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Research Article

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Associations between ambient temperature and acute myocardial infarction

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Abstract: Background. The associations between incidence of acute myocardial infarction (AMI) and the ambient temperature were mixed in prior studies.

Methods. Data of 2033 consecutive admissions of AMI in a central tertiary hospital in North China from 1st Jan 2003 to 31st Dec 2011 were collected. The weather data in this period were from the local meteorological department. Based on the ambient temperature information, we defined several ambient temperature indices, including daily average temperature, extremely low temperature, and daily temperature range, then characterized the independent associations between them and the incidence of AMI.

Results. The daily average temperature one day before was independently associated with AMI incidence rate: a rise of 5°C of the daily average temperature led to a 5% decrease in AMI admissions. Daily average temperature and temperature range two days before were independently associated with AMI incidence rate: a rise of 5°C of the daily average temperature led to a fall of 6% in AMI admissions, and a rise of 2°C of the daily temperature range led to a rise of 4% in AMI admission.

Conclusion. Low ambient temperature has substantial association with AMI, and can play an important role in warning and forecasting the incidence.

Keywords: Myocardial infarction; Temperature; Daily average temperature; Daily temperature range; Extremely low temperature.

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1 Introduction

Coronary heart disease (CHD) is the most common cardiovascular disease and the most common cause of death in the world [1]. CHD contributes to about 7.2 million or 12.2% of the total deaths worldwide [2]. With rapid economic development, China has experienced an epidemiological transition in mortality. The burden of CHD has more than doubled over the past two decades, resulting in over one million deaths annually [3, 4]. Moreover, this trend is expected to get worse, with the World Bank estimating that the number of acute myocardial infarctions (AMI) in China will increase from 8 million in 2010 to 23 million in 2030 [5]. AMI, as the most common CHD emergency, differs in incidence with weather and seasons [6,8], in which ambient temperature was believed to play a key role. However, most of the prior studies were from Western countries, and findings were mixed [9,11].Accordingly, to identify if an association between AMI and ambient temperature existed, we conducted an ecological study based on the admission record of a central tertiary hospital in North China and the local weather data, over a 9-year period. Moreover, we established some specific ambient temperature indices as tools for forecasting AMI incidence.

2 Materials and methods

2.1 Data source

Changzhi Heping Hospital, the highest-level hospital with 1500 beds in a city in North China, serves a population that has been stable from 1st Jan 2003 to 31st Dec 2011 (1/3 of population in the downtown district and suburban district, and 1/6 of population in the 6 surrounding counties, approximately 0.60 million to 0.62 million, with an annual increase of 0.5% [12]), so the number of admissions can be considered as a substitute for the incidence of a particular urgent clinical condition like AMI [13]. We established a database of 2033 patients consecutively admitted during this period, with a confirmed diagnosis of AMI (International Classification of Diseases, Ninth Revision, Clinical Modification codes 410.xx, International Classification of Diseases, Tenth Revision, Clinical Modification codes I21.xx, or text of AMI). We collected the demographic and clinical characteristics by review of medical records. We also obtained the weather records database during the 9 years from the local Bureau of Meteorology, including the daily average temperature, daily highest and lowest atmospheric temperature, and daily temperature range. The daily average temperature is the mean value of the highest and lowest temperature in each day. The daily temperature range equals to the difference between the highest and lowest temperature. We defined extremely low temperature as days with the lowest temperature below -10°C.

2.2 Statistical analyses

The demographic characteristics, clinical factors of the sample, and the AMI hospital admissions (representative of the incidence in the local area covered by the hospital) were all described in the study. To express patient characteristics, we used median and inter-quartile range or mean ± standard error of the mean to describe continuous variables, and frequency and percentages to describe categorical variables. We performed Mann-Whitney rank-sum tests to detect the difference in the admission number between two independent groups (extremely low temperature), and Kruskal-Wallis H tests for a comparison across more than two groups (the daily average temperature and the daily range of temperature). We conducted Poisson regression models with daily number of AMI hospital admissions as the dependent variable, to assess their independent association of temperature indices with the outcomes. All comparisons were two-tailed, with a $P<0.05$ considered statistically significant. All statistical analyses were performed with the SPSS 13.0 software package (SPSS Inc., Chicago, USA).

The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the ethics committee in Shanxi Medical University. Given the retrospective nature of this study, the ethics committee approved the waiver of patients' written consent.

3 Results

3.1 Characteristics of the study sample

Of the 2033 patients admitted with a confirmed diagnosis of AMI during the 9-year period, 1606 were male (79%). The median age was 58 with an age range from 49 to 68. Most of the patients were diagnosed as ST-segment elevation myocardial infarction, the most common type was simple anterior infarction with 670 cases (33%) and 404 simple inferior infarction cases (19.9%) were diagnosed; 15.9% of the patients had an AMI with unspecified location (323 cases). 37.5% of the patients had history of hypertension (762), 12.9% (263) with diabetes, 8.2% (166) with dyslipidemia, 0.6% (13) with chronic kidney disease.

Admissions for AMI increased dramatically each year, which is consistent with the national trend.[14] The number of admissions for AMI varied a lot over the year: there were more in winter, and less in summer, which implied an inverse correlation with the ambient temperature (Figure 1).

3.2 Rate of AMI and daily average temperature

In terms of average temperature, we focused on its relationship with the rate of AMI on the same day (lag 0), a day later (lag 1), and two days later (lag 2). The results suggested that the daily average was significantly inversely correlated with the daily rate of AMI on lag 1 (p=0.017) and lag 2 (p=0.007), meaning that the lower the temperature, on lag 1 or lag 2, the higher the rate of AMI. Ambient temperature was not related with the rate of AMI on lag 0 (p=0.056) (Table 1).

3.3 Rate of AMI in the days with extremely low temperature

During the 9-year period, there were 284 days with an extremely low temperature of less than -10°C, after which the lag 2 number of admissions for AMI was more than that observed after days with normal or above ambient temperature (p=0.043). However the differences were not significant after lag 0 (p=0.304) or lag 1 (p=0.345) (Table 2).

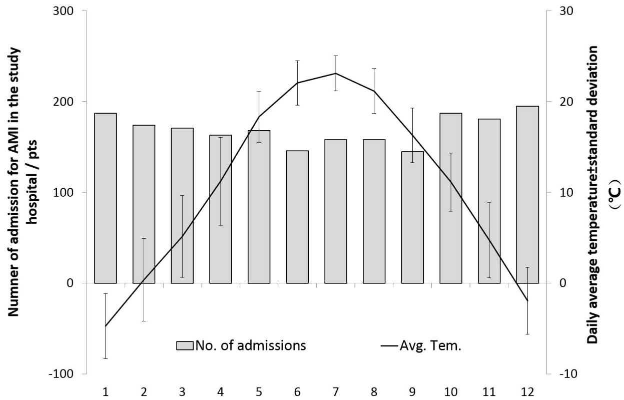

Figure 1: Acute myocardial infarction (AMI) hospitalized cases according to month.

The histogram represents the number of cases of AMI admitted to hospital. The numbers at the top of the graph represent the months of the year in order so January is 1. The line graph represents the average weather temperature, the error bars represent standard deviation.

3.4 Rate of AMI and daily temperature range

The daily temperature range correlated inversely with the number of lag 1 admissions for AMI (p=0.012), but not the number of lag 0 admissions for AMI (p=0.605) or lag 2 (p=0.142) (Table 3).

3.5 Multivariable analyses of the temperature indices

In the multivariable Poisson regression models, daily average temperature was independently associated with the lag 0, lag 1 and lag 2 AMI admission. The chance of lag 1 AMI admission decreased by 4% if the ambient temperature was 5°C higher. With respect to other temperature indices, no independent predictive significance of AMI admission was found in either lag 0, or lag 1 and lag 2 (Table 4).

4 Discussion

In terms of our study on AMI incidence and ambient temperature, we found independent correlations between the incidence of AMI and several temperature indices, with a pattern of lag for 1 or 2 days. This study has some differences to previously published data on the correlation between AMI incidence and ambient temperature. As far as we know, this is only the second study to be published in English relating to a Chinese population, but the other study focused on the patients' body temperatures rather than ambient temperature. We also found significant effects at lag 1 and in particular at lag 2, while other recent studies have not investigated these days in detail but have

Table 1: Daily average temperature correlates with acute myocardial infarction admission (n=2033 patients)

Daily average temperature (°C)	Lag 0※		Lag 1		Lag 2	
	No. of admission†	Incidence rate‡	No. of admission†	Incidence rate‡	No. of admission†	Incidence rate‡
<-5 (n*=226)	0.72±0.06	0.12 (0.112, 0.128)	0.65±0.06	0.108 (0.1, 0.116)	0.68±0.06	0.113 (0.105, 0.121)
-5- <0 (n*=422)	0.64±0.05	0.107 (0.102, 0.112)	0.66±0.04	0.11 (0.106, 0.114)	0.69±0.04	0.115 (0.111, 0.119)
0- <5 (n*=412)	0.70±0.05	0.117 (0.112, 0.122)	0.73±0.05	0.122 (0.117, 0.127)	0.72±0.05	0.12 (0.115, 0.125)
5- <10 (n*=406)	0.67±0.05	0.112 (0.107, 0.117)	0.67±0.05	0.112 (0.107, 0.117)	0.62±0.05	0.103 (0.098, 0.108)
10- <15 (n*=455)	0.61±0.04	0.102 (0.098, 0.105)	0.63±0.04	0.105 (0.101, 0.109)	0.64±0.04	0.107 (0.103, 0.11)
15- <20 (n*=595)	0.52±0.03	0.087 (0.084, 0.089)	0.51±0.03	0.085 (0.083, 0.087)	0.54±0.03	0.09 (0.088, 0.092)
>20 (n*=771)	0.59±0.03	0.098 (0.096, 0.1)	0.58±0.03	0.097 (0.095, 0.099)	0.56±0.03	0.093 (0.091, 0.095)

The daily average temperature was significantly inversely correlated with the daily rate of AMI on lag 1 (chi-square=15.401, p=0.017) and lag 2 (chi-square=17.791, p=0.007).
*Number of days with this temperature.
※Lag 0: the day when the temperature was recorded.
Lag 1: one day after day lag 0.
Lag 2: two days after day lag 0.
† Mean standard deviation
‡ Per 100,000 (95% confidence interval)

Table 2: Extremely low temperature correlates with acute myocardial infarction (AMI) admission (n=2033 patients)

Extremely low temperature	Lag 0※ No. of admission†	Incidence rate‡	Lag 1 No. of admission†	Incidence rate‡	Lag 2 No. of admission†	Incidence rate‡
No (n*=3003)	0.61±0.02	0.102 (0.101, 0.102)	0.61±0.02	0.102 (0.101, 0.102)	0.61±0.02	0.102 (0.101, 0.102)
Yes (n*=284)	0.68±0.06	0.113 (0.106, 0.12)	0.70±0.06	0.117 (0.11, 0.124)	0.73±0.06	0.122 (0.115, 0.129)

*Number of days with this temperature.
※Lag 0: the day when the temperature was recorded.
Lag 1: one day after day lag 0.
Lag 2: two days after day lag 0.
† Mean standard deviation
‡ Per 100,000 (95% confidence interval)

Table 3: Daily temperature range correlates with acute myocardial infarction (AMI) admission (n=2033 patients)

Daily temperature range (°C)	Lag 0※ No. of admission†	Incidence rate‡	Lag 1 No. of admission†	Incidence rate‡	Lag 2 No. of admission†	Incidence rate‡
<7 (n*=526)	0.62±0.04	0.103 (0.1, 0.107)	0.65±0.04	0.108 (0.105, 0.112)	0.64±0.04	0.107 (0.103, 0.11)
7- <9 (n*=361)	0.57±0.04	0.095 (0.091, 0.099)	0.58±0.05	0.097 (0.091, 0.102)	0.55±0.05	0.092 (0.086, 0.097)
9- <11 (n*=482)	0.63±0.04	0.105 (0.101, 0.109)	0.63±0.04	0.105 (0.101, 0.109)	0.56±0.04	0.093 (0.09, 0.097)
11- <13 (n*=521)	0.67±0.04	0.112 (0.108, 0.115)	0.53±0.04	0.088 (0.085, 0.092)	0.69±0.04	0.115 (0.111, 0.119)
13- <15 (n*=509)	0.64±0.04	0.107 (0.103, 0.11)	0.64±0.04	0.107 (0.103, 0.11)	0.61±0.04	0.102 (0.098, 0.105)
15- <17 (n*=495)	0.58±0.04	0.097 (0.093, 0.1)	0.58±0.04	0.097 (0.093, 0.1)	0.64±0.04	0.107 (0.103, 0.11)
>17 (n*=393)	0.61±0.04	0.102 (0.098, 0.106)	0.76±0.05	0.127 (0.122, 0.132)	0.64±0.04	0.107 (0.103, 0.111)

*Number of days with this temperature range.
※Lag 0: the day when the temperature was recorded.
Lag 1: one day after day lag 0.
Lag 2: two days after day lag 0.
† Mean standard deviation
‡ Per 100,000 (95% confidence interval)

Table 4: Multivariate analysis of the temperature indices with acute myocardial infarction incidence (n=2033 patients)

	Lag 0※				Lag 1				Lag 2			
	Parameter estimates	SEM	RR (95%CI)	P-value	Parameter estimates	SEM	RR (95%CI)	P-value	Parameter estimates	SEM	RR (95%CI)	P-value
Average temperature	-0.043	0.013	0.96 (0.93, 0.98)	0.001	-0.043	0.013	0.96 (0.93, 0.98)	0.001	-0.045	0.013	0.96 (0.93, 0.98)	0.001
Daily temperature range	0.003	0.011	1.00 (0.98, 1.03)	0.774	0.018	0.011	1.02 (1.00, 1.04)	0.126	0.013	0.012	1.01 (0.99, 1.04)	0.239
Extremely low temperature event	-0.048	0.090	0.95 (0.80, 1.14)	0.591	-0.027	0.089	0.97 (0.82, 1.16)	0.756	0.009	0.088	1.01 (0.85, 1.20)	0.922

※Lag 0: the day when the temperature was recorded.
Lag 1: one day after day lag 0.
Lag 2: two days after day lag 0.
SEM: standard error; RR: relative risk; 95%CI: 95% confidence interval.

either concentrated on lag 0 and lag 1 or a period of a few days [15, 16].

Changzhi is a city in the Shanxi Province, where the main terrain types are hills and mountains, with an average altitude of 1000 meters. The mountains are well covered with vegetation. The climate is “temperate continental monsoon climate”. Air humidity is 61% on average during a year. The annual average wind speed is 1.1 - 2.3 m/s. The general weather is similar to that of Beijing, but with less air pollution. During the study period there were few extremely high or low temperatures in summer or winter. The year-average temperature varied between 4.9°C to 10.4°C. The coldest month was January and the hottest was July, with average temperatures of -6.9°C and 22.5°C, respectively. Our study suggested that AMI admissions in the Changzhi area distribute differently over seasons. There are fewer admissions in summer and more in winter, inversely correlating with the average temperature.

Ambient temperature is a major contributing factor to morbidity and mortality of cardiovascular and cerebrovascular diseases [17]. According to our study, the daily average temperature inversely correlated with the incidence of AMI at lag 1 and 2. The lower the ambient temperature was, the higher the incidence of AMI became (Table 1). Results also showed a significant increase in AMI incidence at lag 1 and 2 when the ambient temperature was low. This is slightly different from the study by Lee at al [15] that found that the effects of weather variations had a more significant influence on the occurrence of AMI, in females and the younger aged group <65 years. The daily temperature range positively correlated with AMI incidence at lag 1. The wider the temperature range, the higher the AMI incidence (Table 3). These results are supported by Lim et al [16]. Low ambient temperature is associated with AMI incidence, possibly because cold can activate the sympathetic nerve, leading to local over reactivation of the coronary artery, coronary arteriospasm, acute coronary insufficiency, and AMI [18]. Cold can also increase the secretion of catecholamine, which can promote platelet clumping, thrombogenesis, and myocardial infarction [19]. A fall in ambient temperature can increase blood pressure [20]. While even short-term falls in ambient temperature in the normal range has been shown to cause prolonged haemoconcentration and hypertension [21]. In addition to the time needed by the aforementioned pathophysiological mechanisms to trigger myocardial infarction, the lag effects of temperature can also be attributed to the particularly long pre-hospital delay in patients with AMI in China [22].There are two plausible explanations for the time lags demonstrated in the current study: 1) it could take some time that the cold promote platelet clumping, thrombogenesis to increase the AMI risk; 2) about half of patients with AMI in China arrived at hospitals over 12 hours after their onset [22]. We believe the mechanism worth further study in future.

These results implied that compared with an ambient temperature of 0-5°C, AMI incidence is even lower when the daily average temperature is below 0°C, which might be related with the use of indoor heating systems. Outdoor temperature cannot fully reflect a patient’s exposure, since indoor temperature could be much higher because of heating.

The multivariate analyses suggested that the lag 1 daily average temperature has an independent relationship with AMI incidence rates. The chance of AMI admission decreased by 5%, if the lag 1 temperature was 5°C higher (Table 4). In another model built for AMI incidence after lag 2, similar independent predictive significance was found in daily average temperature and daily temperature range. 6% fewer AMI were admitted, if the average lag 2 temperature was 5°C higher; when the lag 2 temperature range increased by 2°C, the AMI incidence rate increased by 4% (Table 4). Bhaskaran et al. [23] investigated 84,010 cases of myocardial infarction admission from 2003 to 2006 in 15 towns in England and Wales, and they found a linear relationship between ambient temperature and myocardial infarction on the day of incidence and for the next 28 days, a decrease of ambient temperature by 1°C enhanced the risk of myocardial infarction by 2.0 (95% CI: 1.1-2.9). The most obvious effect occurred in the median time, namely 2d-7d or 8d-14d; every 1°C increase in ambient temperature led to a fall in incidence by 0.6 (95% CI: 0.2-1.19) and 0.7 (95% CI: 0.3-1.10) respectively. High ambient temperature did not have an effect.

The amplitude of temperature during the day is another important natural factor for AMI incidence, which indicated the increased risk of AMI induced by temperature change during changing season period. Yasue et al [24] found that the coronary artery was under high tension in the morning, and just slight stimulation could cause a spasm. While the coronary artery was under low tension in the afternoon, exercise did not cause spasm, but severe organic heart disease will lead to coronary artery stenosis. The change of coronary artery tension may correlate with change of ambient temperature during the day. In terms of blood pressure it has been demonstrated that the natural daytime variations have a higher magnitude when the ambient temperature is lower than the average [25]. So these factors may all help contribute to the higher incidence of AMI during cold weather.

By collection and analysis of the clinical data of AMI patients over a 9-year period and analysis of the meteorological data during the same time period, the relationship between different temperature factors and AMI incidence risk has been identified and quantified. The hysteresis of the relationship has also been also identified. Our study provides reference for primary prevention of AMI, reminding CHD patients to pay attention to ambient temperature risk factors and protect themselves. We observed that there was no difference over the year or over the seasons (spring as March to May, summer as June to August, fall as September to November, and winter as December to February). This lack of difference may be due to a number of confounding factors such as comorbidities, medical history, time to reach the hospital, first-aid, and treatments.

4.1 Limitations

Certain factors should be considered in the interpretation of our study. Firstly, we did not use community-based incidence data, but estimated rates based on the admission data in a predefined hospital. There may have been some deaths that were not included in the data. Secondly, we assessed several temperature indices on lag 0, lag 1, and lag 2, which may raise the question about the multiple comparison and larger chance of a type I error in the hypothesis tests. However, in the analysis, we did not adjust the α value, since we would rather keep the sensitivity in such an exploratory study. Secondly, some seasonal variation in a risk of AMI, like the lowest rate of AMI in September, rather than July, could not be solo attributed to the temperature. Air pollution and other environmental factors were also influencing the risk of AMI in population [26-29]. The confounding effects and interactions with temperature of these factors could be considered in future studies. Thirdly, the current findings could be confounded by some temperature-dependent risk factors like physical activities, alcohol consumption, and tobacco smoking, for which we lack the data source to detect or adjusted for in our study. Large-scale population cohort studies are needed to generate further knowledge on that. Finally, we did not have the data related to the place of the AMI attack for each patient (indoor or outdoor), which would have affected the temperature he/she was exposed to.

5 Conclusions

Implications for Practice: Low ambient temperature shows forecasting value for AMI, which suggested that high-risk patients with CHD should be aware of the additional risk on cold days, and pay more attention to self-protection, in particular lag 2 temperatures are important. Secondly, the Bureau of Meteorology and other relevant organizations should offer the public information about potential harm before high-risk days. Finally, more comprehensive acute myocardial ischemia forecast indicators and algorithms based on ambient temperature should be established, to pre-warn of the risk of increased AMI risk.

Conflict of interest statement: Authors state no conflict of interest.

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Appendix

Multivariate analysis (Logistic regression model) of the temperature indices with acute myocardial infarction incidence (n=2033 patients)

	Lag 0※				Lag 1				Lag 2			
	Parameter estimates	SEM	OR (95%CI)	P-value	Parameter estimates	SEM	OR (95%CI)	P-value	Parameter estimates	SEM	OR (95%CI)	P-value
Average temperature	-0.06	0.02	0.94 (0.90, 0.98)	0.004	-0.05	0.02	0.95 (0.91, 0.99)	0.015	-0.06	0.02	0.94 (0.90, 0.98)	0.004
Daily temper- ature range	0.04	0.02	1.04 (1.00, 1.08)	0.032	0.03	0.02	1.03 (0.99, 1.06)	0.170	0.04	0.02	1.04 (1.00, 1.08)	0.032
Extremely low temperature event	-0.06	0.11	0.94 (0.75, 1.18)	0.581	-0.09	0.12	0.92 (0.73, 1.15)	0.455	-0.06	0.11	0.94 (0.75, 1.18)	0.581

※Lag 0: the day when the temperature was recorded.
Lag 1: one day after day lag 0.
Lag 2: two days after day lag 0.
SEM: standard error; OR: odds ratio; 95%CI: 95% confidence interval.