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Epidemiology

Epidemiological Characteristics and Meteorological Factors of Sudden Death among General Population of Ethnic Chinese in Taiwan: An Eighteen-Year Follow-Up Report in a Community

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Background: The epidemiological characteristics of sudden death may vary according to ethnicity and country. This study aimed to analyze the distribution of sudden deaths in Taiwan, as well as their epidemiological characteristics and the associated meteorological factors.

Methods: The Chin-Shan Community Cardiovascular Cohort is a longitudinal study conducted in a community in Taipei County since July 1990. A total of 3,602 individuals aged 35 years and older were included in the study. Sudden deaths were prospectively recorded and analyzed.

Results: Eighty-two (68.3% men) sudden deaths (8.56% of all deaths) were reported from July 1990 to December 2008, of which 87.8% were caused by cardiovascular disease. However, only 36.6% were attributed to coronary artery disease. There was a higher incidence of sudden death in the winter [incidence rate ratio (IRR): 1.91, 95% confidence interval (CI): 1.42-2.56], compared to fall, and the highest peak of sudden death occurred between 16:00-20:00 (IRR: 3.00, 95% CI: 1.72-5.22) compared to 00:00-04:00 as the reference group. Additionally, a relatively higher mean temperature was associated with a lower risk of sudden death (IRR: 0.96, 95% CI: 0.93-0.98). On the other hand, higher humidity (IRR: 1.09, 95% CI: 1.02-1.16) and discomfort index (IRR: 1.03, 95% CI: 1.003-1.05) were associated with increased risks of sudden death.

Conclusions: Meteorological factors and circadian patterns were associated with sudden death among our Taiwanese cohort. Our study findings may support potential protective behavior for sudden death via weather forecasting.

Key Words: Cardiovascular risk • Epidemiology • Sudden death

INTRODUCTION

Although modern medicine has made tremendous advances, sudden death remains one of the greatest

Abbreviations	
CAD	Coronary artery disease
CCCC	Chin-Shan Community Cardiovascular Cohort
CI	Confidence interval
IQR	Interquartile range
IRR	Incidence rate ratio
N	Numbers
SCD	Sudden cardiac death
WHO	World Health Organization

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challenges for physicians around the world. It is estimated that approximately 50% of cardiac deaths occur suddenly, despite the fact that cardiovascular deaths have significantly declined during the last 30 years.[1-5] In the United States, sudden deaths are estimated to occur almost once every minute, and over 350,000 people die every year outside the hospital.[6] Moreover, for adults under 65 years of age, it is the leading cause of death.[7] In industrialized countries, the World Health Organization (WHO) also estimates that 25-30% of people suffer sudden death after having a heart attack.[2] The high incidence, unpredictability, low resuscitation rate, and consequent adverse familial and socioeconomic effects mean that sudden death has been an important issue in public health and preventive medicine for years.

In addition, several large-scale epidemiological studies regarding sudden death have been conducted.[7,8] Most previous studies have been conducted in Western industrialized countries.[2,9-11] Other studies have demonstrated a connection between sudden cardiac death (SCD) and environmental factors such as meteorological factors, seasonal variations, and diurnal differences.[12-14] These factors may also lead to a non-uniform distribution of SCD between different regions and races.[4,15,16] Nevertheless, only limited research has been conducted on the epidemiological characteristics of sudden death among the Chinese population. In this study, we investigated the incidence, causes, and associated meteorological factors that may be linked to sudden death in a Taiwanese population.

METHODS

Study design and participants

Chin-Shan is a rural area of metropolitan Taipei in northern Taiwan, and the Chin-Shan Community Cardiovascular Cohort (CCCC) Study has been conducted since July 1990. The study design and baseline epidemiological data have been described in our previous reports.[17-19] The community includes 3,602 residents (1,703 men and 1,899 women, aged 35 years or older), which represents 82.8% of the target population. In addition to initial evaluations and measurements of relevant parameters at baseline, the participants are prospectively followed for cardiovascular events and all-cause mortality with regular biennial follow-up visits. In total, 82 participants with sudden death were analyzed in this study. This study was approved by the Institutional Review Board (IRB Number: 2011003001R) of National Taiwan University Hospital in accordance with the Good Clinical Practice Guidelines. Oral and written informed consent was obtained from all participating adults.

Baseline measurements

The baseline data upon inclusion of the participants were analyzed in this study, including cardiovascular risk factors, biochemical data, and 12-lead electrocardiograms. Hypertension was defined as blood pressure greater than 140/90 mmHg or in patients receiving medical treatment for high blood pressure. The diagnosis of diabetes mellitus was based on a fasting blood glucose reading of more than 125 mg/dL or being treated for hyperglycemia. We assessed the quantity, duration, and persistence of smoking until the inclusion date. Family history of coronary artery disease (CAD) was recorded as positive if the first relative had a coronary event or was diagnosed with CAD before the age of 55 for males or before the age of 65 for females. We examined historical records of temperature and humidity at a city level in Chin-Shan District for the period from 1981-2010. The discomfort index as heat stress was calculated as:[20]

$$(0.81 * \text{Temperature}) + (0.01 * \text{Humidity}) * (0.99 * \text{Temperature} - 14.3) + 46.3$$

(Unit: temperature in °C and relative humidity in %).

Outcome measurements

All deaths were prospectively registered with their causes. Based on the death certificates from the authorities, the causes of death were verified through interviews with families, bystanders, or doctors involved regarding the manner and onset of death. Within 1 month after the event, an expert local assistant conducted the interviews, which were then reviewed and coded independently by three investigating doctors from the study committee.

This study defined sudden death in accordance with the criteria of the WHO, as unexpected death that occurred within 1 hour of symptom onset (witnessed) or within 24 hours of having been observed alive and symptom-free (unwitnessed).[21] Deaths resulting from chronic or malignant diseases or from intoxication were excluded. For the cases of aborted sudden deaths, the data were retrieved and identified from the cardiovascular events documented at each follow-up visit. After identification of the cases, the epidemiological characteristics of these deaths were analyzed. These included the sex and age of the patients, the location of the sudden death, and the distribution of sudden deaths over the year. Through examinations of death certificates, medical records, and interviews with bystanders and family members, our investigators identified the causes of the sudden deaths.

Statistical analysis

Normally distributed continuous variables were presented as mean ± standard deviation. Non-normally distributed continuous variables were reported as median and interquartile range (IQR). Categorical values were expressed as absolute numbers (N) with percentages (%). The incidence rates of sudden death were calculated by dividing the number of cases by the number of person-years of follow-up. Histograms of the trend analysis were generated for the circadian and seasonal patterns.

The incidence rate ratios (IRRs) were calculated using Poisson regression models. The numbers of sudden deaths were summarized by time, season, and age groups (baseline age: 35-54, 55-64, ≥ 65 years), and sex. Risk factors associated with time, season, and meteorology were analyzed using Poisson regression models to determine the age- and sex-adjusted IRRs for evaluating the risk of sudden death under the weight of log (person-years) as the offset variable. Statistics were conducted with two-tailed tests, and probabilities with probability values of < 0.05 were considered statistically significant. SAS version 9.4 (SAS Institute, Cary, NC) was used for the analysis.

RESULTS

Epidemiological characteristics of sudden death

During a median follow-up period of 15.9 years (IQR: 13.1-16.9 years) from July 1990 to December 2008, 3,602 participants were studied. The baseline characteristics of the study population are summarized in Table 1. Eighty-two of these cases (68.3% men and 31.7% wo-

Table 1. Baseline characteristics of victims of sudden death in the Chin-Shan Community Cardiovascular Cohort study

Characteristics	Total (N = 3602)	Non-sudden death (N = 3520)	Victims of sudden death (N = 82)	p value
Baseline age, years	54.9 ± 12.3	54.7 ± 12.2	65.0 ± 10.8	< 0.001
35-44	907 (25.7%)	903 (25.7%)	4 (4.94%)	< 0.001
45-54	904 (25.3%)	892 (25.3%)	11 (13.4%)	
55-64	938 (26.0%)	916 (26.0%)	22 (26.8%)	
65-74	605 (16.8%)	572 (16.3%)	33 (40.2%)	
≥ 75	247 (6.86%)	235 (6.68%)	12 (14.6%)	
Men	1702 (47.3%)	1646 (46.8%)	56 (68.3%)	< 0.001
Body mass index, kg/m^2	23.5 ± 3.43	23.5 ± 3.43	23.3 ± 3.39	0.58
Coronary artery disease	86 (2.39%)	58 (1.65%)	28 (34.1%)	< 0.001
Hypertension	1072 (30.0%)	1030 (29.5%)	42 (51.2%)	< 0.001
Diabetes mellitus	473 (13.3%)	465 (13.4%)	8 (9.88%)	0.36
Stroke	155 (4.30%)	151 (4.29%)	4 (4.88%)	0.78
Heart failure (ejection fraction < 40%)	47 (1.30%)	42 (1.19%)	5 (6.10%)	0.001
Chronic kidney disease	392 (10.9%)	373 (10.6%)	19 (23.2%)	0.001
Smoking history	1311 (36.4%)	1264 (35.9%)	47 (57.3%)	< 0.001
Drinking history	1077 (29.9%)	1048 (29.8%)	29 (35.4%)	0.27
Electrocardiogram				
Left ventricular hypertrophy	283 (7.86%)	263 (7.47%)	20 (24.4%)	< 0.001
Right ventricular hypertrophy	12 (0.33%)	10 (0.28%)	2 (2.44%)	0.029
Bi-lateral ventricular hypertrophy	10 (0.28%)	9 (0.26%)	1 (1.22%)	0.21
Atrial fibrillation	38 (1.05%)	37 (1.05%)	1 (1.22%)	0.59
WPW syndrome	4 (0.11%)	4 (0.11%)	0 (0.00%)	> 0.99
Low voltage QRS	27 (0.75%)	25 (0.71%)	2 (2.44%)	0.13

N, number; WPW, Wolff-Parkinson-White syndrome.

men) met the criteria for sudden death (accounting for 8.56% of all deaths). The incidence rates of sudden death by sex and age subgroups are presented in Table 2, and the specific causes and incidence rates of sudden death are summarized in Table 3. The age standardized incidence rate was 117 [95% confidence interval (CI): 81-152] per 100,000 person-years [163 (95% CI: 119-207) for men and 71 (95% CI: 44-97) for women; Table 2]. The overall incidence rate of sudden death in our Taiwanese cohort was 161 per 100,000 person-years (95% CI: 126-364; Table 3). In total, 87.8% of the sudden deaths were attributable to cardiovascular causes (141 per 100,000 person-years, 95% CI: 109-323), including 73.2% caused by SCD (118 per 100,000 person-years, 95% CI: 88-273), and 36.6% caused by CAD, accounting for 50% of SCD (59 per 100,000 person-years, 95% CI: 38-145). Vascular causes accounted for 14.6% of sudden deaths (24 per 100,000 person-years, 95% CI: 10-65, including 13.4% caused by stroke and intracerebral hemorrhage, and 1.21% caused by ruptured abdominal aortic aneurysms), and 2.43% of sudden deaths involved chronic obstructive pulmonary diseases as the cause of death (4 per 100,000 person-years, 95% CI: 0-15). Despite careful evaluation of the medical history and extensive witness interviews, the cause of sudden death could still not be clearly identified in 8 (9.76%) cases.

Supplementary Table 1 summarizes the locations of sudden death, with the most common being at home or in a nursing home (72 cases, 78.8%). Eight cases of sudden death occurred in public places (9.76%), and two

Table 2. Incidence rate for sudden death per 100,000 person-years by sex and age in the Chin-Shan Community Cardiovascular Cohort study in Taiwan (total number of sudden deaths: N = 82)

Baseline age (years)	Men				Women			
	Total numbers	Cases (N)	Person-years	Incidence rate: Per 100,000 person-years (95% CI)	Total numbers	Cases (N)	Person-years	Incidence rate: Per 100,000 person-years (95% CI)
35-44	388	3	5921	51 (0-108)	520	1	8208	12 (0-36)
45-54	402	7	6016	116 (30-203)	509	4	7964	50 (0-80)
55-64	480	16	6656	240 (123-358)	454	6	6750	89 (18-160)
65-74	320	21	3514	598 (342-853)	294	12	3755	320 (139-501)
≥ 75	113	8	937	854 (262-1446)	122	4	1162	344 (7-681)

CI, confidence interval; N, number.

Table 3. Causes of sudden death

Causes	Number (%)	Incidence rate: Per 100,000 person-years (95% CI)
Total	82 (100%)	161 (126-364)
Cardiovascular disease	72 (87.8%)	141 (109-323)
Heart disease (sudden cardiac death)	60 (73.2%)	118 (88-273)
Coronary artery disease	30 (36.6%)	59 (38-145)
Congestive heart failure	11 (13.4%)	22 (9-60)
Valvular heart disease	2 (2.43%)	4 (0-15)
Arrhythmia	1 (1.21%)	2 (0-9)
Hypertensive heart disease or other heart disease	16 (19.5%)	31 (16-83)
Vascular disease	12 (14.6%)	24 (10-65)
Stroke or intracerebral hemorrhage	11 (13.4%)	22 (9-60)
Abdominal aortic aneurysm rupture	1 (1.21%)	2 (0-9)
Non-cardiovascular disease	2 (2.43%)	4 (0-15)
Lung disorders	2 (2.43%)	4 (0-15)
Others or unknow	8 (9.76%)	16 (5-46)

CI, confidence interval.

cases occurred in a clinic (2.44%, after daily activities). Additional information is provided in the Supplementary Material.

Temporal and seasonal distributions of sudden death

The temporal and seasonal distributions of sudden deaths are shown in Figures 1 and 2. Compared with the fall (September-November) as a reference group, more cases of sudden death occurred during winter (December-February; IRR: 1.91, 95% CI: 1.42-2.56; p < 0.001), followed by spring (March-May; IRR: 1.49, 95% CI: 0.93-2.38; p = 0.10), and summer (June-August; IRR: 1.31,

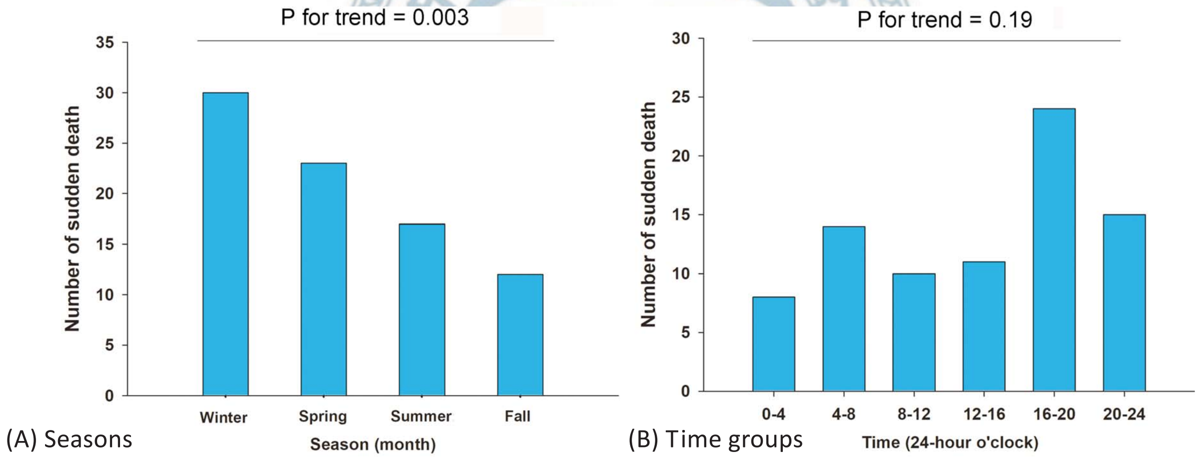

Figure 1. *Distributions of the sudden death cases in the study participants, according to the (A) seasons and (B) time groups (24-hour distribution).*

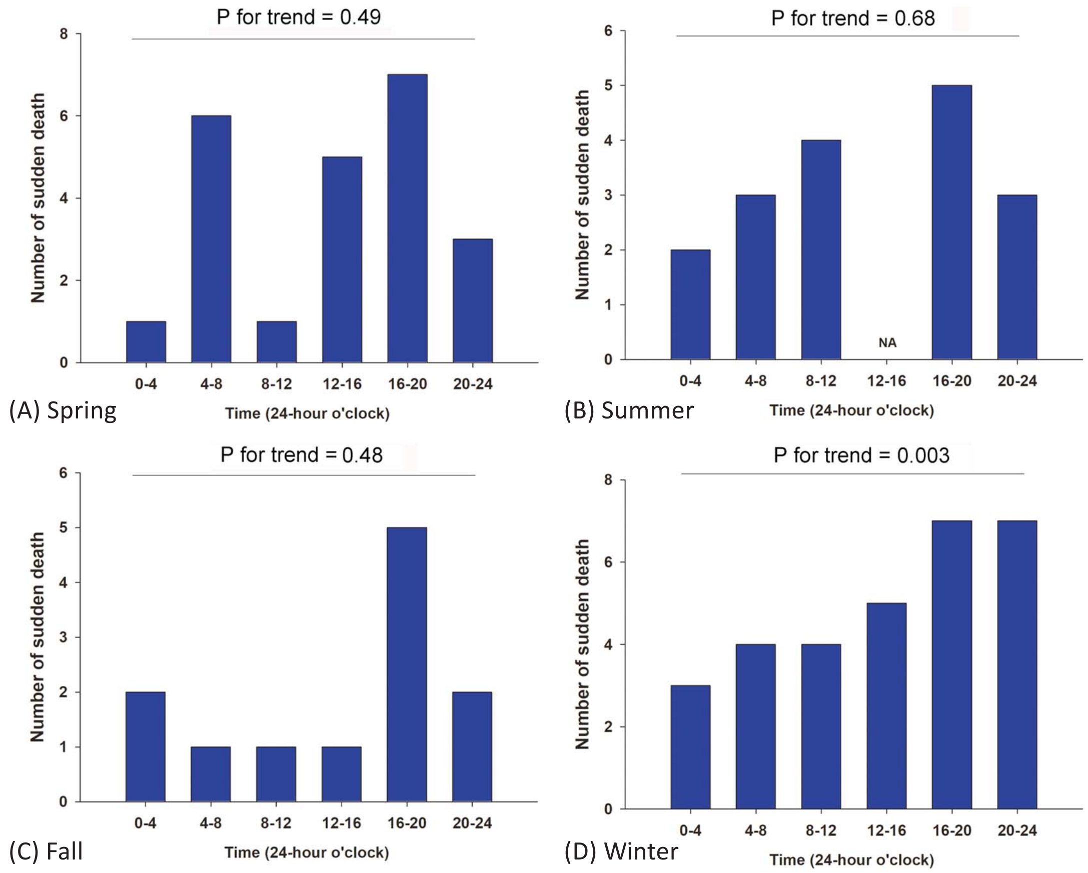

Figure 2. *Distributions of the sudden death cases in the study participants, according to 24-hour o'clock in various seasons. NA, not available.*

95% CI: 0.93-1.83; p = 0.12) (Table 4; Figure 1A: p for trend = 0.003). With regards to time, sudden deaths peaked between 16:00-20:00 (IRR: 3.00, 95% CI: 1.72-5.22) compared to 00:00-04:00 as the reference group (Table 4; Figure 1B: p for trend: 0.19). Figure 2 illustrates the distribution of sudden deaths within 24 hours in various seasons. The highest rates of sudden death were still recorded between 16:00-20:00 from spring to winter (Figure 2 and Table 4; IRR: 7.00 in spring, IRR: 2.50 in summer, IRR: 2.50 in fall, and IRR: 3.00 in winter, for between 16:00-20:00). A significant trend of increased sudden deaths was observed from 00:00-24:00 (Figure 2D: p for trend = 0.003; Table 4) for winter.

The correlation between meteorological factors and sudden death

Table 5 summarizes the distribution of meteorological factors according to seasons. To assess the associations between sudden deaths and meteorological factors, we used Poisson regression models (Table 5) to compare the total number of sudden deaths over a period. A relatively higher mean temperature was associated with a lower risk of sudden death (IRR: 0.96, 95% CI: 0.93-0.98). Furthermore, increases in relative humidity (IRR: 1.09, 95% CI: 1.02-1.16) and discomfort index (IRR: 1.03, 95% CI: 1.003-1.05) were associated with increased risks of sudden death. In analysis of the risk of sudden deaths separately in summer and fall, greater discomfort index was associated with more sudden deaths in both seasons (IRR: 1.04, 95% CI: 1.039-1.042 for summer and IRR: 1.03, 95% CI: 1.01-1.04 for fall).

DISCUSSION

Main findings

In this study, we evaluated the causes and incidence of sudden deaths in a community in Taiwan. In most cases, death occurred at home, away from immediate medical assistance. Deaths were more frequent in winter, with the most deaths occurring during the late afternoon and evening. In addition, we found that cold wea-

Table 4. Poisson regression model for assessing the sudden death risks by seasons and time groups

Time groups	Overall		Winter		Spring		Summer		Fall	
	IRR (95% CI)	p value	IRR (95% CI)	p value	IRR (95% CI)	p value	IRR (95% CI)	p value	IRR (95% CI)	p value
Overall	na	na	1.91 (1.42-2.56)	< 0.001	1.49 (0.93-2.38)	0.10	1.31 (0.93-1.83)	0.12	1: Reference	na
0-4	1: Reference	na	1: Reference	na	1: Reference	na	1: Reference	na	1: Reference	na
4-8	1.75 (0.79-3.86)	0.17	1.33 (0.39-4.53)	0.65	6.00 (0.95-38.1)	0.057	1.50 (0.44-5.09)	0.52	0.50 (0.08-2.99)	0.45
8-12	1.25 (0.51-3.07)	0.63	1.33 (0.33-5.43)	0.69	1.00 (0.10-9.61)	> 0.99	2.00 (0.53-7.54)	0.31	0.50 (0.08-2.99)	0.45
12-16	1.38 (0.60-3.16)	0.45	1.67 (0.48-5.84)	0.42	5.00 (0.98-25.6)	0.053	na	na	0.50 (0.08-2.99)	0.45
16-20	3.00 (1.72-5.22)	< 0.001	2.33 (1.001-6.03)	0.046	7.00 (1.39-35.3)	0.018	2.50 (1.06-5.92)	0.037	2.50 (1.06-5.92)	0.037
20-24	1.88 (0.91-3.87)	0.09	2.33 (0.77-7.04)	0.13	3.00 (0.47-19.0)	0.24	1.50 (0.44-5.09)	0.52	1.00 (0.32-3.10)	> 0.99

IRRs were adjusted by age groups (baseline age: 35-54, 55-64, ≥ 65 years) and gender.
CI, confidence interval; IRR, incidence rate ratio; na, not available.

Table 5. Poisson regression model for assessing the sudden death risks of meteorological factors

Seasons	Mean temperature (°C)		Relative humidity (%)		Discomfort index	
	Mean ± Std	IRR (95% CI); p value	Mean ± Std	IRR (95% CI); p value	Mean ± Std	IRR (95% CI); p value
Overall	22.6 ± 5.08	0.96 (0.93-0.98); p = 0.002	77.8 ± 2.25	1.09 (1.02-1.16); p = 0.016	70.4 ± 7.80	1.03 (1.003-1.05); p = 0.029
Spring	21.2 ± 3.51	1.01 (0.97-1.06); p = 0.53	79.4 ± 1.42	0.98 (0.88-1.09); p = 0.67	68.7 ± 4.51	0.99 (0.96-1.01); p = 0.33
Summer	28.8 ± 0.76	0.98 (0.66-1.44); p = 0.90	75.4 ± 2.07	1.02 (0.89-1.18); p = 0.78	80.5 ± 0.74	1.04 (1.039-1.042); p < 0.001
Fall	23.8 ± 2.75	1.04 (0.98-1.11); p = 0.20	77.3 ± 0.17	1.00 (0.32-3.17); p > 0.99	73.6 ± 3.95	1.03 (1.01-1.04); p < 0.001
Winter	16.5 ± 1.32	1.00 (1.00-1.00); p = 0.44	79.3 ± 2.33	1.00 (1.00-1.00); p = 0.14	61.1 ± 1.73	1.00 (1.00-1.00); p = 0.41

Discomfort index = (0.81 * Temperature) + (0.01 * Humidity) * (0.99 * Temperature – 14.3) + 46.3.
IRRs were adjusted by age groups (baseline age: 35-54, 55-64, ≥ 65 years) and gender.
CI, confidence interval; IRR, incidence rate ratio; na, not available; Std, standard deviation.

ther (lower temperatures), higher relative humidity, and higher discomfort index were associated with a higher risk of sudden death. In Taiwan, the discomfort index as a measure of heat pressure has been associated with increased incidences of sudden death, especially in summer and fall (warm weather in Taiwan).

Incidence and causes of sudden death

Chin-Shan District is a rural area on the coast in northern New Taipei City, Taiwan. Chin-Shan District has been a leisure destination since the 1980s, and it has moved towards non-agricultural aspects since the 1990s. In this study, the incidence of sudden death was generally in line with previous studies, and possibly higher than reports from the neighboring country of Japan.[22-24] In comparison with Western countries such as the United States, Finland, and Denmark, where ischemic heart disease is more prevalent, the incidence in our study population was considerably lower.[25-27] Nevertheless, the incidence rate of sudden death in our study is still higher than that of many European countries, including England, Iceland, and the Netherlands.[7]

Identifying the causes of sudden death in adults is important for risk assessment. SCD is the most common cause of sudden death. Around 70-80% of sudden deaths are caused by SCD, while 80-90% are caused by cardiovascular causes in Western countries.[3,4,28-30] These findings are consistent with our results, and we found that 73.2% of all sudden deaths were caused by SCD, while 87.8% were due to cardiovascular causes. Furthermore, several studies have linked sudden death to CAD, either from clinical observations or postmortem pathological evidence.[10] The leading cause of SCD has been identified as CAD, which is responsible for 70-80% of SCD cases in Western countries.[2,11] Nonetheless, only 36.6% of the patients in the CCCC study were diagnosed with CAD as the primary cause of sudden death. Most often, patients with CAD may suffer from devastating ventricular arrhythmia as a result of acute myocardial infarction, temporal myocardial ischemia with localized electrical instability, or ischemic cardiomyopathy with a susceptible arrhythmogenic myocardial substrate.[31-33] In this study, we found a lower rate of sudden death attributed to CAD compared with Western countries. We suspect that regional differences due to the geographical tradition of human-environment interactions may account for the different characteristics of sudden death.

Circadian patterns and meteorological factors of sudden death

Cardiovascular factors (e.g. blood pressure, heart rate, and vascular endothelial function) have been found to have a day/night pattern in humans,[34] and myocardial function is influenced by circadian cycles (e.g. activity/rest, regeneration, and myocardial repair). Epidemiological studies in Western countries have reported increased rates of myocardial infarction and SCD in the morning hours compared with other times. In a previous study, a relative risk of 2.6 was found for the onset of SCD during the first three hours after awakening,[35] which could be due to an increase in sympathetic activity.[36] In addition, another study reported that ventricular tachycardia and sudden death were more likely to occur in the morning, while atrial fibrillation and heart block were more likely to occur in the evening.[37]

Circadian patterns of sudden death were also observed in the current study, with the highest peak from 16:00-20:00 (IRR: 3.00). The autonomic nervous system and its sympathetic arm play important roles in the regulation of the cardiovascular system, and hemodynamic changes have been causally associated with cardiovascular events and death. Elevated blood pressure is the leading risk factor for cardiovascular disease.[38] Circadian rhythms of blood pressure and heart rate have been reported in prior studies. A prior study reported that the highest number of SCD events peaked in the morning, and a second peak was evident in the evening hours in the general population.[36] Apart from the highest peak of blood pressure in the morning, blood pressure has been demonstrated to reach a second peak from 16:00-20:00.[39] In addition, both epinephrine and norepinephrine can affect heart function and blood vessels, and their levels increase with large peaks at circadian phases corresponding to 07:00-10:00 and 20:00-22:00, which may influence cardiovascular outcomes.[34] There is no clear explanation for the high rate of sudden deaths during 16:00-20:00 in Taiwan. A prior study reported that moderate changes in ambient temperature were associated with alterations in autonomic response.[40] In Taiwan, the higher number of sudden deaths in the evening may be linked to a gradual change in temperature from daytime to nighttime. In the winter, this effect of temperature difference may be more pronounced. Except for temperature changes, many environmental features have been found to have an influence on cardiovascular risks, severity, and progression. Changes in the environment due to migration to different geographic locations, modifications in lifestyle, social policies, and cultural practices may also affect cardiovascular risks.[41] Considering the potential reasons behind the disparity in circadian variations in sudden death between Western countries and Taiwan, future studies regarding non-uniform distributions in comparison with Western countries should be performed.

Most of the temperature-related mortality burden was related to cold weather in this study. In Western countries, cold and dry weather are important risk factors for SCD.[13] According to previous reports, the highest number of sudden deaths occurs in winter.[12,13,42] Arntz et al. reported that sudden death in Berlin was associated with diurnal variation (morning hours) and climatic conditions (winter).[12] There is general consensus that both extremely cold and extremely hot temperatures affect cardiovascular events. However, a prior study found that both cold and heat from moderate to extreme temperatures was associated with death in an analysis of data from 384 locations in countries of Asia (e.g. Taiwan, China, Thailand, and Japan), Europe, and America.[43] In agreement with these findings, we also found that seasonal variations such as relatively lower temperature in winter and higher discomfort index as heat pressure in summer may affect the occurrence of sudden death in Taiwan.

Taiwan is an island with a subtropical climate in the north. The climate in the north (Chin-Shan) is cool and cloudy in winter, with an average maximum temperature of 18 °C (64 °F). In summer, the weather is hot, humid and rainy. The temperature in the summer is uniform from the north to south of Taiwan, and the daily average temperature in the plains hovers around 29/30 °C (84/86 °F). In the fall, the amount of rain decreases, and the muggy heat is replaced by more pleasant weather. Furthermore, the humidity in Taiwan (70-80%) is significantly higher than in Western countries. In this study, we found that higher relative humidity was associated with higher risks of sudden death. Higher humidity may influence human health status. Breathing in cold humid air leads to the effect of supersaturation and liquefaction of water vapor in the airways. Supersaturation can lead to enhanced deposition of inhaled ambient aerosols and increased respiratory and cardiovascular symptoms.[44] On the other hand, the human body cannot endure hot and humid climates. In addition to cold temperature, hot weather has also been associated with an increased risk of cardiovascular events in tropical regions.[45,46] A previous study showed that hot and humid environments could affect cardiovascular adjustments in young men.[47]

However, temperature or humidity alone is not sufficient to explain the effects of meteorological conditions on cardiovascular events.[48] In this study, we demonstrated that lower temperatures and higher humidity may increase the risk of sudden death. A combined temperature-humidity index as discomfort index can be used to evaluate the degree of thermal comfort. Most people are quite comfortable when the discomfort index is below 70 and very uncomfortable when the index is above 80.[20] To our knowledge, this is the first study to demonstrate an association between the discomfort index assessed using both temperature and humidity as heat pressure and an increased risk of sudden death during the summer and fall in a tropical region.

Study limitations

There are several limitations to the study. First, there were no autopsy results or pathological reports to support the etiologies. Furthermore, we did not use biochemical markers in the prediction of risk factors for the potential mechanism, such as inflammation-related markers. Finally, we did not include cases of aborted sudden death – that is, those who were resuscitated. As these individuals would likely increase the cohort, it would be interesting to investigate whether these patients had different characteristics to the non-survivors. Due to the lack of medical health care services in this rural area, there were few aborted sudden deaths in this study cohort.

CONCLUSION

A variety of meteorological factors and circadian patterns have been implicated in sudden deaths among Taiwanese. In addition to cold weather, higher humidity and discomfort index were linked to increased risks of sudden death in this study. Our findings may support potential protective behavior of sudden death via weather forecasting. Identifying the surrogates responsible for the non-uniform distribution compared to Western countries requires further research.

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DECLARATION OF CONFLICT OF INTEREST

All the authors declare no conflict of interest.

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SUPPLEMENTARY MATERIAL

RESULTS

Circumstances surrounding sudden death

Among the 50 witnessed cases in which the circumstances surrounding sudden death were clearer, the presenting symptoms or prodromes included: dyspnea and/or orthopnea in 26 (52.0%) victims, chest pain and/or tightness in 22 (44.0%) victims, syncope in 6 (12.0%) victims, dizziness in 5 (10.0%) victims, cold sweating in 4 (8.0%) victims, palpitation in 2 (4.0%) victims, throat tightness in 2 (4.0%) victims, arm soreness in 1 (2.0%) victim, severe headache in 1 (2.0%) victim, and abdominal pain in 1 (2.0%) victim. Medical help was sought in 56 (68.2%) of the 82 cases, but only 4 (4.87%) were able to reach the hospital alive (these cases were documented to be acute myocardial infarction with death occurring in the emergency room within one hour). Among those with out-of-hospital cardiac arrest, although bystander cardiopulmonary resuscitation was attempted in 21% of the cases, most cases died before arriving at the hospital or being assessed by their family physicians. The mean age for those who were unable to seek any form of medical aid was greater, though statistically not significant (77.7 ± 10.5 vs. 70.0 ± 10.8 years old; $p = 0.13$).

The etiology for sudden death was confirmed in only one case, in which the patient was sent to the emergency department of a hospital in time and diagnosed with acute myocardial infarction based on the clinical and electrogram evidence. Due to the absence of autopsies and pathological examinations, the etiologies for the other cases were estimated clinically based on the patients' underlying diseases, presenting symptoms/signs, and the circumstances surrounding death.

Supplementary Table 1. Occurred locations of sudden death

Locations	Case number (Total N = 82)
Home or nursing home	72 (78.8%)
Clinic (sudden death after daily activity)	2 (2.44%)
Bus	2 (1.22%)
Park	1 (1.22%)
Gambling place	1 (1.22%)
Spring	1 (1.22%)
Work place	1 (1.22%)
Sports field as a spectator	1 (1.22%)
Burial ground	1 (1.22%)

N, number.