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Sudden cardiac arrest mortality in China: temporal trends and risk factors

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Abstract

Background Sudden cardiac death (SCD) accounts for more than half of all sudden death cases, posing a significant health burden in China. However, epidemiological data on SCD are scarce due to the lack of a central data registry and the heterogeneity of case definitions. This study aims to provide reliable estimates of the incidence and risk factors of SCD in China at the national and regional levels from 2013 to 2021, as well as the current status of prevention.

Methods The multi-cause mortality data from 2013 to 2021 were obtained from the National Mortality Surveillance System of China. Deaths related to cardiac arrest were identified. Crude and age-standardized mortality rates were calculated by time, and region. Joint point regression was applied to identify significant changes during the study period. Subgroup analyses and multilevel negative binomial analysis were performed to understand the SCD risk factors. The first-line prevention measures and their current implementation in China and developed countries were also determined from published articles.

Results From 2013 to 2021, the crude mortality rate of sudden cardiac arrest increased markedly from 8.36 deaths per 100,000 population in 2013 to 18.59 deaths per 100,000 population in 2021. There were considerable differences among regions. Subgroup analysis and negative binomial regression results indicated that males and the elderly were at higher risk of SCD. SCD may be associated with poor medical conditions. More than half of SCDs occurred outside hospitals, and approximately 60% of SCDs were related to ischemic heart disease as the underlying cause. Currently, developed countries have widely adopted primary prevention and emergency treatment measures; however, the utilization rate of such measures in China is relatively low and should be improved.

Conclusions With the continuous rise in the prevalence of cardiovascular diseases and their related risk factors in China, the burden of SCD is expected to increase. In addition to strengthening the clinical pathways for sudden cardiac arrest cases in pre-hospital and hospital settings, it is also necessary to enhance public awareness, knowledge and first-line practical training through large-scale policies for governmental and community-based projects.

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Keywords Sudden cardiac death (SCD), Mortality rate, Age-standardized mortality rates (ASMR), National mortality surveillance system (NMSS)

Background

Sudden cardiac death (SCD) is a major and common clinical and public health issue globally, causing 4–5 million cases annually [1], accounting for more than half of all cardiovascular deaths worldwide [2, 3]. Even in developed countries such as the United States and European countries, over 350,000 people die from SCD each year, and resuscitation measures still need further exploration [4, 5]. In China, a previous project titled "the clinical applications of implantable cardioverter defibrillators (ICDs) and the prevention of sudden cardiac death" showed that the overall incidence rate of SCD was 41.8 per 100,000 population [6], equating to approximately 544,000 deaths per year. However, this study was based on surveys of only 4 cities in China. Another study based on a comprehensive literature review also reached a similar conclusion, estimating the incidence of SCD at 40.7 per 100,000 person-years [7]. The increasing prevalence of cardiovascular diseases (CVDs) and the large world population indicate that the incidence of SCD is on the rise [8], and premature mortality rates are also increasing [4, 9]. SCD also poses significant challenges to public health management in China [10]. However, the above epidemiological data on SCD in China are only from a few cities and lack national representativeness. Definitions of SCD vary among studies, and data sources range from disease registries to retrospective autopsies [11, 12]. Furthermore, the disease and risk factor profiles in China have undergone significant changes in recent decades [10, 13], resulting in insufficient epidemiological evidence on SCD in China and a lack of understanding of its burden, key areas, and affected populations.

The incidence of SCD is closely related to the survival outcomes of patients with cardiac arrest. In China, the survival rate of cardiac arrest is significantly lower than that in other countries [14, 15]. A prospective investigation of 12 hospitals in Beijing, China, reported that the in-hospital survival rate of cardiac arrest was approximately 9.1%, which was lower than that reported levels in other industrialized countries [16]. Out-of-hospital cardiac arrest is the main cause of SCD, with a poor prognosis and consistently low survival rate. According to the results of a large-scale national registry study, the Baseline Investigation of Out-of-hospital Cardiac Arrest (BASIC-OHCA), the burden of out-of-hospital cardiac arrest assessed by emergency medical services is heavy, and the proportion of resuscitation attempts is low [17]. A recent meta-analysis indicated that even for patients who received out-of-hospital cardiopulmonary resuscitation (CPR), the discharge survival rate was only 1.8% [15]. However, most studies have shown that timely emergency measures such as CPR can effectively reduce the mortality rate of out-of-hospital cardiac arrest [18–22]. This suggests that current preventive measures may be deficient in practice, resulting in unsatisfactory effectiveness. Thus, strategy implementation of these interventions requires not only a comprehensive understanding of temporal trends and geographic patterns of disease burden and identification of susceptible subgroups but also an understanding of the current state of preventive practice and identification of current gaps. These findings suggest that SCD can be prevented using various strategies, including improvements in bystander response and the prescription of preventative and therapeutic treatments for high-risk individuals [15].

This study utilized the National Mortality Surveillance System (NMSS), one of the most extensive central mortality surveillance databases in China, to estimate the situation of SCD in the Chinese population. It aimed to delineate the geographical and temporal variations of SCD across China, explore the sociodemographic determinants associated with SCD, and compare the current status of SCD prevention in China. The findings of this study shed light on the potential deficiencies in SCD prevention and treatment interventions in the country.

Methods

Study design and data sources

We conducted a population-based longitudinal analysis using mortality data extracted from the NMSS initiated in 1978 by the Chinese government. In 2013, the Chinese government combined the system with the national vital registration system, creating a data collection system from 605 surveillance points [23, 24]. The cause of death section in the standard certificate of death in China (Additional file 1: Table S1) was the same as the standard certificate of death in the United States. Data quality is reviewed annually by the quality control committee. In addition, staff training, the development of regulations for death registration, and site quality inspection are performed to ensure compliance with World Health Organization guidelines [25]. The combination of the disease point surveillance system and vital registration system allows robust estimation of cause-specific mortality at the national and regional levels. Although mortality data before 2013 are available from the former vital registration system, to maintain data consistency, our study focuses on mortality records from January 1, 2013, to December 31, 2021.

The NMSS covers 323.8 million residents, approximately 24.3% of the total population of China. Detailed information about NMSS is provided in Additional file 1: Materials and methods. For deaths that occurred in the hospital setting, the causes of death were recorded and confirmed by clinical staff. For deaths that occurred outside the hospital, verbal autopsies were conducted by community health workers, and subsequently coded and verified by local hospital staff [25]. Rigorous quality control was used at both the local and national levels to verify the accuracy and completeness of the coding. The study was centrally approved by the ethics committee of Fuwai Hospital (2023–2100).

Procedures

SCD was identified using the International Classification of Diseases, 10th Revision (ICD-10) and textual descriptions in the death certificate (Additional file 1: Table S2). A death was SCD if one of the following criteria was met: 1) the presence of ICD codes I46 or I49.0; 2) the presence of R95 or R96 along with any I-series codes or Q20–Q28; 3) descriptions of SCD and its synonyms in clinical notes; or 4) descriptions of sudden cardiac arrest in clinical notes and the presence of any I-series code or Q20–Q28. Records were excluded if the basic cause of death involved accidental injury, malignancy, acquired immunodeficiency syndrome, syphilis, cerebrovascular disease, aging, or mental disorder-like illnesses due to substance use. Following the initial data extraction, death certificates were reviewed by two clinically experienced physicians to identify and eliminate patients with non-SCD, such as acute pulmonary embolism and airway foreign bodies (Additional file 1: Fig. S1).

Five sociodemographic factors, the place of death (medical institution, on the way to the hospital, home or nursing facility, other, or not available), and the cause of death information (ICD-10 classification based on cause of death surveillance reports) were considered in our analysis. The sociodemographic information included gender (male or female), age (0–14 years, 15–34 years, 35–64 years, and ≥ 65 years), marital status (unmarried, married, widowed, or divorced), location (urban or rural), and region (Eastern, Middle, or Western).

We also explored the current status of SCD prevention in China. Owing to the lack of national survey data concerning SCD prevention, we extracted relevant data from published literature to compare the prevalence and utilization of SCD prevention in China and developed countries. The important prevention methods for SCD management include automated external defibrillators (AEDs), ICDs, CPR, and related training.

Statistical analysis

The 2013–2021 national total population by marital status was estimated based on 2010 and 2020 China census data. Age-standardized mortality rate (ASMR) was calculated using the census population in 2020 as a reference. Mortality rates were calculated per 100,000 person-years. In addition, the crude mortality rate was calculated and compared with ASMR to understand the influence of age structure. Joint point regression analyses were performed to examine the mortality trends of the overall population and subgroups from 2013 to 2021 and to identify substantial changes in the trends. To determine the influence of the COVID-19 pandemic on the incidence of SCD, the study periods were divided into "pre-COVID-19 period" (2013–2019) and "COVID-19 period" (2020–2021). The average annual percentage changes (AAPCs) and 95% confidence intervals (CIs) for the whole period and each subgroup period, as well as the annual percentage changes (APCs) for each different time, were calculated to quantify significant changes.

Multilevel negative binomial regression was used to investigate whether there are geographic variations across different provinces in SCD mortality, and the effect of risk factors on SCD. The number of deaths was stratified into 21,204 strata by year, gender, province, location, region, and age (5 year age groups). The number of deaths in these strata was fitted at level 1 of the multilevel model. The geographic variation between provinces was fitted at level 2 of the multilevel model. The baseline model includes variables of demographics (year, gender, location, and region). Provincial-level variables include socioeconomics and medical and health care resources (GDP per capita, number of doctors per 1000 population, number of hospital beds per 1000 population, mean years of education, and sectoral employment distribution), all in quartiles, were introduced into models. All fixed-effect parameters were exponentiated to odds ratios (*OR*s) with 95% CI.

Two-sided Z tests with a significance level of 0.05 were used to determine statistical significance.

Geospatial maps were created using QGIS 3.22. Joint point regression was performed using Jointpoint 4.8.0.1. Other statistical analyses were performed using SAS version 9.4.

Results

National SCD mortality burden in China from 2013 to 2021

Between 2013 and 2021, a total of 401,291 SCDs were recorded in the NMSS. At the national level, the estimated crude mortality rate was 8.36 deaths per 100,000 population in 2013 and steadily increased to 18.59 deaths per 100,000 population in 2021. ASMRs were considerably higher than crude mortality rates. ASMR was estimated to be 10.95 deaths per 100,000 population in 2013 and increased to 18.85 deaths per 100,000 population in 2020. This was followed by a slight but statistically non-significant decline in 2021, with a rate of 18.38 deaths per 100,000 population (Fig. 1a). Based on the crude mortality rate, the number of sudden cardiac arrest deaths was estimated to be 114,320 in 2013 and increased to 262,635 in 2021 in the country (Table 1). Upon stratification of

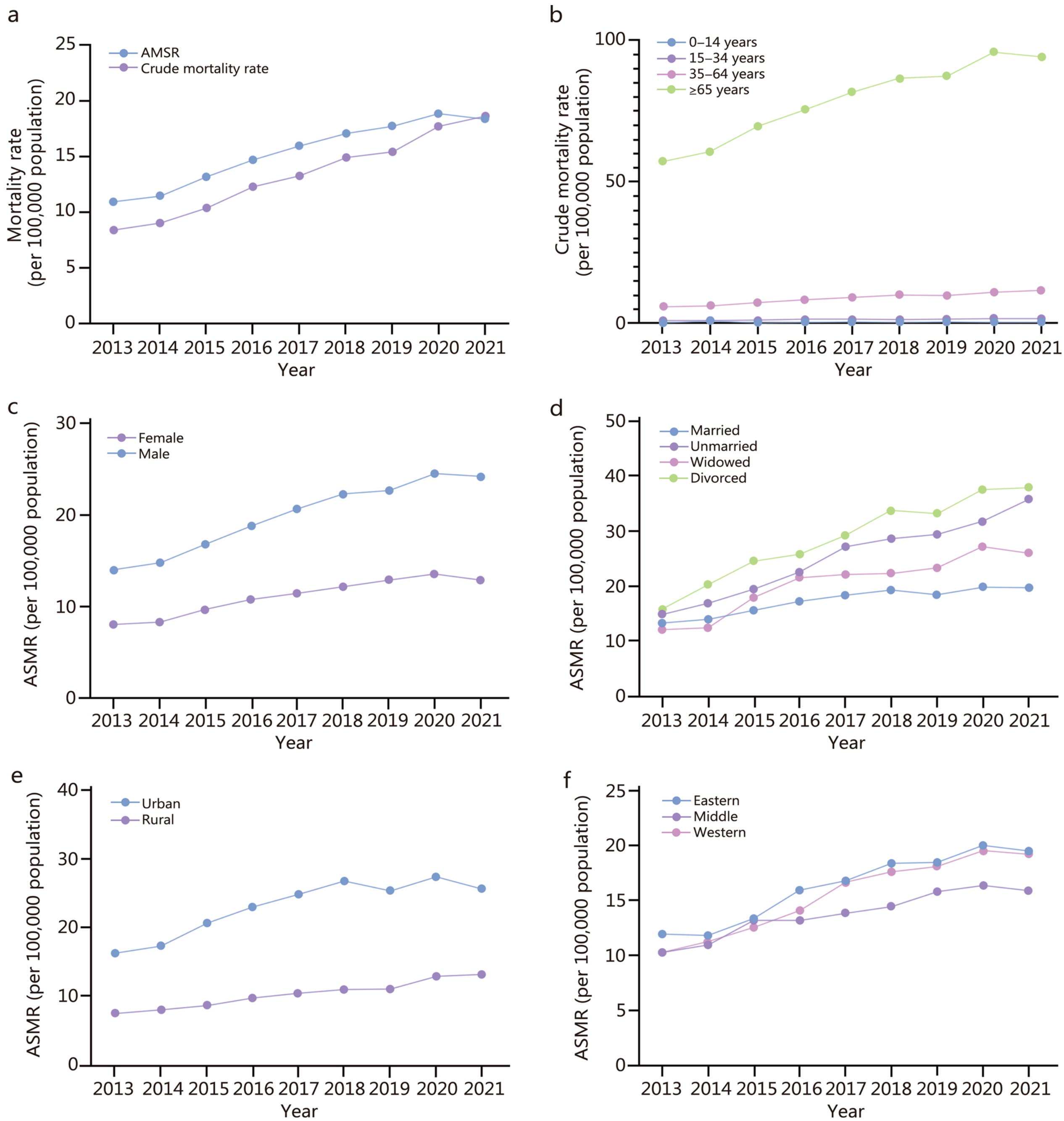

Fig. 1 SCD mortality per 100,000 population from 2013 to 2021. **a** Total mortality. **b** Mortality by age groups. **c** ASMR by gender. **d** ASMR by marital status (married-unmarried-widowed-divorced). **e** ASMR by location (urban–rural). **f** ASMR by region (Eastern-Middle-Western). SCD sudden cardiac death, ASMR age-standardized mortality rate

Table 1 National estimation of SCD-related deaths by year

Variables	2013	2014	2015	2016	2017	2018	2019	2020	2021
Numbers	114,320	124,334	143,272	170,615	185,815	208,885	217,018	249,606	262,635
Age (years, mean ± SD)	68.64 ± 17.50	68.94 ± 17.62	69.55 ± 17.32	70.12 ± 17.23	70.22 ± 17.23	70.86 ± 17.09	71.04 ± 17.05	71.56 ± 16.64	71.86 ± 16.64
Gender									
Male	71,053	77,701	88,208	104,058	114,842	128,842	133,857	153,055	161,853
Female	43,267	46,633	55,099	66,557	70,973	80,043	83,161	96,551	100,782
Location									
Urban	81,608	88,617	106,727	128,400	141,415	162,370	169,218	196,816	201,670
Rural	32,712	35,717	36,545	42,215	44,400	46,515	47,800	52,790	60,965
Region									
Eastern	55,194	57,290	66,946	81,954	88,993	102,235	101,672	119,735	122,942
Middle	32,799	35,931	44,386	46,694	49,397	53,627	58,663	64,739	69,333
Western	26,327	31,113	31,940	41,967	47,725	53,023	56,683	65,131	70,360

Region: Eastern includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan; Middle includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan; Western includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Xizang, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang. *SCD* sudden cardiac death

the study periods based on the COVID-19 pandemic, our results revealed a statistically significant upward trajectory in SCD incidence during the pre-COVID-19 period (AAPC = 8.71, 95% CI 7.73–10.08). However, this upward trend appeared to plateau during the COVID-19 period, as evidenced by the absence of significant temporal variation in SCD rates (AAPC = 2.51, 95% CI –3.44 to 5.70) (Additional file 1: Table S3).

SCD burden based on risk factors

During the study period, negative binomial regression results demonstrated that age, gender, location, and medical and health care resources contributed to the variance among SCDs below the province scale (Table 2). Overall, 4.58% of the variation in SCD mortality between provinces was explained by the fitted variables (Table 2: Model 5). The mortality rates associated with SCD increased with age, with the highest rates observed in the ≥ 65 years group. In 2021, the mortality rate at the age of ≥ 65 years was estimated to be 94.12 per 100,000 population, which was 8.07-times higher than that of the 35–64 years group (Fig. 1b). In these 4 age groups, the AAPC is estimated to be 6.80 (95% CI 4.99–8.64) in the ≥ 65 years group, 8.87 (95% CI 6.41–11.38) in the 35–64 years group, 7.73 (95% CI 6.21–9.27) in the 15–34 years group, and 0.63 (–6.48 to 8.29) in the 0–14 years group (Additional file 1: Table S4).

As shown in Fig. 1c, considerable gender differences were observed. Across the study period, ASMR was 1.73 to 1.88-times higher in males than in females ($Z = 57.53$, $P < 0.001$). Mortality rates steadily increased for both males and females (ASMR: 14.03 deaths per 100,000 population in 2013 to 24.49 deaths per 100,000 population in 2020 among males, and from 8.03 deaths per 100,000 population in 2013 to 13.57 deaths per 100,000 population in 2020 among females). This translates to an AAPC of 7.42 (95% CI 5.59–9.29) for males and 6.30 (95% CI 3.59–9.07) for females (Additional file 1: Table S4). A slight but non-significant decline was observed in 2021, with ASMR reduced to 24.19 deaths per 100,000 population in males and 12.89 deaths per 100,000 population in females.

ASMR varies across marital statuses. The ASMR was the highest among divorced individuals and the lowest among married individuals ($Z = 11.82$, $P < 0.001$). In 2021, ASMR was estimated to be 38.24 deaths per 100,000 population among divorced individuals compared with 19.62 deaths per 100,000 population among married individuals, 35.73 deaths per 100,000 population among unmarried individuals, and 25.93 deaths per 100,000 population among widowed individuals (Fig. 1d). Except for married individuals, all other marital status subgroups presented increasing trends, with the most significant increase among divorced individuals with an AAPC of 12.21 (95% CI 7.85–16.75), followed by unmarried individuals with an AAPC of 11.45 (95% CI 9.83–13.10) (Additional file 1: Table S4).

Compared with those in rural areas, ASMR in urban areas was 1.94 to 2.45-times higher from 2013 to 2021 ($Z = 79.04$, $P < 0.001$). ASMR in urban areas increased from 16.26 deaths per 100,000 population in 2013 to 25.50 deaths per 100,000 population in 2021 (Fig. 1e). This corresponded to an estimated AAPC of 6.45 (95% CI 3.80–9.16) (Additional file 1: Table S4). ASMR in rural areas has also increased but at a slightly slower pace, with an estimated AAPC of 7.39 (95% CI 6.37–8.41)

Table 2 Associated factors of sudden cardiac mortality from NMSS in China, 2013–2021: estimated from negative binomial regression

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Fixed effects					
Year	1.065 (1.060–1.071)*	1.069 (1.061–1.077)*	1.088 (1.074–1.103)*	1.089 (1.075–1.104)*	1.092 (1.073–1.111)*
Age (5 year group)	1.421 (1.416–1.426)*	1.421 (1.416–1.426)*	1.421 (1.416–1.426)*	1.421 (1.416–1.426)*	1.421 (1.416–1.426)*
Gender					
Female	1	1	1	1	1
Male	1.930 (1.877–1.985)*	1.931 (1.877–1.986)*	1.931 (1.878–1.986)*	1.931 (1.878–1.986)*	1.931 (1.877–1.986)*
Location					
Rural	1	1	1	1	1
Urban	1.900 (1.846–1.956)*	1.902 (1.847–1.957)*	1.903 (1.849–1.959)*	1.903 (1.849–1.959)*	1.904 (1.850–1.960)*
Region					
Eastern	1	1	1	1	1
Middle	1.002 (0.597–1.680)	0.965 (0.582–1.602)	0.947 (0.567–1.581)	0.945 (0.564–1.581)	0.886 (0.530–1.481)
Western	1.017 (0.639–1.619)	0.965 (0.610–1.527)	0.966 (0.607–1.538)	0.938 (0.586–1.500)	0.846 (0.523–1.371)
GDP per capita					
< 11,895		1	1	1	1
11,895–21,237.1		1.166 (1.084–1.255)*	1.173 (1.089–1.265)*	1.184 (1.097–1.276)*	1.186 (1.100–1.279)*
21,237.1–36,013.8		1.046 (0.940–1.165)	1.053 (0.942–1.176)	1.053 (0.943–1.177)	1.058 (0.946–1.183)
> 36,013.8		0.961 (0.838–1.102)	0.962 (0.835–1.109)	0.959 (0.832–1.106)	0.965 (0.836–1.115)
Number of doctors per 1000 population					
< 57			1	1	1
57–65			0.992 (0.939–1.048)	0.985 (0.932–1.041)	0.994 (0.939–1.051)
65–74			0.966 (0.898–1.039)	0.958 (0.890–1.031)	0.970 (0.899–1.046)
74			0.869 (0.793–0.952)*	0.865 (0.788–0.948)*	0.882 (0.801–0.971)*
Number of hospital beds per 1000 population					
< 48.88			1	1	1
48.88–55.92			0.981 (0.925–1.041)	0.977 (0.921–1.037)	0.983 (0.926–1.043)
55.92–64.08			0.980 (0.906–1.061)	0.980 (0.905–1.060)	0.988 (0.912–1.070)
> 64.08			0.952 (0.857–1.057)	0.948 (0.854–1.053)	0.957 (0.861–1.064)
Mean years of education					
< 8.76				1	1
8.76–9.20				0.926 (0.861–0.995)*	0.925(0.860–0.995)*
9.20–9.56				0.945 (0.868–1.029)	0.933 (0.855–1.018)
> 9.56				0.961 (0.867–1.066)	0.957 (0.862–1.062)
Sectoral employment distribution					
The proportion of employment in the primary sector					1.054 (0.040–27.704)
The proportion of employment in the secondary sector					0.637 (0.025–16.151)
The proportion of employment in the tertiary sector					0.689 (0.026–18.353)
Random effects					
Variance among provinces (SE)	0.320 (0.087)	0.307 (0.084)	0.313 (0.086)	0.316 (0.087)	0.306 (0.087)
MRR (provinces)	1.714	1.696	1.707	1.710	1.696
PCV (provinces) (%)	–	4.12	2.37	1.41	4.58

Data for fixed effects are presented in odds ratio and 95% confidence intervals. Region: Eastern includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan; Middle includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan; Western includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Xizang, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang. *$P < 0.05$. "–" indicates no data. *MRR* median rate ratio (an MRR of 1 suggests no geographic variation in the outcome variable, whereas MMR > 1 indicates significant influence of geographical variables on the outcome), *PCV* proportional change in variance

(Additional file 1: Table S4). The ASMR was estimated to be 7.54 deaths per 100,000 population in 2013 and 13.16 deaths per 100,000 population in 2021 (Fig. 1e).

Figure 1f shows the geographical differences among 3 regions in China. In general, the ASMR was significantly higher in the Eastern region than in the Western ($Z=5.50$, $P<0.001$) and Middle regions ($Z=16.31$, $P<0.001$). In 2021, the estimated mortality rates were 19.51 deaths per 100,000 population, 15.88 deaths per 100,000 population, and 19.22 deaths per 100,000 population in the Eastern, Middle, and Western regions, respectively. The Western region (AAPC = 8.53, 95% CI 6.57–10.52) showed the most rapid increase (Additional file 1: Table S4).

As shown in Fig. 2a, approximately half of SCD cases occurred at home, and the proportion remained stable between 2013 and 2021. The proportion of SCDs that occurred in hospitals was between 35.00% and 39.00% across the 9 year study period. In terms of the basic causes of death associated with SCDs, ischemic heart disease, other CVDs, and hypertension were the top 3 causes, accounting for 56.74%, 22.32%, and 9.12% of SCD cases, respectively, in 2021 (Fig. 2b).

Prevention practices of SCD

The current status of the trends, outcomes of sudden cardiac arrest, and important SCD prevention measures in China and developed countries are summarized in Additional file 1: Table S5. There are 4 important measures for preventing SCD, including ICDs, AEDs, CPR, and training. According to the previous surveys, the number of ICD implantations, AEDs, and use of CPR have become increasingly available, while their utilization rates and related training programs still require significant improvement [10, 17, 18, 26–31] (Additional file 1: Table S5). The training on CPR and basic life support in China currently also requires improvement [5, 29, 32, 33], and with a need for more high-standard training, as well as co-construction efforts. In China, it is necessary to further improve relevant measures to enhance public accessibility, strengthen related training, and continuously promote localization in line with national conditions.

Discussion

This is a study to provide epidemiological data on SCD in China at the national level using data from the NMSS, an enhanced integrated disease surveillance and vital registration system. In this study, we found a steady increase in SCD mortality rates from 2013 to 2020 and a modest non-significant decrease in 2021. Substantial geographical disparities were observed, with mortality rates in 2021 ranging from 15.88 deaths per 100,000 population to 19.51 deaths per 100,000 population across regions and Western region showed the most rapid increase. Moreover, SCD mortality rates increased with age and were higher among males, urban residents, those who died of ischemic heart disease, and those who experienced sudden cardiac arrest outside of a hospital setting. We also found low utilization of SCD prevention, which may partly explain why SCD has not declined in China. Our study highlights the burden of disease in patients with SCD and provides evidence for the government to develop appropriate preventive policies.

Despite a growing awareness and advancements in sudden cardiac arrest prevention and treatment [10, 34], the number of SCDs has continued to rise in China over

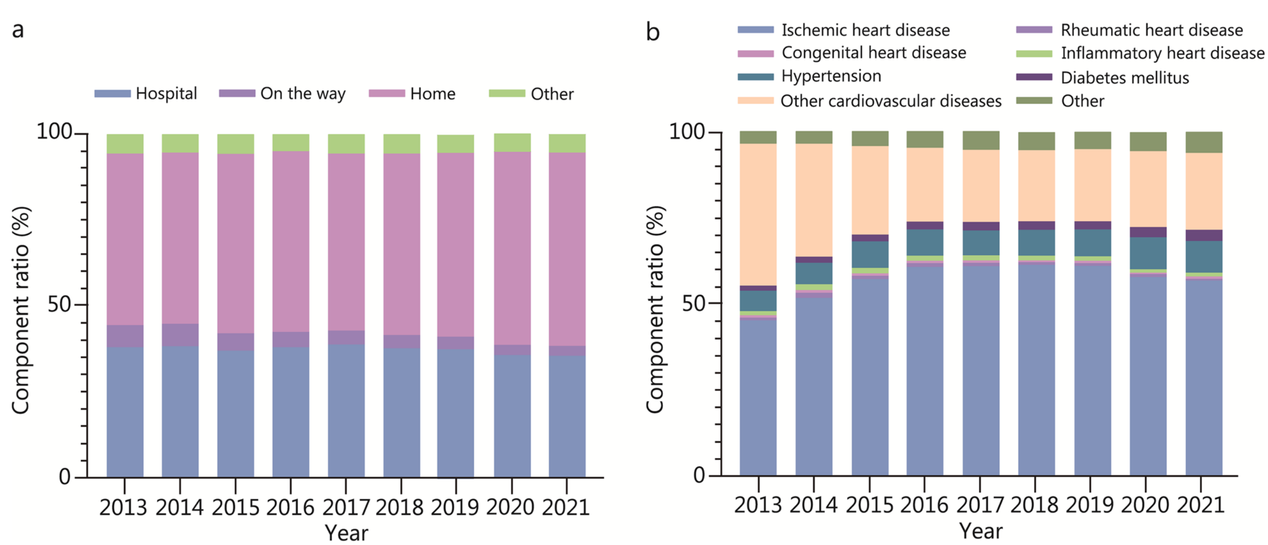

Fig. 2 Proportion of SCD mortality from 2013 to 2021 by (**a**) place of death and (**b**) basic cause of death. SCD sudden cardiac death

the past decade. For Europeans, no significant variability in the yearly incidence rates of SCD was observed [35]. Although the increase in China is partly due to improved diagnostic capabilities, this is more likely due to the continuous increase in CVD burden and the changes in risk factors and the disease spectrum in the country [36]. In the past decade, CVD has become the first major cause of death in China [37]. In 2019, CVD accounted for 46.74% and 44.26% of all deaths in rural and urban areas, respectively [38]. Despite a moderate reduction, the prevalence of smoking in China remains high [39], whereas the prevalence of obesity and hypertension is increasing [40]. Without effective strategies to prevent and manage CVDs and their associated risk factors, a high SCD mortality rate will likely persist. Our study revealed a minor decline in SCD mortality rates in 2021. It is unclear whether this is driven by an actual downward trend or is a result of data anomalies stemming from COVID-19 [41–43]. This is because standard medical coding practices were disrupted early in the pandemic, resulting in gaps in cause-of-death data [44].

At the individual level, SCD mortality rates differ based on sociodemographic characteristics, including age, gender, and marital status. Elderly individuals and males are prone to SCD at a relatively high rate, which can be attributed to their severe risk factors. With respect to marital status, the lowest mortality rates were observed among married individuals. This finding aligns with those of previous studies, suggesting that marriage potentially enhances financial and psychological stability [45] and serves as a protective factor against mortality [46]. In contrast, divorced and unmarried individuals tended to live alone and were more prone to isolation and poorer health outcomes [47, 48]. It is essential to expand social services to address the unmet needs of this susceptible population to provide more timely emergency care for the elderly and singles.

At the area level, significant regional disparities in SCD mortality rates reveal underlying differences in epidemiological profiles and socioeconomic development. Driven by variability in CVD incidence and associated risk factors [49], ASMR is different in regions with higher in Eastern region. Moreover, we observed a higher incidence of SCD in urban areas, which may be attributed to the generally elevated levels of air pollution, unfavorable temperatures, and roadway proximity in these regions [50–52]. Additionally, people living in urban areas are more likely to experience psychological stress [53], which could also contribute to elevated SCD risk, particularly sudden unexplained cardiac death [54, 55]. Although the incidence rates are higher in these developed regions, it must be acknowledged that their public prevention measures are better equipped. For example, Shanghai and Zhejiang are among the areas with the highest per capita ICD implementation [10].

The majority of SCD cases occur outside of hospital settings, and the survival rate of out-of-hospital cardiac arrest in China is low, remaining at approximately 2% [15–17, 56, 57]. Several contributing factors, including insufficient primary prevention, poor public knowledge, and awareness of proper responses during sudden cardiac events and capacity constraints in existing pre-hospital emergency systems, have been reported [14, 58]. Our research results also indicated that the accessibility of medical resources is an important factor affecting SCD (Table 2). Notably, ischemic heart disease, the leading cause of SCD, is currently effectively managed in clinical practice. Owing to the increased utilization of reperfusion therapies such as percutaneous coronary intervention and coronary artery bypass grafting, acute myocardial infarction patients exhibited favorable outcomes [59, 60]. In addition, for other high-risk SCD patients with comorbid CVDs, valve surgeries play an essential role in preventing SCD by restoring normal valve function and improving cardiac hemodynamics. In China, although the application of these surgeries has increased, the prevention and treatment of SCD after revascularization remain relatively inadequate at present. ICDs have become important procedures for both primary and secondary prevention of SCD. However, despite their proven efficacy [61, 62], ICD utilization remains suboptimal worldwide. In China, the implantation rates of ICD are substantially low [26, 63]. Even in the United States, underutilization persists among high-risk populations. However, although ICD therapy is critical for prevention, it can only address a small proportion of SCD cases.

In fact, the majority of SCD events occur in the general population—predominantly among individuals without prior clinical diagnosis of cardiac disease. This underscores the importance of public health initiatives to make AEDs more accessible. AEDs education and availability have greatly changed our approach to reviving out-of-hospital cardiac arrest patients regardless of their pre-existing health status and currently form the cornerstone of CPR and advanced life support protocols [19]. Regrettably, the coverage of AEDs is generally low in some areas in China, and the placement of AEDs lacks strategic planning [27, 29, 64, 65]. Although progress has been made in recent years in some provinces, such as Hangzhou, Shanghai, Shenzhen, and Haikou, the implementation of SCD prevention policies remains in the early phases and is not optimal in other regions of China [27, 66]. In 2016, the 525+ project was launched to promote CPR training and awareness. Since its inception, 177 training centers have been established, showing notable progress.

However, uncertainty remains regarding the validation of training, indicating a need for further efforts in emergency education and practice [29, 31]. To improve the survival rate and reduce SCD, multisectoral reform is needed to improve pre- and post-hospital service connections, bystander laws, bystander training, and public knowledge [32, 33].

In addition to public health and policy interventions, cardiac arrest and SCD registries have been shown to be crucial in improving population-level outcomes. By providing timely data for epidemiological analysis, sudden cardiac arrest registries highlight gaps in care linkages among hospital, forensic and ambulance services. In China, the establishment of sudden cardiac arrest registries remains at the naissance stage. Efforts in nationwide data collection have recently started. Two registration systems, Baseline Investigation of In-hospital Cardiac Arrest (BASIC-IHCA) [67] and BASIC-OHCA [66], have been established to capture in-hospital cardiac arrest and out-of-hospital cardiac arrest, respectively. As the coverage of registries continues to expand, they will provide invaluable and confident insights for monitoring SCD burden and serve as a source of cross-validation for existing national disease and mortality surveillance programs.

To our knowledge, this was a study to demonstrate the temporal trends and risk factors of SCD in China at the national level. One strength was that our data were derived from the NMSS, which was designed to achieve national representativeness. Moreover, we also performed stratified analyses to elucidate SCD. This study also has several limitations. First, accurate ascertainment of causes of death is challenging, as a previous study suggested that SCD inferred from death certificates is prone to overestimation [13]. In particular, a large proportion of cardiac arrests were reported outside of hospitals, making it difficult to verify the actual cause of death and introducing potential errors. Second, we did not distinguish between the actual cause of death and the mechanism of death. Cardiac arrest is a common mechanism of death, but may not be the primary cause [67]. In the absence of a complete medical history or autopsies, confirming actual causes is impossible. Third, owing to the lack of relevant data at the individual level, it was not possible to perform an analysis to quantify the effects of disease-specific risk factors such as obesity, dyslipidemia, COVID-19, and pre-hospital emergency care. Although the results of AAPC stratified based on pre-COVID-19 periods and COVID-19 periods revealed differences in SCD incidence trends, causal attribution remains inconclusive. Future longitudinal studies with robust designs are essential to clarify the relationship between the COVID-19 pandemic and SCD. Fourth, data related to SCD prevention and control measures are lacking, so we are unable to estimate the utilization rate at the national level. Future studies should systematically document SCD onsets and emergency response data to strengthen prevention efforts. Nevertheless, we contend that our current estimates, despite the inherent constraints, address the important data gaps in the literature by offering insights into geographical and temporal trends of SCD.

Conclusions

In conclusion, SCD is a major public health threat in China. There is an urgent need to intensify existing interventions, including strengthening public knowledge and awareness of emergency response and expanding AEDs placement, CPR and basic life support training. To improve progress in the treatment of cardiac arrest and increase the survival rate, efforts should be made at the national level. It is also essential to strengthen the implementation of public emergency measures such as AEDs and provide training for the public.

Abbreviations

AAPC	Average annual percentage change
AEDs	Automated external defibrillators
BASIC-OHCA	Baseline investigation of out-of-hospital cardiac arrest
CIs	Confidence intervals
CPR	Cardiopulmonary resuscitation
ICDs	Implantable cardioverter defibrillators
ICD-10	International classification of diseases, 10th revision
NMSS	National mortality surveillance system
OR	Odds ratio
SCD	Sudden cardiac death
ASMR	Age-standardized mortality rate

Supplementary Information

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Additional file 1. Materials and methods. Table S1 Standard certificate of death in China_English edition. **Table S2** Codes used for screening in International Statistical Classification of Diseases and Related Health Problems 10th Revision ICD-10)-2015-World Health Organization version. **Table S3** Average annual percent change (AAPC) of sudden cardiac mortality by periods in China. **Table S4** Average annual percent change (AAPC) of sudden cardiac mortality stratified by sociodemographic factors in China. **Table S5** Comparison of current status of trends, outcomes, and prevention practices for sudden cardiac arrest. **Fig. S1** Flowchart for screening population for sudden cardiac death in China from 2013 to 2021

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Author contributions

YY and JFW analyzed the data. YY and JW drafted the manuscript. HSA, MGZ, MN, and YL designed this work and revised the manuscript. JML, XJL, YCG, SW, and YD contributed to data collection. All authors contributed to the development of the manuscript and approved the final draft. HSA, MGZ, MN, and YL took responsibility for the integrity of the data and the accuracy of the data analysis. All gave final approval and agreed to be accountable for all aspects of work ensuring integrity and accuracy.

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Data availability
Data cannot be made available a priori for institutional policy but can be provided upon reasonable request.

Declarations

Ethics approval and consent to participate
The study was centrally approved by the ethics committee of Fuwai Hospital (2023–2100).

Consent for publication
Not applicable.

Competing interests
All authors declare no disclosure of interest for this contribution.

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