

Analysis of lifetime death probabilities for major death causes among residents in China

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Abstract

Background: Cumulative mortality rate and cumulative risk are the two commonly used indicators at present to measure the significance and severity of diseases, while both of them have limitations and cannot represent the life-time death probability. This study aims to use a new indicator, lifetime death probability (LDP), to estimate the lifetime death probabilities for the top five leading causes of death in China and explore the regional differences and trends over time. **Methods:** The LDPs were calculated using a probability additive formula and an abridged life table. **Results:** In 2014, the LDPs for heart disease, cerebrovascular disease, malignant tumor, respiratory disease, and injury and poisoning were 24.4%, 23.7%, 19.2%, 15.5%, and 5.3%, respectively. Compared to 2004-2005, the LDPs for heart disease and malignant tumor in 2014 increased 7.3% and 0.5%, respectively. In contrast, the LDPs for cerebrovascular and respiratory diseases in 2014 were 1.0% and 3.9% respectively lower than that in 2004-2005. In the eastern region, malignant tumors had the highest LDP among the five diseases, while in the central and western regions they were 'cerebrovascular and heart diseases' and 'respiratory diseases, and injury and poisoning', respectively. **Conclusions:** LDP is an effective indicator for comparing health outcomes, which can be applied in future disease surveillance. Heart disease and cancer are the two major lifetime risks of death in China, but with regional differences. There is a need to take targeted preventive measures to prevent diseases in different regions.

Background

With the rapid socioeconomic development in the past decades in China and the consequent changes in lifestyle and living environment, chronic diseases have gradually replaced infectious and malnourished diseases as the leading causes of mortality[1]. According to the latest national statistics, the top five leading underlying causes of death were malignant neoplasms, cerebrovascular diseases, heart diseases, respiratory diseases, and injury and poisoning in 2014 [2]. They resulted in substantial years of life lost (YLLs) and disability adjusted life years (DALYs)[3], affecting population health and burdening the overloaded healthcare system. Only for neoplasms, its DALYs could reach as high as 1,893 per 100,000 in the 15–49 age group[4].

Measurement of the major causes of deaths can help explain differences and changes in population health over time, evaluate health strategies and performance, and guide policy-making. Currently, cumulative mortality rate and cumulative risk are the two commonly used indicators to measure the significance and severity of diseases[5, 6]. However, cumulative mortality rate is a probability index which can only be calculated in people without death competition and in certain age groups (0–74 years or 0–85 years)[5–7]. In contrast, cumulative risk can be used to calculate the probability of death, while it is affected by cut-off time and cannot represent the entire life time[8, 9]. For example, Hao[10] reported that the cumulative death risk for malignancies was 13% before the age of 74-year-old. However, if one's life expectancy was longer than 74 years old, the probability of death could not be estimated.

To estimate the probability of death over the entire life span (lifetime risk), a new method-lifetime death probability (LDP) based on cumulative risk, was introduced to indicate the likelihood of death throughout the whole life span in our previous study[11–14]. LDP not only takes the risk of death competition into account, moreover, it is not affected by demographic composition. However, to date few studies have used LDP to calculate the mortality. In this study, we aim to (1) use LDP to calculate the probabilities of lifetime death for the top 5 leading causes of death in mainland China; and (2) explore the regional differences and trends over time. Results of this study may provide useful evidence for the development of chronic disease prevention strategies, performance evaluation, and the allocation of healthcare resources for targeted interventions.

Methods

Data sources

The age-specific mortality rates for 2014 were extracted from the Chinese National Death Cause Monitoring Dataset[2], which was conducted through 605 national disease surveillance system monitoring stations compiled by the National Health and Family Planning Commission of the People's Republic of China. The age-specific mortality rate for 2004–2005 was sourced from the third National Death Cause Survey[15]. The survey covered 213 counties across the country hosted by the Ministry of Health of the People's Republic of China. In China, these two systems have been used for decades to provide nationally representative data on health status for health-care decision-making and performance evaluation. However, the systems overlapped to a considerable extent, thereby entailing a duplication of effort. In 2013, the Chinese Government combined these two systems into an integrated national mortality surveillance system to provide a provincially representative picture of total and cause-specific mortality and to accelerate the development of a comprehensive vital registration and mortality surveillance system for the whole country. This new system increased the surveillance population from 6 to 24% of the Chinese population[16].

Malignant neoplasm, cerebrovascular disease, heart disease, respiratory disease and injury and poisoning were classified according to the International Classification of Diseases, 10th revision (ICD-10) (WHO, 1992).

Statistical analysis

Based on the probability additive formula[12, 13], an abridge life table[8] was used to calculate the LDPs for the 5 leading causes of diseases. The series of formulas is as follows:

$$q_x = \sum_i q_x^i \quad (1)$$

$$D_x = \sum_i D_x^i \quad (2)$$

$$r_x^i = \frac{D_x^i}{D_x} = \frac{m_x^i}{m_x} \quad (3)$$

$$q_x^i = r_x^i q_x \quad (4)$$

$$d_x^i = r_x^i d_x \quad (5)$$

$$P_x^i = \frac{\sum_x^w d_x^i}{l_x} \quad (6)$$

$$P_0^i = \frac{\sum_{x=0}^w d_x^i}{l_0} \quad (7)$$

(1) q means the death probability, horn x means age group, horn i means the cause of death; (2)

D means the actual death; (3) m means mortality, r means proportional mortality; (5) d means

death toll on the life table. (6) l means survival number from the life table; (7) w means the

oldest age group. In the end, P_0^i of age group 0 is representative of one person's life-time death

probability[11].

China is a vast country with varying socioeconomic development status in different regions. Moreover, mortality pattern and trends in disease burden differ significantly at a provincial level. To facilitate the identification of health priorities at a regional level, we calculated the region-specific lifetime death probabilities for the 5 major causes of death[3]. According to the National Bureau of Statistics, geographically China can be divided into three regions: the eastern, central, and western regions [14]. The eastern region includes the following municipalities and provinces: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; the central region includes Heilongjiang, Jilin, Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan; and the western region includes

Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.

Results

From 2004 to 2005, the total number of deaths in the monitoring areas of China was 868484, with males and females accounting for 57.9% (502434) and 42.1% (366050), respectively. The death toll was 331521 in eastern China, 299406 in central China and 237557 in western China, accounting for 38.2%, 34.5% and 27.4% respectively[15]. In 2014, the total number of deaths in the monitoring areas increased to 1643,377, with males and females accounting for 58.7% (965,261) and 41.3% (678,116), respectively. Specifically, the death toll was 656,709 in eastern China, 565,285 in central China and 421,383 in western China, accounting for 40.0%, 34.4% and 25.6%, respectively[2].

Using cerebrovascular diseases as an example, based on the life table method the LDP of cerebrovascular diseases in 2014 was 23.7% (Table1). Similarly, the LPDs in 2014 for heart diseases, respiratory diseases, malignant tumor, “injury and poisoning” were 24.4%, 19.2%, 15.5%, and 5.3%, respectively (Table 3).

As shown in Table 2, malignant tumor had the highest mortality rate during 2004-2005 in China, followed by cerebrovascular disease, heart disease, respiratory disease, and ‘injury and poisoning’. However, in terms of lifetime death probability, the priority pattern is totally different. During the same period, the most likely cause of death for Chinese residents in a lifetime was cerebrovascular disease (24.7%), followed by respiratory disease (19.4%), malignant tumor (18.7%), heart disease (17.1%), and ‘injury and poisoning’ (6.5%). Similarly, the discrepancies between mortality rate and LDP in the measurement of the top five causes of death were also observed in 2014. Compared to 2004-2005, the priority pattern by mortality rate for the 5 leading causes of death remained unchanged in 2014 (Table 3). Nevertheless, the most likely cause of death for a lifetime has changed from cerebrovascular disease in 2004-2005 to heart disease in 2014. Specifically, during the 10-year period the LDPs for heart disease and malignant tumor have increased by 7.3% and 0.5%, respectively. In contrast, lifetime death probabilities due to respiratory disease, ‘injury and poisoning’, and cerebrovascular disease decreased by 3.9%, 1.3%, and 1.0%, respectively.

We also observed discrepancies between mortality rate and LDP in the measurement of the top five causes of death at a regional level. In the eastern region, malignant tumor was the most prevalent cause of death during the two periods, while causes with the highest lifetime death probability were cerebrovascular disease in 2004-2005 and heart disease in 2014. In the western region, the most prevalent cause of death (namely, mortality rate) has changed from respiratory disease in 2004-2005 to malignant tumor in 2014. However, in terms of lifetime death probability, the most significant cause of death was cerebrovascular disease in 2014. Differing from the eastern and western regions, priority patterns identified using the two metrics were consistent in the central region. Among the five leading causes of death, mortality rate and LDP for cerebrovascular and heart diseases were relatively higher in

the central region than that in the other two regions during the two periods. For malignant tumor, relatively higher mortality rate and LDP were observed in the eastern region. As to respiratory disease and 'injury and poisoning', they were more likely to be the cause of death in the western region than other two regions.

Discussion

To our best knowledge, this is the first epidemiological study using LDP to evaluate the severity and risk for the five leading underlying causes of death in China. Comparison of regional differences and changes over time may provide insights into the current priorities of disease prevention in different regions.

LDPs for the top five leading causes of death: implications for priority identification

Although malignant tumors were the first cause of death, the probability of death due to malignant tumors in a person's lifetime was lower than that of cerebrovascular and heart diseases which respectively were the second and third causes of death in 2014. This phenomenon could be due to the differences in mortality rate between the diseases in certain age groups. The mortality rate of cancer (53.7 per 100,000) was more than two times higher than that of cardiovascular and cerebrovascular diseases (20.2 per 100,000 and 21.3 per 100,000) at the age of 40–45[2]. However, the mortality of cancer (1265.6 per 100,000) was much lower than that of cardiovascular and cerebrovascular diseases (2066.4 per 100,000 and 2140.42 per 100,000) at the age of 80–85[2]. The age-specific mortality rate is influenced by demographic composition and competitive risk. If the young age groups contribute more to the entire cancer mortality rate and the impact of competition risk is low, the LDP of cancer could be low in one's lifetime. In this study, the mortality rate of cancer in the young age groups was higher than cardiovascular and cerebrovascular diseases, while the mortality rate of cardiovascular and cerebrovascular diseases was lower than cancer, so the LDP of cardiovascular and cerebrovascular diseases was higher than that of cancer. When formulating disease prevention policies, we should not only focus on tumor prevention, but also strengthen the prevention of cardiovascular and cerebrovascular diseases.

Change Of Trends In Ldp

Compared to 2004–2005, we found the probabilities of death from heart disease and malignant tumors in a person's lifetime increased in 2014, while the probabilities of death for respiratory diseases and 'injury and poisoning' in a person's lifetime declined. Government at all levels has actively promoted effective prevention measures to control major risk factors in recent years; respiratory disease, cerebrovascular disease and injuries and poisoning have declined, but heart disease and cancer are still increasing[17]. These changes may require an integrated government response to improve primary health

care and take action to address key risks. Early diagnosis and prevention of heart disease and cancer, as well as reducing the impact of poor diet, high blood pressure, smoking and cholesterol on residents, are priorities of public policy in China.

Regional Differences

In this study, we found LDPs for the top five leading causes of death varied by region. In the eastern region, malignant tumors had the highest LDP among the five diseases, while in the central and western regions they were 'cerebrovascular and heart diseases' and 'respiratory diseases, and injury and poisoning', respectively. A wide range of factors may contribute to the differences between regions, including different lifestyles and eating habits, geographical locations and living environment, socioeconomic status, availability of medical resources, diagnosis and treatment level in different regions. It is of great importance in etiology and public health to explore the generality and characteristics of interregional disease incidence and mortality. The eastern region is well developed, with a faster working pace and greater work pressure than other two regions. Additionally, there may be more attention to screening for and treating cancer[18–20].

Factors contributing to obesity and overweight include rapid economic development and urbanization process, the change of residents' dietary structure, unhealthy lifestyle. Obesity is associated with cardiovascular and cerebrovascular diseases[21, 22]. Mechanisms potentially linking obesity to cardiovascular and cerebrovascular diseases are insulin resistance and chronic subclinical inflammation [23]. In recent years, the obesity rate in the central region has been on the rise which increased more than that in eastern and western regions[24]. Probably, that is why hypertension and death of blood pressure related diseases are significantly higher than those of the eastern and western regions[25]. In contrast, for residents in the western regions respiratory diseases had the highest LDP. Relatively speaking, the western region has a lagging economy and small population, with poor and uneven distribution of medical resources. The common use of indoor coal may be a causative factor in the heavy burden of respiratory disease in this region [26–28]. In addition, relatively higher smoking rate in the western region may also contribute to the higher LDP, compared to other two regions[29].

Strengths And Limitations

In this study, we used LDP as an indicator to estimate the lifetime death probability for the top 5 leading causes of death. Compared to cumulative mortality and cumulative risk, which are currently widely used metrics to indicate the severity of a certain death cause, LDP has its advantages. LDP refers to the probability of death for a person from a certain death cause in the presence of various death causes in one's life time. Moreover, LDP is based on the principle of probability addition, and not affected by population composition and considering the risk of death competition[12]. In contrast, although cumulative mortality or cumulative risk can indicate the severity of a certain death cause, it does not take into account competition risks [3–5]. In the analysis of time event data, some subjects may experience

competition risks when the events of interest are excluded by different types of events occurred previously[30]. In addition, cumulative mortality or cumulative risk can only be calculated for a specific age group (usually 0–74 years old), however, cannot calculate the probability of death for a person's lifetime. Therefore, LDP may be a more appropriate statistical indicator for situations that multiple causes of death and competing risks should be considered.

This study has potential limitations and caution should be exercised in interpreting the results. The number of mortality monitoring points in China has increased from 213 in 2004–2005 to 605 in 2014, which may potentially affect the consistency in estimating the age-specific mortality rates. Nevertheless, in 2013 the National Health and Family Planning Commission combined the vital registration system and the disease surveillance points system to create an integrated national mortality surveillance system[2]. As the two mortality surveillance systems were similar in diseases coding and classification, sampling method, and regional divisions, the age-specific rates between 2004–2005 and 2014 should be comparable.

Conclusion

LDP is an effective indicator for comparing health outcomes, which can be applied in future disease surveillance. Heart disease and cancer are the two major lifetime risks of death in China, but with regional differences. There is a need to take targeted preventive measures to prevent diseases in different regions.

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: All authors have read and approved the final version.

Availability of data and material: It uses data from published, peer-reviewed studies.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: Yuan Ping performed the literature search and wrote the paper, Xiang Jianjun revised the manuscript, Chen Tiehui collected data, Lin Xiuquang analyzed data, Kui-Cheng Zheng supervised and approved the final version of this study.

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Tables

Table 1: Calculation on LDP of cerebrovascular disease in 2014

(1)	(2)	(3)	(4)	(5)	(6)	(7)=(3)/(2)	(8)=(6)*(7)	(9)	(10)=(9)/(5)
0~	460.6	0.000	0.005	100 000	461	0.000	0	23 743	0.237
1~	50.0	0.000	0.002	99 539	199	0.002	0	23 742	0.239
5~	21.6	0.000	0.001	99 341	107	0.009	1	23 742	0.239
10~	26.1	0.000	0.001	99 233	130	0.012	2	23 741	0.239
15~	35.9	0.000	0.002	99 104	178	0.032	6	23 740	0.240
20~	37.7	0.000	0.002	98 926	186	0.040	7	23 734	0.240
25~	62.7	0.000	0.003	98 740	309	0.043	13	23 727	0.240
30~	85.2	0.000	0.004	98 430	419	0.073	30	23 713	0.241
35~	104.2	0.000	0.005	98 012	509	0.094	48	23 683	0.242
40~	174.4	0.000	0.009	97 503	847	0.122	103	23 635	0.242
45~	230.0	0.000	0.011	96 656	1 105	0.144	159	23 531	0.243
50~	437.1	0.001	0.022	95 551	2 066	0.171	353	23 372	0.245
55~	557.5	0.001	0.027	93 485	2 570	0.180	462	23 018	0.246
60~	1014.7	0.002	0.049	90 915	4 498	0.202	907	22 557	0.248
65~	1755.2	0.004	0.084	86 417	7 265	0.232	1 682	21 650	0.251
70~	2820.0	0.007	0.132	79 152	10 425	0.252	2 625	19 968	0.252
75~	4367.1	0.012	0.197	68 727	13 530	0.283	3 833	17 343	0.252
80~	8051.6	0.021	0.335	55 197	18 498	0.266	4 917	13 509	0.245
85+	16640.0	0.039	1.000	36 699	36 699	0.234	8 592	8 592	0.234

Table 2: Mortality rates and lifetime death probabilities for the five leading causes of death by region, 2014, China.

Top 5 leading causes of death	Overall		Eastern region		Central region		Western region	
	Mortality rate (per 100,000)	Death probability (%)						
Malignant tumors	155.4	19.2	175.4	21.2	144.7	18.3	139.2	16.7
Cerebrovascular diseases	143.6	23.7	142.5	23.0	149.0	24.9	137.6	22.5
Heart diseases	141.3	24.4	144.9	23.9	151.4	27.3	121.6	20.3
Respiratory diseases	78.2	15.5	70.9	13.7	64.3	13.2	108.7	21.4
Injury and poisoning	49.7	5.3	45.7	5.1	48.1	5.1	58.1	5.7

Table 3: Mortality rates and lifetime death probabilities for the five leading causes of death by region, 2004-2005, China.

Top 5 leading causes of death	Overall		Eastern region		Central region		Western region	
	Mortality rate*	Death probability (%)						
	(per 100,000)		(per 100,000)		(per 100,000)		(per 100,000)	
Malignant tumors	135.9	18.7	154.7	20.2	135.9	19.3	111.4	15.8
Cerebrovascular diseases	136.6	24.7	146.6	25.2	146.8	26.4	111.2	21.8
Heart diseases	90.2	17.1	96.8	17.3	99.7	19.0	70.0	14.0
Respiratory diseases	96.3	19.4	91.2	17.9	84.1	17.2	117.9	24.7
Injury and poisoning	61.5	6.5	58.5	6.3	60.1	6.6	67.2	6.7