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Association between Diurnal Temperature Range, Daily Mean Temperature and Sarcopenia States in Older Adults: Evidence from the CHARLS

Yang Zhong[1], Suyuan Wang[2], Doudou Hao[1], Suyin Zhu[3], Yanli Chen[4,5], Zhiyou Shi[3], Qing Yang[6*†] and Yunhong Wu[2*†]

Abstract

Background With growing concern about global climate change and its potential consequences, its health impacts have been widely studied. However, the association between temperature and sarcopenia states in Chinese older adults remains unclear. The study aimed to examine the association based on a nationally representative large-scale survey.

Methods The study used data from three waves (2011, 2013, 2015) of the China Health and Retirement Longitudinal Study (CHARLS) for adults aged ≥ 60 years, combined with meteorological and $PM_{2.5}$ data from the China Research Data Services (CNRDS) Platform (2011–2015). Sarcopenia states were assessed using the Asian Working Group for Sarcopenia criteria 2019 (AWGS2019). Cross-sectional analysis used generalized additive models with cubic splines to identify non-linear relationships between temperature and sarcopenia states prevalence. For longitudinal analysis, four multivariable logistic regression models were developed to assess the association, adjusting for confounders. Subgroup analyses evaluated population sensitivity to temperature exposure.

Results The prevalence of possible sarcopenia was 29.4%, 28.5%, and 24.8% in 2011, 2013, and 2015, respectively, while sarcopenia rates were 9.6%, 10.7%, and 9.8%. Cross-sectional analysis showed that possible sarcopenia was associated with a higher risk of falls (OR: 1.31, $P < 0.001$) and hip fractures (OR: 1.63, $P < 0.001$). Longitudinal analysis revealed that a 1℃ increase in the three-year average diurnal temperature range (mDTR) raised the risk of possible sarcopenia by 8% (OR: 1.08, 95% CI: 1.01–1.15) and sarcopenia by 13% (OR: 1.13, 95% CI: 1.01–1.26). Conversely, a 1℃ increase in the three-year average daily mean temperature (mDMT) within 0–25℃ reduced the risk of possible sarcopenia by 4% (OR: 0.96, 95% CI: 0.94–0.99). Individuals living at altitudes ≥ 500 m were more vulnerable to the adverse effects of temperature fluctuations on possible sarcopenia.

†Qing Yang and Yunhong Wu contributed equally to this work.

*Correspondence:
Qing Yang
yangqing@scu.edu.cn
Yunhong Wu
wu_yunhong@163.com

Full list of author information is available at the end of the article

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Conclusions Our study found that temperature is associated with sarcopenia states in Chinese older adults. Increased mDTR raised the risk of possible sarcopenia and sarcopenia, while mDMT (0–25 ℃) lowered possible sarcopenia risk. Individuals living at altitudes ≥ 500 m were more vulnerable to the adverse effects of temperature fluctuations on sarcopenia.

Keywords Sarcopenia, Possible sarcopenia, Diurnal temperature range, Daily mean temperature, Falls, Hip fractures

Background

Global climate change is having a profound impact on human health and health systems [1]. Diurnal Temperature Range (DTR) and Daily Mean Temperature (DMT) are key indicators of climate change, with DTR reflecting the difference between daily high and low temperatures and DMT representing the daily mean temperature. These parameters are essential for understanding regional climate conditions. Previous research has shown that variations in DTR and DMT can lead to adverse health effects and exacerbate socioeconomic burdens. A systematic review in China [2] found an association between lower daily mean temperatures and higher mortality risk, especially among older adults. Studies in Japan [3] and the United Kingdom [4] found similar significant effects of extreme DTR exposure on mortality. In addition, South Korean emergency department data have shown that both low temperature and high DTR affect the occurrence of acute arrhythmic episodes or symptoms [5], and that high DTR is associated with an increased risk of emergency department visits for respiratory infections [6]. Therefore, studying the impact of temperature on populations, particularly vulnerable groups, is essential for assessing health risks, developing public health strategies, and providing social support to reduce the burden of disease.

Sarcopenia, characterised by progressive and systemic skeletal muscle wasting leading to accelerated loss of muscle mass and function [7], affects 10–16% of the world's elderly population and is strongly associated with adverse health outcomes such as reduced survival rates and increased postoperative complications [8]. Research on risk factors for sarcopenia has been relatively scarce, particularly prospective cohort studies, resulting in an overall low level of evidence. For example, previous studies [9, 10] have shown a negative association between being overweight or obese and the risk of sarcopenia, and it is worth noting that the relationship between muscle mass and body mass index may confound this negative association. Conversely, a meta-analysis [9] demonstrated that smoking was associated with an increased risk of sarcopenia. Furthermore, much of the existing research has focused on individual-level factors, and the potential impact of environmental exposures (e.g., climate-related temperature fluctuations) on sarcopenia has not been fully explored [11].

Therefore, this study investigated the association between body temperature and sarcopenia risk in Chinese older adults using longitudinal data from the China Health and Retirement Longitudinal Study (CHARLS) [12]. We analysed three waves of data (2011, 2013, 2015) collected from participants aged ≥ 60 years through integrated cross-sectional and longitudinal approaches. Furthermore, we conducted subgroup analyses to identify populations demonstrating heightened susceptibility to temperature variations.

Methods

Study Population

This study utilized data from three waves (2011, 2013, 2015) of the CHARLS survey [12] (https://charls.pku.edu.cn; accessed on November 16, 2023), including two longitudinal tracking periods (2011–2013, 2013–2015). Initiated in 2011, CHARLS employed multi-stage proportional to population size (PPS) sampling to establish a nationally representative cohort of individuals aged ≥ 45 years, covering 450 villages across 28 provinces (excluding Taiwan, Tibet, Hainan, Ningxia, Hong Kong, and Macao). The biennial survey collected multidimensional data, including demographics, health status, healthcare, employment, income, and physical measurements. The baseline survey enrolled 17,708 participants, with follow-ups in 2013 and 2015. The CHARLS survey project received approval from the Biomedical Ethics Committee of Peking University, and all participants provided informed consent.

The study included 5385, 5715, and 7402 participants aged ≥ 60 years in 2011, 2013, and 2015, respectively, after excluding those aged < 60 and those with missing relevant variables. For the 2011–2013 and 2013–2015 cohorts, 2263 and 2715 participants were selected, respectively, after excluding those with unavailable longitudinal data linkage or meeting "possible sarcopenia" criteria at baseline. The participant selection process was shown in Fig. 1.

Assessment of Related Diseases and Events

Sarcopenia States

Sarcopenia assessment followed the 2019 Asian Working Group for Sarcopenia (AWGS2019) criteria [13], including muscle strength, appendicular skeletal muscle mass (ASM), and physical performance. Sarcopenia was defined as low muscle mass plus either low muscle strength or low physical performance. Possible sarcopenia was defined as

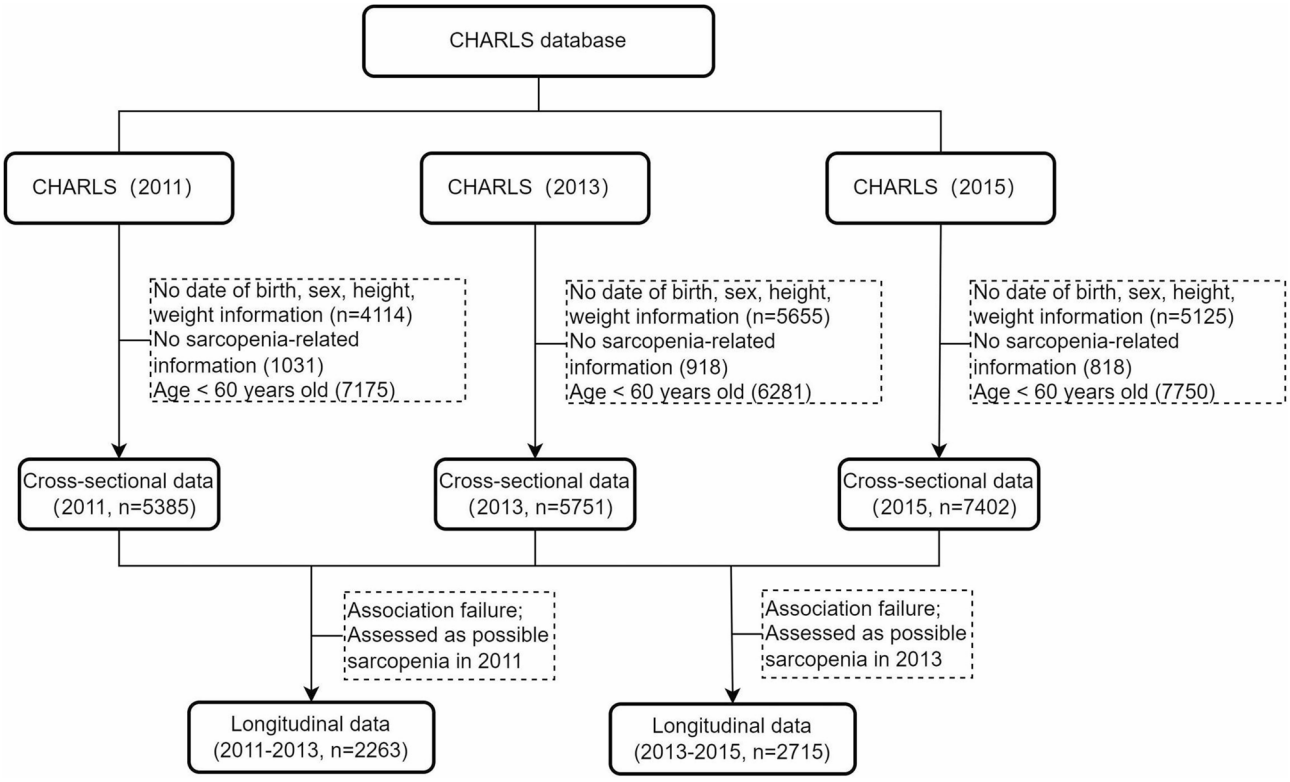

Fig. 1 Flowchart of the Participants Selection Process

meeting either the low muscle strength or low physical performance criterion without low muscle mass. Considering the dynamic progression of sarcopenia, shared risk factors across stages, and sample size validity, participants with possible sarcopenia and sarcopenia were combined into a single group termed "sarcopenia categories" to facilitate analyses for early prevention. "Sarcopenia categories" was defined as meeting either the low muscle strength or low physical performance criterion.

Grip strength (in kg) was measured using the YuejainT-MWL-1000 dynamometer, with participants squeezing as hard as possible. Each hand was tested twice at a 90° angle, and the maximum value was recorded. If one hand couldn't be measured, the other hand's value was used. Sarcopenia thresholds were < 28.0 kg for males and < 18.0 kg for females, per AWGS2019 guidelines. ASM was estimated using established formulae for the Chinese population [14, 15].

$$ASM = 0.193 \times \text{body}\, weight + 0.107 \times height - 4.157 \times gender - 0.037 \times age - 2.631$$

Body weight and height were measured using calibrated digital instruments (Omron™ HN-286 scale and Seca™ 213 stadiometer). Sex was categorized as male = 1 and female = 0. The formula used showed strong agreement with dual-energy X-ray absorptiometry (DXA), with an adjusted R^2 of 0.90 and a standard error of estimate (SEE) of 1.63 kg in prior validation studies [16]. Low muscle mass was defined as the 20th percentile of appendicular skeletal muscle mass adjusted by height squared (ASM/height²) within the study population [17, 18]. Diagnostic cut-offs were: 4.95 kg/m^2 (female) and 6.80 kg/m^2 (male) in 2011; 5.05 kg/m^2 (female) and 6.85 kg/m^2 (male) in 2013; 5.07 kg/m^2 (female) and 6.88 kg/m^2 (male) in 2015. Physical performance was assessed using AWGS2019 criteria, with low performance defined as a 6-m walk < 1.0 m/s, Short Physical Performance Battery (SPPB) score ≤ 9, or 5-time chair stand test ≥ 12 s.

In both cross-sectional and longitudinal analyses, participants were stratified into three sarcopenia states: non-sarcopenia, possible sarcopenia, and sarcopenia. Possible sarcopenia and sarcopenia were combined as "sarcopenia categories".

Hip Fracture and Falls

History of hip fracture and falls was collected via face-to-face questionnaires in the CHARLS survey, with responses to "Have you had a fall in the last two years?" and "Have you ever had a hip fracture?" categorised as "yes" or "no". Participants with positive responses were classified as having a history of falls or hip fractures.

Exposure Assessment

Meteorological and annual mean $PM_{2.5}$ data (2011–2015) were sourced from the China Research Data Service (CNRDS) Platform (https://www.cnrds.com; accessed on December 28, 2023). The meteorological dataset included daily maximum and minimum temperatures for 28 provinces and 124 cities. DTR was calculated as the difference between maximum and minimum temperatures, while DMT was their average ((maximum + minimum)/2). Annual averages of DTR (mDTR) and DMT (mDMT) were calculated using provinces or cities as spatial units and calendar years as temporal units. $PM_{2.5}$ data, derived from satellite monitoring and processed using ArcGIS, provided annual mean concentrations for Chinese prefecture-level cities [19]. Individual survey data were spatially linked to provincial/municipal meteorological and $PM_{2.5}$ data using geocoded addresses. To represent long-term exposure, three-year averages of DTR, DMT, and $PM_{2.5}$ were calculated for 2011–2013 and 2013–2015.

The original map data was derived from the publicly available standard map No. GS Jing (2022) 1061, which was obtained from the Ministry of Natural Resources Standard Base Map Service website (http://bzdt.ch.mnr.gov.cn). No changes have been made to the base map.

Potential Covariates

Based on prior knowledge, we adjusted for potential confounders that might influence the association between temperature and sarcopenia. Specifically, the covariates encompassed demographic characteristics, socioeconomic and health behavior factors, as well as temperature, air pollution variables, and altitude. Demographic characteristics included age and sex; socioeconomic and health behaviour factors included area of residence (urban or rural), marital status (married or cohabiting, separated or widowed, etc.), level of education (illiterate, primary and secondary school or higher), current smoking status, current alcohol consumption, body mass index (BMI), sleep duration and social frequency. Temperature factors were considered by examining the mutual influence between mDMT and mDTR. $PM_{2.5}$ was selected as the representative variable for air pollution due to its significant contribution to air pollution-related mortality in China and its availability in the CNRDS database. Additionally, the altitude of participants' residences was included to partially account for the effects of air pressure.

Statistical Analysis

First, the study conducted a disease mapping of the prevalence of sarcopenia states, fall rates, hip fracture rates, mDTR, and mDMT across provinces and cities to visualise their spatial distribution.

For cross-sectional data, generalised additive models (GAMs) with cubic splines were used to fit non-linear curves of possible sarcopenia prevalence in 2013 and 2015 against mDTR and mDMT changes, supplemented by Spearman's rank correlation analysis. Logistic regression models, adjusted for age, sex, and area of residence, assessed associations between sarcopenia states and falls or hip fractures.

For the longitudinal data, the study sequentially utilized chi-squared tests and multivariable logistic regression models to analyse the association between temperature and sarcopenia states. Based on the chi-squared test results, four models (with 2–11 covariates) were developed to progressively adjust for potential confounders. Multicollinearity was assessed using the generalised variance inflation factor (GVIF) and GVIF^(1/2×df), where df is the degree of freedom of the variable [20]. Variables with GVIF^(1/2×df) > 2 were screened based on public health importance. Model 1 adjusted for demographics (age, sex). Model 2 added socioeconomic and health behaviour factors (residence, marital status, education, smoking, alcohol, BMI, sleep). Model 3 included other temperature factors (mDMT or mDTR), and model 4 further adjusted for $PM_{2.5}$, serving as the full model.

To assess heterogeneity in the effects of mDTR or mDMT on sarcopenia outcomes, subgroup analyses were conducted based on nine baseline characteristics: sex, age, area of residence, marital status, education level, smoking status, alcohol consumption, sleep duration, and altitude. For this exploratory analysis, results were reported with point estimates and confidence intervals, with *P* values unadjusted for multiple comparisons [21].

All analyses were performed using R software version 4.1.3 and the significance level of statistical tests was 0.05.

Results

The Distribution of Diseases and Temperature

In 2011, 2013, and 2015, the prevalence of possible sarcopenia was 29.36%, 28.45%, and 24.78%, while sarcopenia were 9.60%, 10.70%, and 9.80%, respectively (Table 1). Northern China, including Qinghai, Xinjiang, Gansu, and Inner Mongolia, consistently showed higher prevalence of possible sarcopenia across all three years, and Yunnan and Guangxi exhibiting relatively high sarcopenia prevalence (Fig. 2 and Figure S1).

Fall rates in 2011, 2013, and 2015 were 18.51%, 11.51%, and 19.18%, respectively, while fracture rates were 1.69%, 0.54%, and 2.05% (Table S1). As illustrated in Fig. 3, the distribution of falls and hip fractures was relatively scattered, with common areas including Qinghai, Chongqing, Hunan, Guangxi, etc. Overall, the rates of falls and hip fractures were higher among participants in 2015, and the geographical distribution was more comprehensive.

Table 1 Distribution of the Prevalence of Sarcopenia States in China based on the China Health and Longitudinal Study in 2011, 2013 and 2015

	2011 (*N* = 5385)			2013 (*N* = 5751)			2015 (*N* = 7402)		
	Category 1(%)	Category 2(%)	Category 3(%)	Category 1(%)	Category 2(%)	Category 3(%)	Category 1(%)	Category 2(%)	Category 3(%)
Anhui	45.72	39.82	5.90	30.98	25.59	5.39	41.58	33.42	8.17
Beijing	24.59	21.31	3.28	37.50	32.50	5.00	33.33	23.81	9.52
Fujian	35.71	25.97	9.74	44.38	28.09	16.29	43.85	28.34	15.51
Gansu	47.62	38.10	9.52	59.03	49.31	9.72	48.21	35.71	12.50
Guangdong	33.92	21.55	12.37	39.41	26.06	13.36	31.98	21.80	10.17
Guangxi	30.94	17.04	13.90	32.65	18.37	14.29	24.48	13.79	10.69
Guizhou	42.17	27.71	14.46	20.37	12.96	7.41	23.47	13.27	10.20
Hebei	51.14	43.18	7.96	52.89	41.83	11.06	40.00	32.67	7.33
Henan	38.63	32.46	6.16	32.90	26.97	5.92	33.87	27.39	6.49
Heilongjiang	43.59	38.46	5.13	26.47	21.57	4.90	22.79	20.59	2.21
Hubei	44.38	32.54	11.83	33.33	19.54	13.79	43.15	25.89	17.26
Hunan	41.10	27.18	13.92	39.79	23.53	16.26	25.28	15.17	10.11
Jilin	50.79	39.68	11.11	61.45	43.37	18.07	27.22	18.34	8.88
Jiangsu	35.37	27.24	8.13	41.84	29.59	12.25	32.67	23.69	8.98
Jiangxi	34.41	22.22	12.19	39.94	24.68	15.26	34.10	18.66	15.44
Liaoning	29.22	22.08	7.14	46.91	39.51	7.41	41.78	32.86	8.92
Inner Mongolia	43.06	38.89	4.17	50.46	44.50	5.96	51.49	43.83	7.66
Qinghai	62.00	54.00	8.00	78.85	65.38	13.46	70.18	52.63	17.54
Shandong	42.31	35.07	7.24	40.51	33.90	6.61	29.74	22.96	6.78
Shanxi	62.20	48.78	13.42	37.36	28.74	8.62	36.36	28.14	8.23
Shaanxi	46.71	35.33	11.38	47.92	36.46	11.46	47.37	36.84	10.53
Shanghai	23.08	23.08	0.00	50.00	50.00	0.00	13.79	13.79	0.00
Sichuan	26.68	17.98	8.70	29.30	20.33	8.97	29.20	20.74	8.46
Tianjin	35.00	35.00	0.00	65.22	65.22	0.00	58.07	54.84	3.23
Xinjiang	72.22	58.33	13.89	39.39	33.33	6.06	65.39	53.85	11.54
Yunnan	40.20	23.65	16.55	46.93	25.77	21.17	35.17	20.46	14.71
Zhejiang	29.95	21.83	8.12	25.50	18.33	7.17	19.82	13.31	6.51
Chongqing	16.67	8.82	7.84	41.41	23.23	18.18	54.02	29.93	24.09
Overall	38.96	29.36	9.60	39.15	28.45	10.70	34.58	24.78	9.80

Data were reported using percentages. Category 1: Sarcopenia categories; Category 2: Possible sarcopenia; Category 3: Sarcopenia. Data for Taiwan, Tibet, Hainan, Ningxia, Hong Kong, and Macao were excluded due to lack of CHARLS coverage

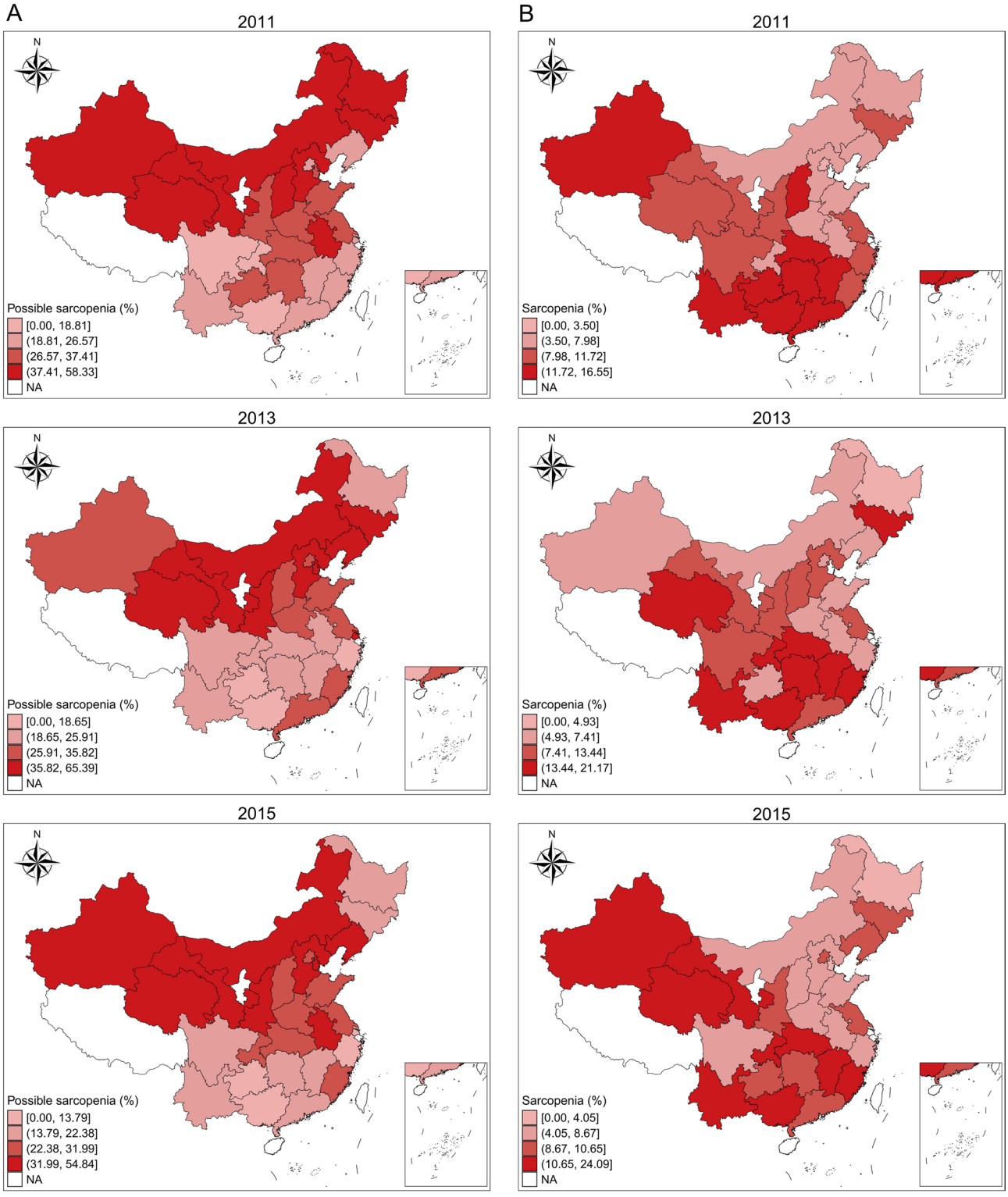

Fig. 2 Geographical Distribution of the Prevalence of Sarcopenia Categories. Possible sarcopenia (**A**) and sarcopenia (**B**) in China, based on the China Health and Retirement Longitudinal Study database in 2011, 2013 and 2015

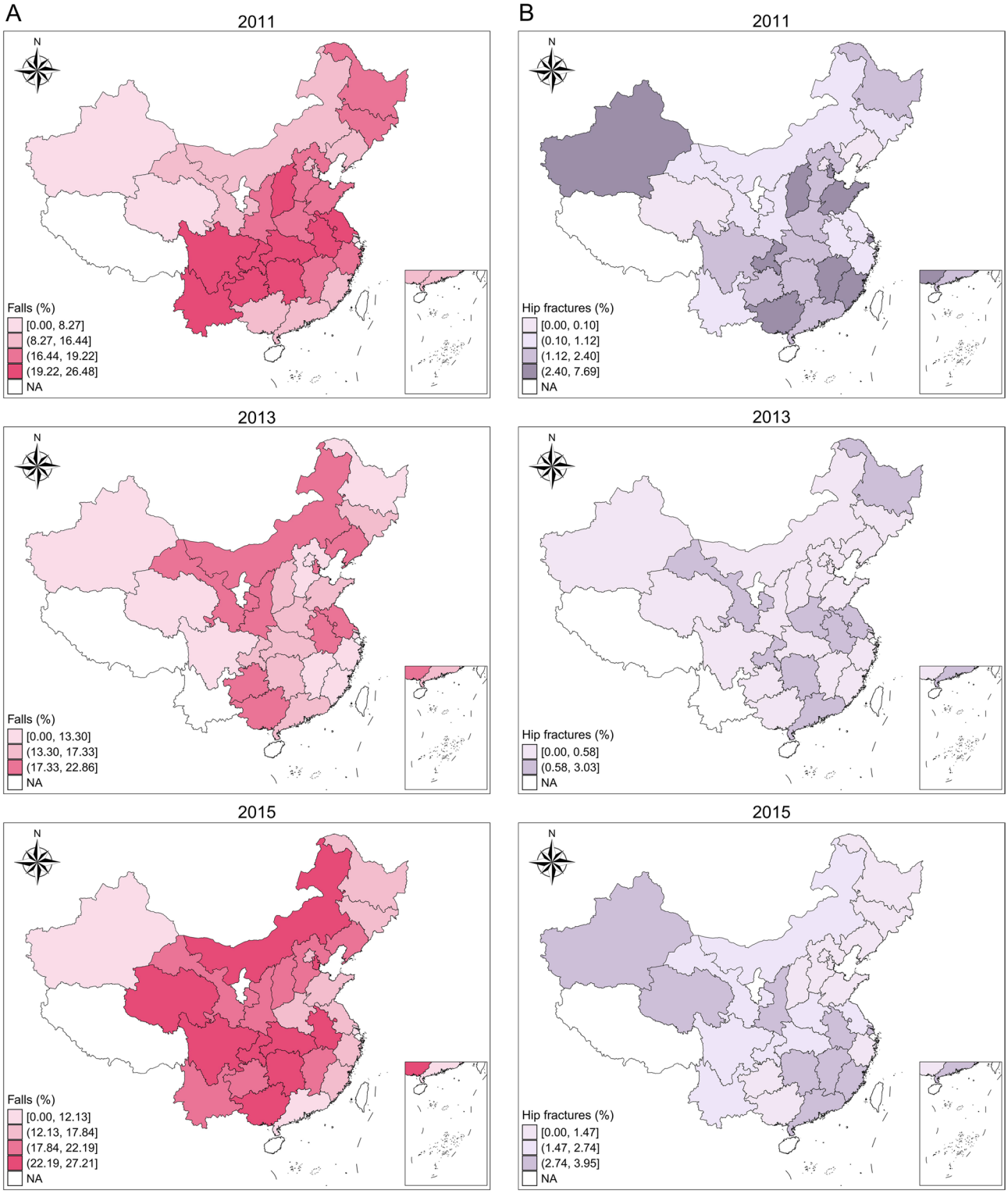

Fig. 3 Geographical Distribution of the Prevalence of Falls and Hip Fractures. Falls (**A**) and hip fractures (**B**) in China, based on the China Health and Retirement Longitudinal Study database in 2011, 2013 and 2015

As shown in Fig. 4, the southeastern regions of China displayed lower mDTR, while the northern regions such as Qinghai, Gansu, Xinjiang, and Inner Mongolia exhibited higher mDTR. The overall distribution pattern of mDTR was similar to the distribution of possible sarcopenia prevalence in Fig. 2. The distribution pattern of mDMT was opposite to that of mDTR. Overall mDTR and mDMT increased slightly in 2013–2015 compared to 2011–2013 (Table S2).

Correlation Analysis of Sarcopenia States with Temperature

In 2013, the Spearman correlation analysis revealed a positive correlation between the prevalence of sarcopenia categories and mDTR (Total: $Rs = 0.39$, $P < 0.001$; male: $Rs = 0.25$, $P = 0.005$; female: $Rs = 0.43$, $P < 0.001$), whereas it exhibited a negative correlation with mDMT (Total: $Rs = -0.27$, $P = 0.003$; male: $Rs = -0.19$, $P = 0.036$;female: $Rs = -0.27$, $P = 0.002$) (Fig. 5). The correlation pattern between the prevalence of sarcopenia categories and temperature in 2015 was similar to that in 2013 (Figure S2).

In 2013 and 2015, a positive association was observed between the prevalence of possible sarcopenia and mDTR ($P < 0.001$), and a negative association was observed between the prevalence of possible sarcopenia and mDMT ($P < 0.001$, Figure S3). However, no significant association was observed between the prevalence of sarcopenia and temperature (Figure S4).

Correlation Analysis of Sarcopenia States with Falls and Hip Fractures

Analysis of the 2015 survey data revealed significant associations between sarcopenia categories and adverse outcomes, after adjusting for age, sex and residential area. Compared with individuals without sarcopenia categories, those with sarcopenia categories exhibited a 33% increased odds of falls (OR: 1.33, 95% CI: 1.17–1.51) and an 83% higher risk of hip fractures (OR: 1.83, 95% CI: 1.30–2.58). Similarly, individuals classified as having possible sarcopenia showed a 31% increased odds of falls (OR: 1.31, 95% CI: 1.15–1.49) and a 63% elevated risk of

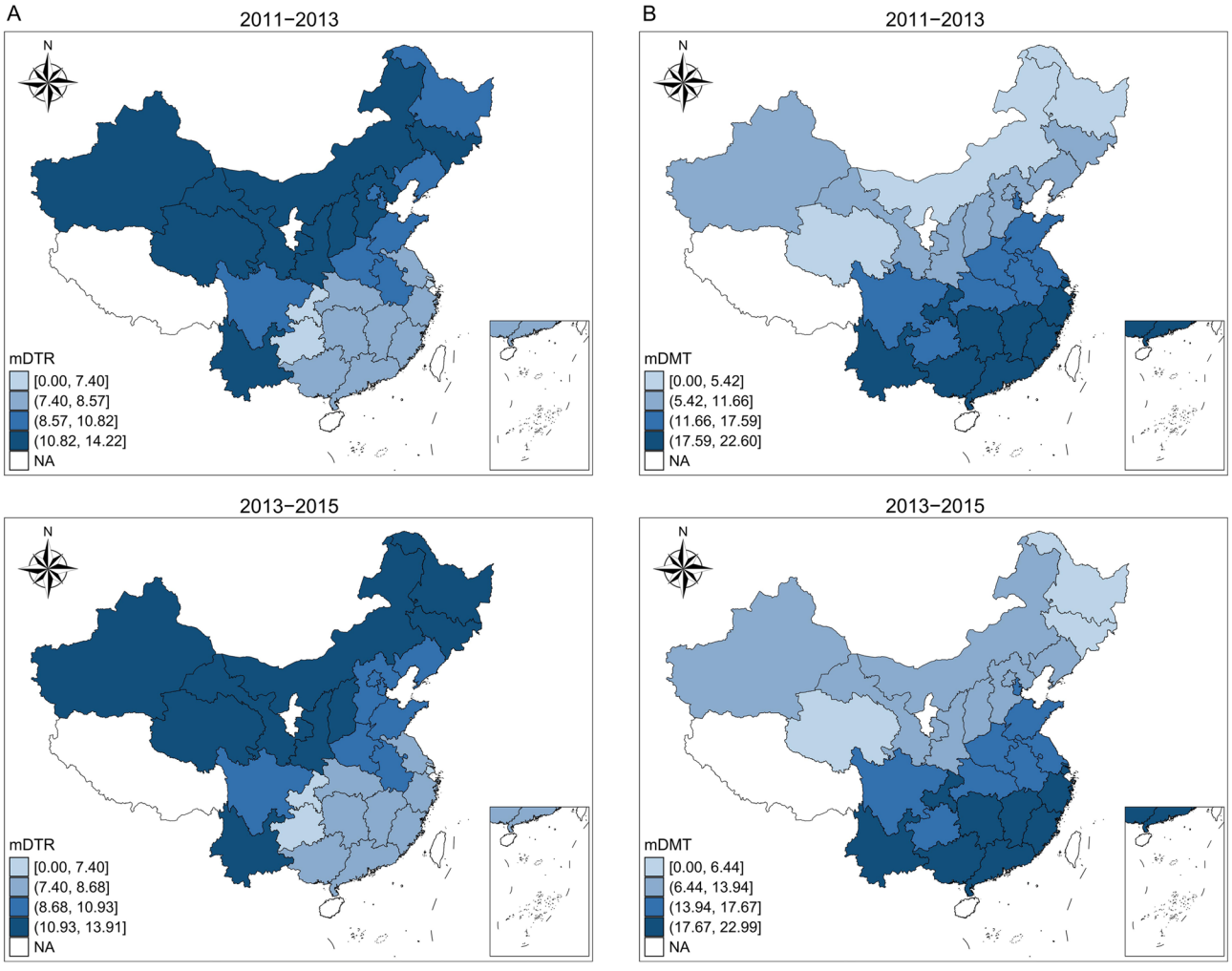

Fig. 4 Geographical Distribution of mDTR and mDMT Ranging from 2011 to 2013, 2013 to 2015. The unit of mDTR and mDMT is °C

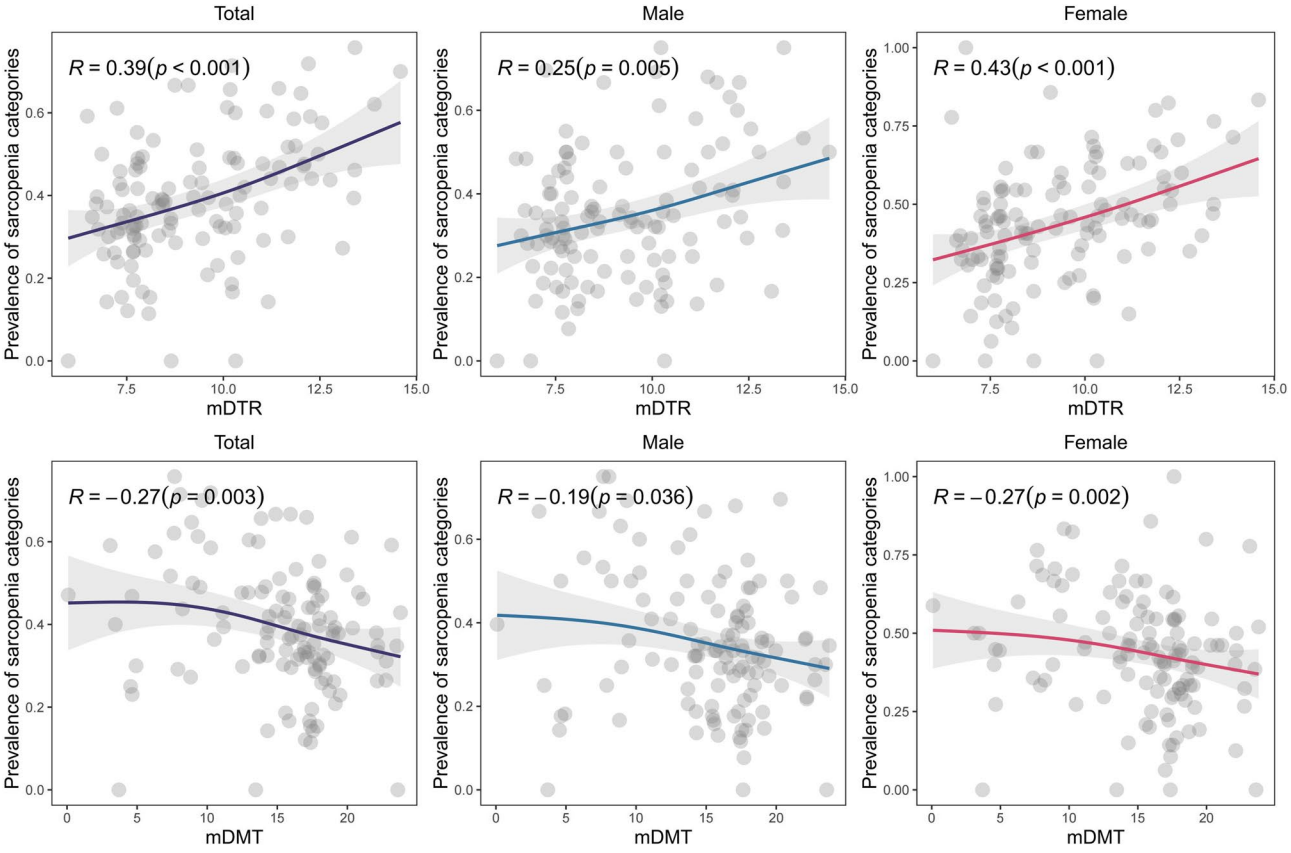

Fig. 5 Scatter Plot of the Correlation between the Prevalence of Sarcopenia Categories and mDTR or mDMT in Cities from 2011 to 2013. Cubic spline GAMs were used to fit the non-linear curve, complemented by Spearman's rank correlation analysis

Table 2 Association between Sarcopenia States and Falls or Hip Fractures in 2015

	Falls		Hip factures	
	Model A	**Model B**	**Model A**	**Model B**
Sarcopenia categories	1.43 (1.27,1.61)***	1.33 (1.17,1.51)***	1.92 (1.39,2.64)***	1.83 (1.30,2.58)***
Possible sarcopenia	1.37 (1.21,1.56)***	1.31 (1.15,1.49)***	1.69 (1.20,2.36)**	1.63 (1.16,2.28)**
Sarcopenia	1.26 (1.05,1.51)*	1.09 (0.89,1.32)	1.57 (0.96,2.42)	1.35 (0.80,2.18)

Values were odds ratio (95% confidence intervals). Model A: No adjustment. Model B: Model A + age, sex, residential area. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$

hip fractures (OR: 1.63, 95% CI: 1.16–2.28) compared with those without possible sarcopenia (Table 2).

Notably, individuals with sarcopenia demonstrated a 26% higher odds of falls compared with those without sarcopenia (OR: 1.26, 95% CI: 1.05–1.51), although this association was no longer statistically significant after further adjustment for confounders.

Characteristics of the Participants in Longitudinal Data

As shown in Table 3, the 2011–2013 cohort ($n = 2,263$) showed an incidence of sarcopenia categories of 29.1% (possible: 20.7%; confirmed: 8.4%), whereas the 2013–2015 cohort ($n = 2,715$) showed a lower incidence of 22.6% (possible: 17.1%; confirmed: 5.5%).

In both the 2011–2013 and 2013–2015 cohorts, demographics of individuals with sarcopenia categories were alike. Most were aged 60–65 years, primarily Han, rural residents, with primary education, married/cohabitated, and had a BMI within the normal range. Over 60% of the population reported current smoking or alcohol consumption behavior, and over 70% participated in social activities at least once a week. About 35% reported sleeping less than 6 h per night in the past month, and over 70% lived < 500 m above sea level.

Association between mDTR, mDMT and Sarcopenia States

The associations between mDTR, mDMT, and sarcopenia states based on logistic regression models were presented in Table 4. In the 2011–2013 cohort, the full model (model 4a) showed a positive association between mDTR and sarcopenia categories. Specifically, for each 1℃ increase in mDTR, the risk of sarcopenia categories

Table 3 Characteristics of Participants in the 2011–2013 and 2013–2015 Cohorts

Variable	Cohort 2011–2013				Cohort 2013–2015			
	Non-sarcopenia	Sarcopenia categories		*P*	Non-sarcopenia	Sarcopenia categories		*P*
		Possible sarcopenia	Sarcopenia			Possible sarcopenia	Sarcopenia	
All participants	1602 (70.7)	469 (20.7)	192 (8.4)		2102 (77.4)	463 (17.1)	150 (5.5)	
Sex				0.060				0.005
Male	945 (59.0)	255 (54.4)	100 (52.1)		1178 (56.0)	227 (49.0)	71 (47.3)	
Female	657 (41.0)	214 (45.6)	92 (47.9)		924 (44.0)	236 (51.0)	79 (52.7)	
Age (years)				< 0.001				< 0.001
[60, 65)	807 (50.4)	206 (43.9)	41 (21.4)		1071 (51.0)	178 (38.4)	22 (14.7)	
[65, 70)	450 (28.1)	127 (27.1)	50 (26.0)		612 (29.1)	138 (29.8)	46 (30.7)	
[70, 75)	252 (15.7)	76 (16.2)	46 (24.0)		279 (13.3)	92 (19.9)	39 (26.0)	
≥ 75	93 (5.8)	60 (12.8)	55 (28.6)		140 (6.7)	55 (11.9)	43 (28.7)	
Race				0.222				0.104
Han	1525 (95.2)	437 (93.2)	181 (94.3)		2005 (95.4)	435 (94.0)	138 (92.0)	
Minority	77 (4.8)	32 (6.8)	11 (5.7)		97 (4.6)	28 (6.0)	12 (8.0)	
Residential area				0.006				< 0.001
Urban	596 (37.2)	151 (32.2)	52 (27.1)		777 (37.0)	148 (32.0)	23 (15.3)	
Rural	1006 (62.8)	318 (67.8)	140 (72.9)		1325 (63.0)	315 (68.0)	127 (84.7)	
Marital status				0.001				< 0.001
Married/Cohabitated	1346 (84.0)	370 (78.9)	143 (74.5)		1775 (84.4)	364 (78.6)	106 (70.7)	
Separated/Widowed etc.	256 (16.0)	99 (21.1)	49 (25.5)		327 (15.6)	99 (21.4)	44 (29.3)	
Education level				< 0.001				< 0.001
Illiterate	380 (23.7)	152 (32.4)	95 (49.5)		565 (26.9)	164 (35.4)	69 (46.0)	
Primary school	835 (52.1)	223 (47.5)	83 (43.2)		1049 (49.9)	220 (47.5)	65 (43.3)	
Middle school or above	387 (24.2)	94 (20.0)	14 (7.3)		488 (23.2)	79 (17.1)	16 (10.7)	
BMI (kg/m^2)				< 0.001				< 0.001
< 18.5	124 (7.70)	9 (1.90)	73 (38.00)		99 (4.7)	7 (1.5)	51 (34.0)	
[18.5, 25)	1063 (66.40)	329 (70.10)	118 (61.50)		1355 (64.5)	283 (61.1)	99 (66.0)	
[25, 30)	370 (23.10)	113 (24.10)	1 (0.50)		569 (27.1)	151 (32.6)	0 (0.0)	
≥ 30	45 (2.80)	18 (3.80)	0 (0.00)		79 (3.8)	22 (4.8)	0 (0.0)	
Current smoking status				0.037				0.013
Yes	1073 (67.0)	286 (61.0)	132 (68.8)		1403 (66.7)	287 (62.0)	112 (74.7)	
No	529 (33.0)	183 (39.0)	60 (31.2)		699 (33.2)	176 (38.0)	38 (25.3)	
Current alcohol consumption				0.010				0.004
Yes	1004 (62.7)	258 (55.0)	120 (62.5)		1333 (63.4)	256 (55.3)	89 (59.3)	
No	598 (37.3)	211 (45.0)	72 (37.5)		769 (36.6)	207 (44.7)	61 (40.7)	
Social frequency				0.827				0.145
Almost daily/every week	1185 (74.0)	352 (75.1)	145 (75.5)		1684 (80.1)	374 (80.8)	130 (86.7)	
Less often/No	417 (26.0)	117 (24.9)	45 (24.5)		418 (19.9)	89 (19.2)	20 (13.3)	
Sleep duration (hours)				0.001				0.289
< 6	473 (29.5)	171 (36.5)	84 (43.8)		682 (32.4)	169 (36.5)	54 (36.0)	
[6, 7)	360 (22.5)	96 (20.5)	35 (18.2)		491 (23.4)	99 (21.4)	27 (18.0)	
[7, 8)	314 (19.6)	74 (15.8)	23 (12.0)		379 (18.0)	75 (16.2)	22 (14.7)	
≥ 8	455 (28.4)	128 (27.3)	50 (26.0)		550 (26.2)	120 (25.9)	47 (31.3)	
Altitude (m)				< 0.001				< 0.001
< 500	1319 (82.3)	363 (77.4)	144 (75.0)		1699 (80.8)	336 (72.6)	102 (68.0)	
[500, 1500)	206 (12.9)	62 (13.2)	22 (11.5)		293 (13.9)	98 (21.2)	30 (20.0)	
≥ 1500	77 (4.8)	44 (9.4)	26 (13.5)		110 (5.2)	29 (6.3)	18 (12.0)	

Data were reported using n(%). Differences among three groups were compared using the chi-square test

Table 4 Association between mDTR, mDMT and Sarcopenia States Based on Longitudinal Data

	OR (95% CI)	
	mDTR	mDMT
Sarcopenia categories		
Cohort 2011–2013		
Model 1a	1.16 (1.10,1.22)***	0.95 (0.93,0.97)***
Model 2a	1.18 (1.12,1.24)***	0.94 (0.92,0.96)***
Model 3a	1.11 (1.03,1.19)**	0.96 (0.94,0.99)*
Model 4a	1.09 (1.01,1.18)*	0.96 (0.94, 0.99)*
Cohort 2013–2015		
Model 1b	1.14 (1.08,1.20)***	0.97 (0.95,0.99)**
Model 2b	1.14 (1.08,1.20)***	0.96 (0.94,0.98)***
Model 3b	1.12 (1.04,1.20)**	0.99 (0.96,1.02)
Model 4b	1.12 (1.04, 1.21)**	0.99 (0.96,1.02)
Possible sarcopenia		
Cohort 2011–2013		
Model 1a	1.15 (1.09,1.21)***	0.94 (0.92,0.96)***
Model 2a	1.16 (1.09,1.22)***	0.94 (0.92,0.96)***
Model 3a	1.08 (1.01,1.16)*	0.96 (0.92,0.99)**
Model 4a	1.08 (1.01,1.15)*	0.96 (0.93,0.99)**
Cohort 2013–2015		
Model 1b	1.12 (1.06,1.18)***	0.96 (0.93,0.98)***
Model 2b	1.12 (1.06,1.19)***	0.96 (0.94,0.98)**
Model 3b	1.08 (1.01,1.17)*	0.98 (0.95,1.01)
Model 4b	1.08 (1.01,1.17)*	0.98 (0.95,1.01)
Sarcopenia		
Cohort 2011–2013		
Model 1a	1.09 (1.00,1.18)*	1.01 (0.98,1.05)
Model 2a	1.14 (1.04,1.24)**	0.96 (0.93,1.00)
Model 3a	1.14 (1.01,1.29)*	1.00 (0.95,1.06)
Model 4a	1.13 (1.01, 1.26)*	1.00 (0.94,1.05)
Cohort 2013–2015		
Model 1b	1.13 (1.03,1.24)*	1.01 (0.97,1.06)
Model 2b	1.13 (1.03,1.24)*	0.97 (0.93,1.02)
Model 3b	1.17 (1.03,1.33)*	1.02 (0.96,1.09)
Model 4b	1.19 (1.04,1.37)*	1.03 (0.97,1.11)

Values were odds ratio (95% confidence intervals). Model 1a: Adjusted for sex and age; Model 2a: Model 1a + residential area, education level, marital status, BMI, smoking status, alcohol consumption and sleep duration; Model 3a: Model 2a + mDMT; Model 4a: Model 3a + $PM_{2.5}$; Model 1b: Adjusted for sex and age; Model 2b: Model 1b + residential area, education, marital status, body mass index, smoking status and alcohol consumption; Model 3b: Model 2b + mDTR; Model 4b: Model 3b + $PM_{2.5}$. *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$

increased by 9% (OR: 1.09, 95% CI: 1.01–1.18). Conversely, a negative association was observed between mDMT and sarcopenia categories. For each 1℃ increase in mDMT, the risk of sarcopenia categories decreased by 4% (OR: 0.96, 95% CI: 0.94–0.99). The 2013–2015 cohort exhibited a similar pattern of association to the 2011–2013 cohort.

Notably, in both the 2011–2013 and 2013–2015 cohorts, mDTR was positively associated with both possible sarcopenia (OR: 1.08) and sarcopenia (OR: 1.13 or 1.19), whereas mDMT was only negatively associated with possible sarcopenia (OR: 0.96) and the association with sarcopenia was not statistically significant.

Subgroup Analysis

As shown in Fig. 6, the 2011–2013 cohort exhibited a consistent association between mDTR and sarcopenia categories across eight subgroups, except for altitude (P for interaction = 0.049). Specifically, individuals living ≥ 500 m were more adversely affected by mDTR than those < 500 m (OR: 1.27, 95% CI: 1.09–1.49). Similar altitude-related differences were observed in subgroup analyses with possible sarcopenia as the outcome (P for interaction = 0.016, Figure S6), but not with sarcopenia as the outcome. The association between mDMT and sarcopenia categories remained consistent across all subgroups (P for interaction > 0.05).

In the 2013–2015 cohort, the associations of mDTR and mDMT with sarcopenia categories were consistent across all nine subgroups (P for interaction > 0.05, Figure S5).

Discussion

This study, the first to explore the link between temperature and sarcopenia states in older Chinese adults using CHARLS data, analyzed both cross-sectional and longitudinal perspectives. Cross-sectionally, mDTR was positively associated with possible sarcopenia, while mDMT showed a negative association. Possible sarcopenia increased the risk of falls and hip fractures, but no significant associations were found between sarcopenia and the risk of falls or hip fractures. Longitudinally, after adjusting for confounders, higher mDTR was a risk factor for possible sarcopenia, while elevated mDMT within a certain range acted as a protective factor. For sarcopenia, higher mDTR remained a risk factor, but mDMT showed no significant protective effect. These findings enhance understanding of temperature's impact on sarcopenia states, aiding decision-making and resource allocation to address climate change and reduce disease burden.

Sarcopenia, an age-related condition marked by muscle mass and function loss, is linked to adverse outcomes like fractures, functional decline, and mortality [7]. A recent systematic review [22] found its prevalence varied by definition criteria, ranging from 5% (European Working Group on Sarcopenia in Older People, EWGSOP) to 17% (International Working Group on Sarcopenia, IWGS). Using AWGS criteria, a meta-analysis of 13 studies on sarcopenia [8] reported a prevalence of 8% (95% CI: 3-15%), while 16 studies on possible sarcopenia [23] showed a meta-analysed prevalence of 28.7% (95% CI: 22.0-36.5%). The prevalences in this study aligned with prior findings. Notably, sarcopenia cases were concentrated in the southwestern, potentially due to the ASM formulae's reliance on body weight and height, whereas

Subgroup	Sarcopenia states		mDTR	*P* for interaction	mDMT	*P* for interaction
	Yes	No	OR (95%CI)		OR (95%CI)	
All Participants	661	1602	1.09 (1.01 to 1.18)		0.96 (0.94 to 0.99)	
Sex				0.516		0.402
Male	355	945	1.10 (0.99 to 1.21)		0.97 (0.94 to 1.02)	
Female	306	657	1.10 (0.99 to 1.24)		0.95 (0.91 to 0.99)	
Age(years)				0.535		0.735
[60, 65)	247	807	1.06 (0.94 to 1.20)		0.95 (0.91 to 0.99)	
[65, 70)	177	450	1.17 (1.01 to 1.36)		0.98 (0.92 to 1.05)	
≥70	237	345	1.06 (0.92 to 1.23)		0.97 (0.92 to 1.03)	
Residential area				0.892		0.314
Urban	203	596	1.16 (1.00 to 1.36)		1.00 (0.95 to 1.05)	
Rural	458	1006	1.06 (0.97 to 1.16)		0.94 (0.91 to 0.98)	
Marital status				0.216		0.714
Married/Cohabitated	513	1346	1.05 (0.96 to 1.14)		0.95 (0.92 to 0.98)	
Separated/Widowed etc.	148	256	1.29 (1.09 to 1.53)		1.00 (0.94 to 1.08)	
Education level				0.682		0.871
Illiterate	247	380	1.18 (1.03 to 1.36)		0.99 (0.93 to 1.06)	
Primary school	306	835	1.04 (0.94 to 1.16)		0.95 (0.91 to 0.99)	
Middle school or above	108	387	1.15 (0.94 to 1.41)		0.97 (0.90 to 1.03)	
Current smoking status				0.745		0.554
Yes	418	1073	1.10 (1.01 to 1.20)		0.97 (0.94 to 1.01)	
No	243	529	1.07 (0.91 to 1.27)		0.94 (0.89 to 1.00)	
Current alcohol consumption				0.953		0.428
Yes	378	1004	1.10 (1.00 to 1.21)		0.97 (0.93 to 1.02)	
No	283	598	1.06 (0.91 to 1.23)		0.95 (0.90 to 1.00)	
Sleep duration(hours)				0.162		0.579
<6	255	473	1.09 (0.96 to 1.25)		0.94 (0.89 to 1.00)	
[6, 7)	131	360	1.29 (1.08 to 1.54)		1.01 (0.95 to 1.07)	
[7, 8)	97	314	0.91 (0.75 to 1.10)		0.92 (0.85 to 0.99)	
≥8	178	455	1.10 (0.95 to 1.27)		0.98 (0.92 to 1.04)	
Altitude(m)				0.049		0.878
<500	507	1319	0.98 (0.86 to 1.11)		0.94 (0.90 to 0.97)	
≥500	154	283	1.27 (1.09 to 1.49)		0.99 (0.93 to 1.05)	

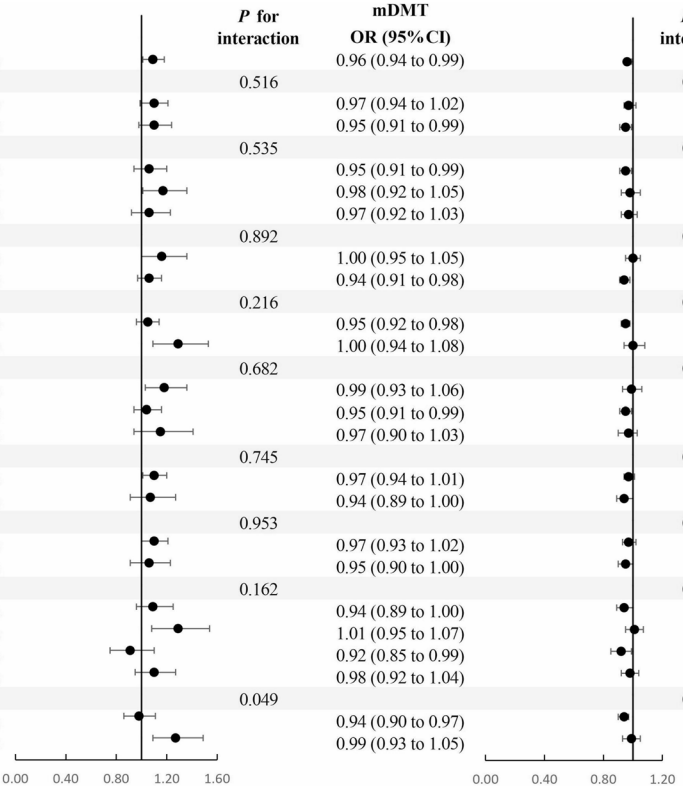

Fig. 6 Subgroup Analyses of the Association between mDTR or mDMT and Sarcopenia Categories Based on the 2011–2013 Cohort. Adjusted for sex, age, residential area, education, marital status, body mass index, smoking status, alcohol consumption, sleep duration, mDMT and $PM_{2.5}$

more accurate tools like DXA [24] may be needed for precise assessment. The longitudinal analysis revealed that after 2 years, 20.7% and 17.1% of non-sarcopenic individuals developed possible sarcopenia, while 8.4% and 5.5% progressed to confirmed sarcopenia. Notably, sarcopenia's progression was not linear but a multistage, multidirectional process with transitional probabilities between health states [25]. For example, in the 2011–2013 cohort, 20.7% of baseline non-sarcopenic individuals transitioned to possible sarcopenia, which could be due to early pathological changes or partial reversions from confirmed cases, as well as a return to non-sarcopenic status, progression to confirmed sarcopenia, or mortality. The rate of 20.7% reflected disease status within specific short-term observation windows, differing slightly from conventional epidemiological incidence measurements.

Sarcopenia is linked to adverse health outcomes such as falls, fractures, metabolic disorders, and cognitive impairment [26]. In this study, patients with possible sarcopenia showed a higher risk of falls (OR: 1.31, 95% CI:1.15–1.49) and hip fractures (OR: 1.63, 95% CI: 1.16–2.28) in adjusted Models, though the association between sarcopenia and hip fractures was not statistically significant. Evidence for this association is limited outside CHARLS, and its strength varies by diagnostic criteria. A meta-analysis (10 studies) reported an increased risk of falls (OR: 1.52, 95% CI:1.32–1.77) and a systematic review (17 studies) reported an increased risk of fractures (OR: 1.84, 95% CI:1.30–2.62) in older adults [27, 28]. However, a 2-year Korean cohort study [29] found no association between sarcopenia and falls or fractures when sarcopenia was defined by both low muscle mass and low hand grip strength, indicating that diagnostic tools influence the assessment of health outcomes, which may explain the non-significant association between sarcopenia and hip fractures in this study.

Research on sarcopenia risk factors has been limited, particularly from prospective cohort studies [8]. Previous observational studies have linked malnutrition, smoking, and extreme sleep duration to increased sarcopenia risk [30–32]. However, evidence on environmental factors like temperature remains scarce. This study, using longitudinal CHARLS data and adjusting for confounders, found that mDTR was positively associated with possible and confirmed sarcopenia risk, while mDMT was negatively associated with possible sarcopenia. DTR has been identified as a risk factor for various diseases in prior epidemiological studies [2–4]. The human body adapts to environmental changes through thermoregulation, but sudden weather shifts can compromise immunity, triggering or worsening diseases [33].

Older adults (≥60 years), with lower immunity, may be more vulnerable to temperature fluctuations. A recent study in mice showed that temperature changes alter microbial composition, increasing circulating ammonia levels, which impair muscle function by causing mitochondrial dysfunction, potentially explaining bidirectional transitions between sarcopenia states [34]. The effect size of mDTR (OR = 1.13) was smaller than common risk factors like age (OR = 3.58) but comparable to smoking (OR = 1.14) [35], with substantial population-wide implications. Specifically, reducing mDTR to the 25th percentile in the 2011–2013 cohort could prevent nearly one-fifth of sarcopenia cases (Population attributable fraction, PAF = 17.22%). This underscores the need for public health strategies, such as meteorological health early warning systems and health education programs, to mitigate temperature-related risks. For mDMT, a 1℃ increase within the 0–25℃ range was associated with a 4% reduction in possible sarcopenia risk (OR: 0.96, 95% CI: 0.94–0.99). Previous studies have suggested non-linear temperature-disease relationships (e.g., U-shaped, V-shaped, or J-shaped) [36], with threshold temperatures varying by disease and location [37, 38]. The observed negative correlation in this study may reflect the first half of such a curve, but further research is needed to confirm the association with extreme temperatures.

Meanwhile, our study found that people living in areas between 500 and 2100 m were more susceptible to the negative effects of mDTR on sarcopenia categories (OR: 1.27, 95% CI: 1.09–1.49) than those living below 500 m. This may be attributed to higher physical activity levels and lower BMI at medium altitudes, increasing susceptibility to mDTR effects [39]. Additionally, reduced air density at higher altitudes amplifies DTR, potentially triggering adaptive physiological responses. However, these findings remain speculative, and further evidence is needed to confirm the role of altitude in the DTR-health relationship.

While this study had notable strengths, several limitations should be acknowledged. Firstly, temperature exposure was estimated using the three-year average diurnal temperature range and daily mean temperature, without accounting for individual time-activity patterns, potentially introducing exposure estimation bias. Secondly, the analysis was constrained by annual data availability, limiting it to cross-sectional and two-year longitudinal follow-up data, which precluded examining associations at smaller time intervals (e.g., monthly or daily) and capturing short-term or seasonal effects. Finally, although we considered $PM_{2.5}$ and the interaction between mDTR and mDMT as confounders, other environment variables (e.g., PM_{10}, humidity) were not included. Consistent with previous studies [40, 41], temperature-related health risks remained largely unchanged regardless of air pollution control.

Conclusions

Our study emphasized the association between temperature and the risk of developing sarcopenia categories in Chinese older adults through cross-sectional and longitudinal analyses. Specifically, mDTR were positively associated with the risk of developing both possible sarcopenia and sarcopenia, especially for those living at an altitude of 500 m and above. Conversely, mDMT (0–25℃) was negatively associated with the risk of possible sarcopenia, consistent across demographic subgroups. Notably, possible sarcopenia may increase the risk of falls and hip fractures in older adults. This study deepens our understanding of the impact of temperature, particularly temperature fluctuations, on sarcopenia states in Chinese older adults, and provides a basis for developing preventive programmes for vulnerable populations in response to climate change.

Abbreviations

ASM	Appendicular Skeletal Muscle Mass
AWGS	Asian Working Group for Sarcopenia
BMI	Body Mass Index
CHARLS	China Health and Retirement Longitudinal Study
CNRDS	China Research Data Services Platform
DMT	Daily Mean Temperature
DTR	Diurnal Temperature Range
DXA	Dual-energy X-ray Absorptiometry
EWGSOP	European Working Group on Sarcopenia in Older People
GAMs	Generalized Additive Models
GVIF	Generalised variance inflation factor
IWGS	International Working Group on Sarcopenia
PAF	Population attributable fraction
PPS	Probability Proportional to Size
SPPB	Short Physical Performance Battery

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-025-06179-y.

Supplementary Material 1

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Not applicable.

Authors' Contributions

Yang Zhong, Qing Yang and Yunhong Wu conceived and designed the study. Yang Zhong analysed the data and wrote the main manuscript text. Suyuan Wang analysed part of the data. Doudou Hao, Suyin Zhu, Yanli Chen and Zhiyou Shi collected and organised the data. All authors reviewed and approved the final version of the manuscript.

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Data Availability

The datasets generated and/or analysed in the current study are available on the China Health and Retirement Longitudinal Study (CHARLS) website

[https://charls.pku.edu.cn] and the Chinese Research Data Services (CNRDS) Platform [https://www.cnrds.com].

Declarations

Ethics Approval and Consent to Participate

The CHARLS data collection was approved by the Biomedical Ethics Review Committee of Peking University. A written informed consent form was signed by each participant prior to being surveyed.

Consent for Publication

Not applicable.

Competing Interests

The authors declare no competing interests.

Author details

[1]Department of Biobank, Hospital of Chengdu Office of People's Government of Xizang Autonomous Region (Hospital.C.X.), Chengdu 610041, China
[2]Department of Endocrinology, Hospital of Chengdu Office of People's Government of Xizang Autonomous Region (Hospital.C.X.), Chengdu 610041, China
[3]Department of Basic Medicine, Tibet University, Lhasa 850000, China
[4]Department of Basic Medicine, Xizang Minzu University, Shaanxi 712082, China
[5]Outpatient Department, Sichuan Academy of Medical Sciences & Sichuan Provincial People's Hospital, Chengdu 610072, China
[6]Department of Cardiology, West China Hospital, Sichuan University, Chengdu 610041, China

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