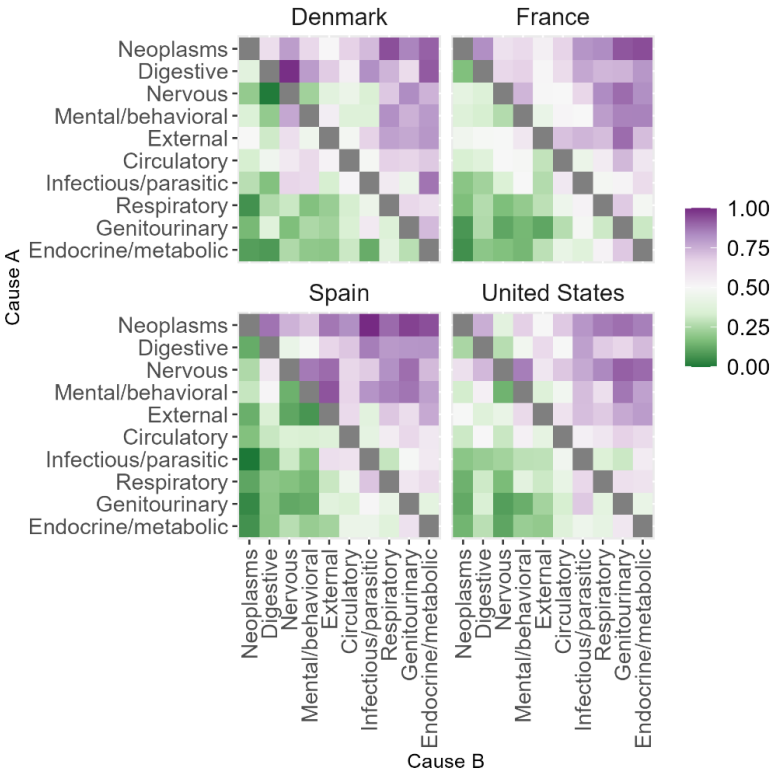

Figure 1: Probability to die from cause A (y-axis) before cause B (x-axis) in Denmark, France, Spain and the United States over the period 2016-2019, Females.

We can expect that, if all countries would agree on the competing risk, all squares above the diagonal would be purple and all those below the diagonal would be in green. The figure shows that there is a general agreement across countries about which causes if most likely to lead to death before the other, with the notable exceptions of diseases of the nervous system and mental and behavioral disorders. There is a lower chance that these diseases would be the UCD in Denmark, compared with the other countries, with a higher probability of dying from external causes, diseases of the circulatory system and infectious and parasitic diseases before, unlike in the other countries. On the other hand, diseases of the nervous system tend to be more often reported as the UCD in the U.S., compared with the other countries.

Table 1 shows the results of the "real" risk analysis compared with the MCD approach. The table reveals that both approaches agree on which cause is most likely to lead to death, with a higher chance of dying of CPOD before dementia and diabetes. But both models found significantly different probabilities, with the real competing risk showing a more "crisp" probability than the MCD approach.

Table 1 Probability (in %) to die from cause A before cause B, comparing this probability measured from multiple causes of death data and from diseases national register, Denmark 2016-2019, Females

Die of A before B	**Real**	**MCD**
COPD before dementia	77.3 [75.6,78.9]	62.3 [58.1,66.4]
COPD before diabetes	91.8 [90.9,92.8]	80.6 [77.1,84.5]
Dementia before diabetes	88.0 [86.3,89.5]	73.1 [66.3,77.6]

Conclusion and next steps

As a general trend, MCD can inform on which diseases are most likely to lead to death before others, with the probability being, generally, in the same "direction" across countries and when comparing the MCD and real competing risks. However, the cross-country and real-risk comparison reveals some significant differences. As such, MCD data can inform on which cause is considered "most lethal" but cannot capture to which extend this probability is.

We found that, despite diseases of the cardiovascular system being a very common causes of death, these diseases are not necessarily the ones considered to initiate the train of event leading to death. Instead, neoplasms and diseases of the digestive system have a higher probability of initiating the mortality process.

Next steps of this project comprise including more diseases in the "real risk" analysis, specifically neoplasms using the Danish Cancer Register and computing confidence intervals, comparing the Chiang models (Chiang 1960) and a bootstrapping model.

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