

Effects of ambient temperature on daily emergency department visits for abdominal pain: a distributed lag nonlinear time series analysis in Wuhan

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Abstract

Background: Ambient temperature has been shown to have a positive association with the increasing emergency department burden. However, no studies have investigated the effects of ambient temperature on the number of emergency department visits (EDVs) for abdominal pain. Therefore, we conducted this study to evaluate the relationship between the two, with the aim of rationally allocating medical resources.

Methods: We collected daily numbers of EDVs for abdominal pain data from the Zhongnan Hospital of Wuhan University and daily meteorological data from Wuhan from January 1, 2016, to December 31, 2018. We chose a generalized additive model combined with a distributed lag nonlinear model to assess the short-term effects of ambient temperature on EDVs for abdominal pain. We conducted stratification analyses according to sex, age, and the Chinese Emergency Triage Scale.

Results: A total of 16,318 visits for abdominal pain were identified during the study period. The significant effects of extremely low temperature (-1°C) and moderately high temperature (26°C) were observed at Lag 0 day and Lag 0–1 day models. In the Lag 0 day model, the relative risks for extremely low and moderately high temperatures were 0.83 (95% confidence interval [CI]: 0.70–0.99; $P = 0.038$) and 1.15 (95% CI: 1.06–1.25; $P = 0.001$), respectively. Younger people were more likely to be affected by temperature. Cold and mildly hot weather were associated with the L2 and L3 levels, respectively. Moreover, low temperatures were negatively correlated with the risk of urolithiasis and cholecystitis.

Conclusion: Low temperatures significantly reduced abdominal pain-related EDVs, whereas high temperatures had the opposite effect.

Keywords: Abdominal pain, Ambient temperature, Chinese emergency triage scale, Distributed lag nonlinear model, Emergency department visits, Time-series study

Introduction

Multiple systems of the human body are affected by ambient temperature, such as the cardiovascular, respiratory, and urinary systems.^[1–3] Extreme temperatures have been shown to have a positive association with the increasing mortality risk and loss of health.^[4,5] Some meta-analyses have demonstrated a positive correlation between heat exposure and an increase in disease-related morbidity and mortality.^[6,7] The risk of disease-related

morbidity and mortality increases by 1.1% and 2.1%, respectively, when the temperature rises by 1°C . Furthermore, this phenomenon is more pronounced in urban areas of China.^[7] The Intergovernmental Panel on Climate Change has warned us about the risk of extreme temperatures.^[8] Wuhan has been called the “oven city” because of its extremely hot and humid summer, but it is also cold in winter without central heating.^[9] Thus, it is beneficial for us to figure out the potential correlations between ambient temperature and some diseases.

Hospital emergency departments play an integral role in handling public health events; however, overcrowding is a recurrent problem. China has initiated the Chinese Emergency Triage Scale (CETS), which divides emergency visits into four grades (L1, L2, L3, and L4) according to the illness and risk of patients, to relieve the chaos and allow for rational medical resource allocation. Some studies investigating the relationships between ambient temperature and emergency department visits (EDVs) have revealed that extreme temperatures will increase the burden of emergency care.^[10–12] A study including 18 sites in China has indicated that a 1°C increase in average daily temperature would lead to a 1.07% increase in EDVs.^[10] In addition, a correlation between rising temperatures and ambulance callouts can be found in some research. An increase of 7% increase in the risk of ambulance dispatches due to all causes is associated with a 5°C increase in average daily temperature. Similar results were observed in a separate study in Australia.^[12,13]

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Among all the EDVs, people whose chief complaint is abdominal pain account for a large proportion.^[14,15] Among all the common diagnoses of highly frequent visitors to the emergency department, abdominal pain accounts for 8.4%.^[16] Similarly, abdominal pain is also a common complaint and the reason for return visits to the pediatric emergency room.^[17,18] Abdominal pain is a nonspecific symptom, the etiology of which includes but is not limited to acute myocardial infarction, gastrointestinal infection, urinary calculi, and rupture bleeding of ectopic pregnancy, among others. Therefore, a timely diagnosis and treatment are required. Some studies have indicated that ambient temperature affects diseases that manifest as abdominal pain, but others have yielded conflicting results. For example, temperature has been positively correlated with the risk of gastrointestinal infections, as seen not only in China, but also around the world.^[19–21] However, a study has shown that lower temperatures may lead to an increased risk of viral gastrointestinal infections.^[22] A positive correlation between ambient temperature and hospitalization for biliary tract disease and urolithiasis has also been reported.^[23,24] However, studies on the potential correlations between ambient temperature and specific symptoms such as abdominal pain in EDVs are still lacking. Such studies will contribute to determining the characteristics of EDVs, allowing for precautions and maintenance of order in hospitals.

Therefore, we conducted this study to investigate the correlation between ambient temperature and EDVs for abdominal pain in the Zhongnan Hospital of Wuhan University using data from January 1, 2016, to December 31, 2018. We also studied the correlations between sex, age, and CETS grades to identify at-risk populations. Our study may be beneficial for risk assessment, reduction of health decline, and rational allocation of medical resources.

Methods

Wuhan lies in central China (latitude 30°35'N and longitude 114°17'E) and is the capital of Hubei Province, with a population size of over 10 million. It comprises 7 urban and 6 rural districts, covering 8569.15 km² in total. Wuhan has a humid monsoon, subtropical climate (<https://www.wuhan.gov.cn/>). The average daily temperature during the study period was 30°C in July and 4°C in January.

Emergency department visits data

The majority of EDVs at Zhongnan Hospital were from the Wuchang District of Wuhan, where the hospital is located. It is a district that contains 10.9% of the population of the whole urban area (<https://tjj.wuhan.gov.cn/>). We acquired EDVs data between January 1, 2016, and December 31, 2018, from the Zhongnan Hospital of Wuhan University and specifically selected patients with abdominal pain according to their chief complaint (N=16,318) from the medical database. All visits were diagnosed by doctors in the emergency department, according to the Tenth version of the International Classification of Diseases (ICD-10). Using the ICD-10, some common diseases with abdominal pain as the main complaint were categorized as follows: urolithiasis, N20.9; cholecystitis, K81.0; gastroenteritis, K52.9; appendicitis, K35; pancreatitis, K85; and ileus, K56. The study protocol was approved by the Medical Ethics Committee of Zhongnan Hospital (approval number: 2021018K).

To evaluate the distribution of the data, we calculated the dispersion parameter φ for the EDVs, obtaining a value of 3.91.

Subsequently, we constructed a quasi-Poisson regression model, which yielded an estimated φ of 3.70. This also supported the fact that the data adhered to a quasi-Poisson distribution.

Patient and public involvement

Patients and the general public were not involved in the study. Anonymization procedures were applied during the data extraction process, and further deidentification measures were taken prior to data analysis. Data analysis was performed at the aggregate level. Therefore, this study did not necessitate consent for participation nor publication.

Environmental and meteorological data

The mean daily temperature better summarizes the temperature of an entire day. We acquired the data of average daily temperature (°C) and relative humidity (%) from January 1, 2016, to December 31, 2018, from the China Meteorological Data Sharing Service System. The relative humidity data for August 2, 2018, were missing (<0.01%), and we eliminated the hospital data for that day.

The World Health Organization's (WHO) definition of extreme temperatures is not yet definite, and there is no global consensus on specific values. Because of the different climatic conditions in different regions, extreme temperature standards vary. According to the China Meteorological Administration (<https://www.cma.gov.cn/>), the criteria for extremely low and high temperatures should be determined based on multiple factors such as local climate conditions, agriculture, production, and life. Based on previous studies, the 1st and 99th percentiles of temperature were defined as extremely low and extremely high, respectively.^[25,26]

Statistical analysis

First, we conducted Shapiro-Wilk and Kolmogorov-Smirnov tests on the variables related to research duration and total number of participants, respectively. The results showed that the variables did not follow a normal distribution ($P < 0.001$). Therefore, we used the median and interquartile range (IQR) to represent the overall data profile. Considering the lag effect and nonlinear exposure-response dependencies of environmental stressors, we selected the semiparametric generalized additive model (GAM) with distributed lag nonlinear model (DLNM), to perform a time-series analysis, to explore the acute effect of ambient temperature on EDVs for abdominal pain. GAM was used to adjust for confounders, whereas DLNM estimated temperature-related risks. The DLNM is a method that can model the effect of factors, showing both nonlinear dependencies and delayed effects simultaneously.^[27] Thus, it has been widely used to evaluate the lag-exposure response in time-series effects. Covariates were included in the main model. The core model is described as follows:

$$\log [E(Y_t)] = cb(\text{temperature}, df = 5, \text{lag}, df = 5) + ns\left(\text{time}, df = \frac{7}{\text{year}}\right) + ns(\text{humidity}, df = 2) + DOW + \text{Holiday} + \text{intercept}$$

where $E(Y_t)$ represents the count of EDVs for abdominal pain on day t , cb is the cross-basis for daily mean temperature, df indicates the degrees of freedom, ns is the natural cubic spline for nonlinear variables, DOW is a dummy variable for the day of the week, and $Holiday$ is a binary variable for public holidays. We chose a degree of freedom $df = 7/\text{year}$ in order to control for

Table 1**Summary of Daily Weather Conditions and EDVs for Abdominal Pain**

Variables	Min	P25	Median	P75	Max
Temperature (°C)	−4	10	19	26	35
Humidity (%)	36	65	76	86	100
Number of EDVs for abdominal pain	1	9	13	20	42
Male	0	4	6	10	25
Female	0	5	7	11	25
<45	0	5	8	12	31
≥45	0	3	6	8	24
L1	0	0	0	0	3
L2	0	0	1	2	8
L3	0	4	8	15	36
L4	0	1	2	4	16

All variables were tested for normality using the Shapiro-Wilk test and Kolmogorov-Smirnov test. None of the variables followed a normal distribution ($P < 0.001$).

CETS, Chinese Emergency Triage Scale; EDVs, emergency department visits; Max, maximum; Min, minimal; P25, 25th percentile; P75, 75th percentile.

the effects of seasons and long-term trends, as per previous studies.^[28] In order to achieve the best balance among interpretation bias, prediction accuracy, and model complexity, we chose the “bs” function and set 5 df for the temperature space, “ns” function and 5 df for its lag space, and 2 df for relative humidity, after adjusting the parameters of multiple models (using GAM). This model explained a variance of 63.3%, indicating moderate predictive capability. A generalized cross-validation value of 1.58 can mitigate the risk of overfitting. The results of the hyperparameter debugging are shown in Supplemental Table 1 (<http://links.lww.com/ECCM/A97>). To confirm the robustness of the results, we conducted sensitivity analyses of single-day lag effects and cumulative temperature effects on lags 0 to 14, 0 to 21, and 0 to 28 to justify the 7-day maximum period. Furthermore, we selected 2 other models with better performance to draw the exposure-response (E-R) curve and evaluated the robustness of this model.

The Q-Q plots of deviance residuals, deviance residuals versus linear predictor, histogram of deviance residuals, and response values versus fitted values are drawn to verify the fitting effect of the model (Supplemental Figure 1, <http://links.lww.com/ECCM/A98>).

The effects are shown as the relative risks (RRs) and 95% confidence intervals (CIs) of the EDVs for abdominal pain at the 1st, 25th, 75th, and 99th percentiles of temperature relative to median temperature (19°C). The E-R relationship curves between

the temperature and EDVs for abdominal pain with different lags are also plotted.

We conducted three stratification analyses, according to sex, age (<45 years old and ≥45 years old), and CETS (L1, L2, L3, L4), to explore the differing correlations among different groups of people. We also subdivided the patients according to their primary diagnoses to further explore the correlations between ambient temperature and certain diseases.

All statistical models were run in R software (version 4.4.2; supplier, The R Foundation for Statistical Computing, in Vienna, Austria) using the “mgcv” and “dlnm” packages. Statistical tests were 2-sided, with correlations of $P < 0.05$ meaning statistically significant.

Results

Data from 212,612 EDVs at Zhongnan Hospital (from January 1, 2016, to December 31, 2018) were obtained, among which 16,318 (7.68%) visits were for complaints of abdominal pain. Males and middle-aged and elderly people (≥45 years) comprised 48.5% and 41.8% of the visits, respectively. The median relative humidity was 76% (ranging from 36% to 100%), and the median temperature was 19°C (IQR: 10–26°C). The results are summarized in Table 1. During the study period, the minimum and maximum temperatures in Wuhan were −4°C and 35°C, respectively. Depending on the threshold set (1st and 99th), the cutoff values of extremely low temperature and extremely high temperature were −1°C and 33°C, respectively. Extreme ambient temperatures occurred on 25 days in Wuhan.

We used GAM to control for confounders and DLNM to estimate the temperature-lag associations. The DLNM results from DLNM were presented unless otherwise noted. Table 2 shows that the RR of EDVs for abdominal pain correlated with daily mean temperature at the 1st, 25th, 75th, and 99th percentiles of temperature relative to the median temperature over different lag days (0, 0–1, 0–2, 0–3, 0–4, 0–5, 0–6, and 0–7 day). At Lag 0 day, moderately high temperature (75th percentile, 26°C) significantly increased the risk (RR: 1.15; 95% CI: 1.06–1.25; $P = 0.001$), whereas extremely low temperature (1st percentile, −1°C) reduced the risk (RR: 0.83; 95% CI: 0.70–0.99; $P = 0.038$). At Lag 0–1 day, the positive association remained significant at moderately high temperature with RR of 1.11 (95% CI: 1.01–1.20; $P = 0.017$).

Fig. 1 presents the E-R curves of the daily mean temperature and the RR of EDVs for abdominal pain on different lag days.

Table 2**Relative Risks of EDVs for Abdominal Pain Correlated with Daily Temperature**

Lag Effects	RR (95% CI) of 1st*	RR (95% CI) of 25th*	RR (95% CI) of 75th*	RR (95% CI) of 99th*
Lag 0 day	0.83 (0.70–0.99)†	0.93 (0.85–1.02)	1.15 (1.06–1.25)‡	1.07 (0.90–1.27)
Lag 0–1 day	0.87 (0.73–1.03)	0.97 (0.89–1.06)	1.11 (1.01–1.20)†	1.04 (0.87–1.22)
Lag 0–2 day	0.89 (0.73–1.08)	1.00 (0.91–1.11)	1.06 (0.96–1.16)	0.95 (0.80–1.11)
Lag 0–3 day	0.90 (0.80–1.13)	1.04 (0.94–1.16)	1.00 (0.90–1.10)	0.98 (0.82–1.18)
Lag 0–4 day	0.92 (0.74–1.15)	1.06 (0.94–1.19)	0.98 (0.88–1.10)	0.99 (0.81–1.20)
Lag 0–5 day	0.93 (0.73–1.18)	1.07 (0.94–1.21)	1.00 (0.89–1.13)	0.97 (0.79–1.20)
Lag 0–6 day	0.97 (0.75–1.24)	1.05 (0.95–1.26)	0.95 (0.84–1.08)	0.89 (0.71–1.11)
Lag 0–7 day	1.00 (0.76–1.30)	1.11 (0.96–1.29)	1.94 (0.82–1.08)	0.88 (0.69–1.11)

* Median temperature, 19°C.

† $P < 0.05$.

‡ $P < 0.01$.

CI, confidence interval; EDVs, emergency department visits; RR, relative risk.

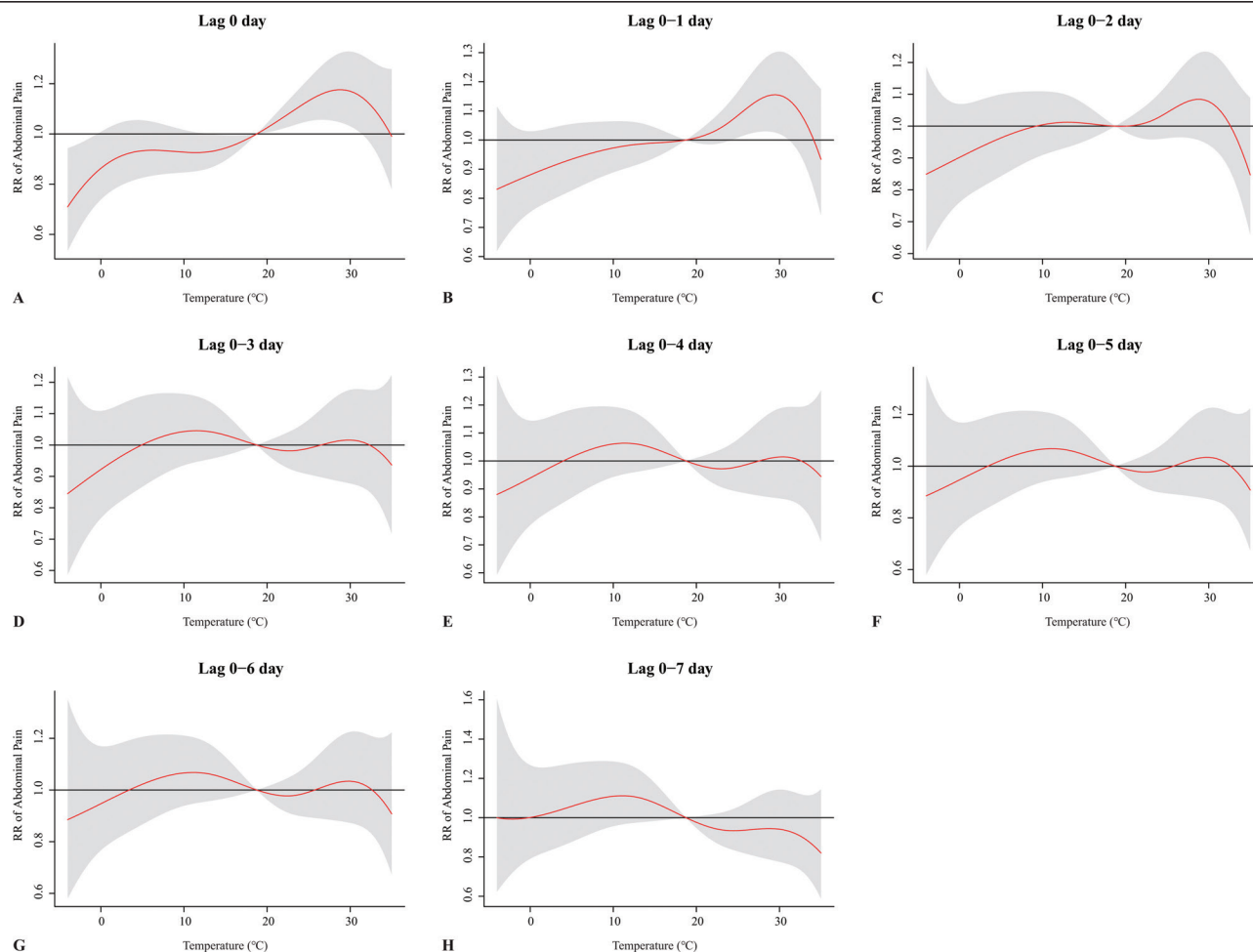


Figure 1. The E-R curves of daily mean temperature and RR of EDVs for abdominal pain at different lag days. Daily mean temperatures are shown on the abscissa, and the RRs of the EDVs for abdominal pain are shown on the ordinate. The red lines represent the RRs, and the gray areas represent the 95% CIs for the risk estimates. (A)–(H) The E-R curves of Lag 0 day, Lag 0–1 day, Lag 0–2 day, Lag 0–3 day, Lag 0–4 day, Lag 0–5 day, Lag 0–6 day, and Lag 0–7 day, respectively. CI, confidence interval; EDVs, emergency department visits; E-R, exposure-response; RR, relative risk;

This association remained marginally significant at Lag 0–1 day but disappears with longer lag periods (Lag 0–2 day and beyond). In the Lag 0 day model, increasing temperature was associated with an elevated risk of EDVs, within the temperature range of 18.8°C to 34.8°C. This risk reached a peak at 29.0°C, with an RR of 1.18 (Supplemental Figure 2, <http://links.lww.com/ECCM/A99>). The overall trend of the Lag 0–1 day model was similar to that of the Lag 0 day model. These results suggested that the influence of temperature on the risk of EDVs for abdominal pain is short-term, with opposing effects for extremely cold and moderately high temperatures. The results of the sensitivity analysis also revealed that the impact of temperature was not persistent over the long term (Supplemental Figure 3, <http://links.lww.com/ECCM/A100>; Supplemental Figure 4, <http://links.lww.com/ECCM/A101>). In addition, the results calculated using the GAM remained robust after adjusting the model parameters (Supplemental Figure 5, <http://links.lww.com/ECCM/A102>; Supplemental Figure 6, <http://links.lww.com/ECCM/A103>).

Fig. 2 shows the E-R curves of daily mean temperature and the RR of daily EDVs for abdominal pain at lag 0 days, stratified by sex, age, and CETs. The RRs of the EDVs for abdominal pain correlated with the daily mean temperature among the subgroups at the selected cutoff points are detailed in Table 3. EDVs for abdominal pain of males significantly decreased in extremely

cold temperatures (RR: 0.78; 95% CI: 0.62–0.98; $P=0.034$), whereas the risk was elevated among females at moderately high temperatures (RR: 1.22; 95% CI: 1.10–1.36; $P<0.001$). An increased risk of EDVs for abdominal pain was found at moderately high temperatures in both younger and middle-aged and elderly people (≥ 45 years old). The risk of the former (RR: 1.16; $P=0.006$) was higher than that of the latter (RR: 1.13; $P=0.044$). The interaction test implemented within the DLNM-GAM framework showed statistically significant differences only in the age subgroups ($P=0.004$). However, in the age subgroup, the RR differences approached 0 throughout the temperature spectrum (Supplemental Figure 7, <http://links.lww.com/ECCM/A104>). Extremely (RR: 0.49; 95% CI: 0.30–0.79; $P=0.004$) and moderately (RR: 0.72; 95% CI: 0.56–0.92; $P=0.010$) cold weather may help reduce the EDVs for abdominal pain with L2 of CETs, but no significant effects on visits with other grades were observed. In addition, there existed a significant positive relationship between moderately high temperature and EDVs for abdominal pain with L3 (RR: 1.23; 95% CI: 1.11–1.38; $P<0.001$).

To further explore the possible mechanisms, we subdivided patients according to their preliminary diagnoses. Fig. 3 and Table 3 illustrate the E-R curves of daily mean temperature and the RR of daily EDVs for some diseases that may manifest as abdominal pain. The results demonstrated that moderately low temperatures

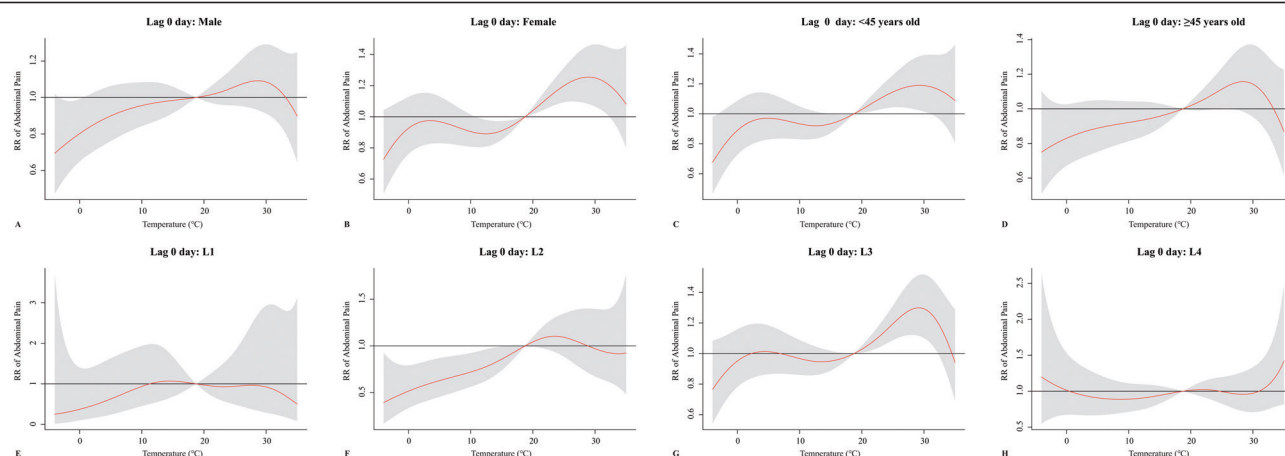


Figure 2. E-R curves of daily mean temperature and RR of daily EDVs for abdominal pain at Lag 0 day, stratified by sex, age, and CETS. Daily mean temperatures are shown on the abscissa, and the RRs of the EDVs for abdominal pain are shown on the ordinate. The red lines represent the RRs, and the gray areas represent the 95% CIs for the risk estimates. (A) and (B) The E-R curves of the sex subgroup at Lag 0 day. (C) and (D) The E-R curves of the age subgroup at Lag 0 day. (E)–(H) The E-R curves of the CETS subgroup at Lag 0 day. CETS, Chinese Emergency Triage Scale; CI, confidence interval; EDVs, emergency department visits; E-R, exposure-response; RR, relative risk.

were associated with a reduced incidence of urolithiasis and cholecystitis (both $P=0.047$). Extremely low temperatures were significantly correlated with an increased risk of appendicitis (RR: 1.78; $P=0.015$), whereas extremely high temperatures were significantly associated with a decreased risk of pancreatitis (RR: 0.29; $P=0.003$). No significant correlations were observed among ambient temperature, gastroenteritis, and ileus.

Discussion

The median temperature of Wuhan during our study period was 19°C, with a lowest temperature of −4°C and a highest of 35°C. The increase in temperature due to climate change warns us that

it is necessary to determine the mechanisms by which hot temperatures affect human health. Hitherto, there have been few studies investigating the correlation between ambient temperature and daily visits for abdominal pain, let alone complaints resulting from emergency department visits.

Our study concluded that hypothermia is associated with a decrease in EDVs for abdominal pain, and hyperthermia is positively associated with the risk of EDVs for abdominal pain. This conclusion is similar to our previous study.^[29] Previous studies have shown that a cold environment can reduce the body's reaction to pain stimulation.^[30] In addition, the abdomen has great heat loss in high air temperatures but little heat loss in low air temperatures.^[31] If there is a greater loss of core temperature,

Table 3

Relative Risk of EDVs for Abdominal Pain Correlated with Daily Temperature Among Different Groups

Groups	1st Percentile Relative to Median Temperature RR (95% CI)*	25th Percentile Relative to Median Temperature RR (95% CI)*	75th Percentile Relative to Median Temperature RR (95% CI)*	99th Percentile Relative to Median Temperature RR (95% CI)*
Sex				
Male	0.78 (0.62–0.98)†	0.96 (0.84–1.08)	1.07 (0.95–1.21)	0.98 (0.78–1.24)
Female	0.89 (0.72–1.11)	0.91 (0.81–1.01)	1.22 (1.10–1.36)§	1.16 (0.93–1.43)
Age				
<45 years old	0.85 (0.68–1.06)	0.93 (0.83–1.05)	1.16 (1.04–1.30)‡	1.14 (0.92–1.40)
≥45 years old	0.81 (0.64–1.03)	0.92 (0.81–1.04)	1.13 (1.00–1.28)†	0.99 (0.77–1.26)
CETS				
L1	0.33 (0.07–1.53)	0.94 (0.45–1.94)	0.95 (0.45–2.04)	0.67 (0.16–2.80)
L2	0.49 (0.30–0.79)‡	0.72 (0.56–0.92)†	1.07 (0.84–1.37)	0.92 (0.57–1.47)
L3	0.92 (0.74–1.14)	0.97 (0.86–1.09)	1.23 (1.11–1.38)§	1.10 (0.89–1.37)
L4	1.05 (0.66–1.67)	0.89 (0.71–1.11)	0.98 (0.79–1.21)	1.18 (0.78–1.79)
Primary diagnosis				
Urolithiasis	0.98 (0.65–1.48)	0.79 (0.63–1.00)†	1.15 (0.94–1.41)	1.15 (0.78–1.71)
Cholecystitis	0.76 (0.50–1.15)	0.79 (0.63–1.00)†	1.19 (0.96–1.47)	1.03 (0.67–1.60)
Gastroenteritis	0.99 (0.68–1.46)	0.93 (0.76–1.14)	1.05 (0.88–1.26)	0.83 (0.59–1.17)
Appendicitis	1.78 (1.12–2.84)†	0.97 (0.75–1.26)	1.01 (0.80–1.28)	0.66 (0.40–1.08)
Pancreatitis	1.60 (0.81–3.16)	0.98 (0.65–1.47)	0.99 (0.67–1.47)	0.29 (0.13–0.65)‡
Ileus	1.09 (0.58–2.02)	0.79 (0.55–1.12)	0.91 (0.65–1.28)	0.94 (0.46–1.90)

* Median temperature, 19°C.

† $P<0.05$.

‡ $P<0.01$.

§ $P<0.001$.

CETS, Chinese Emergency Triage Scale; CI, confidence interval; EDVs, emergency department visits; RR, relative risk.

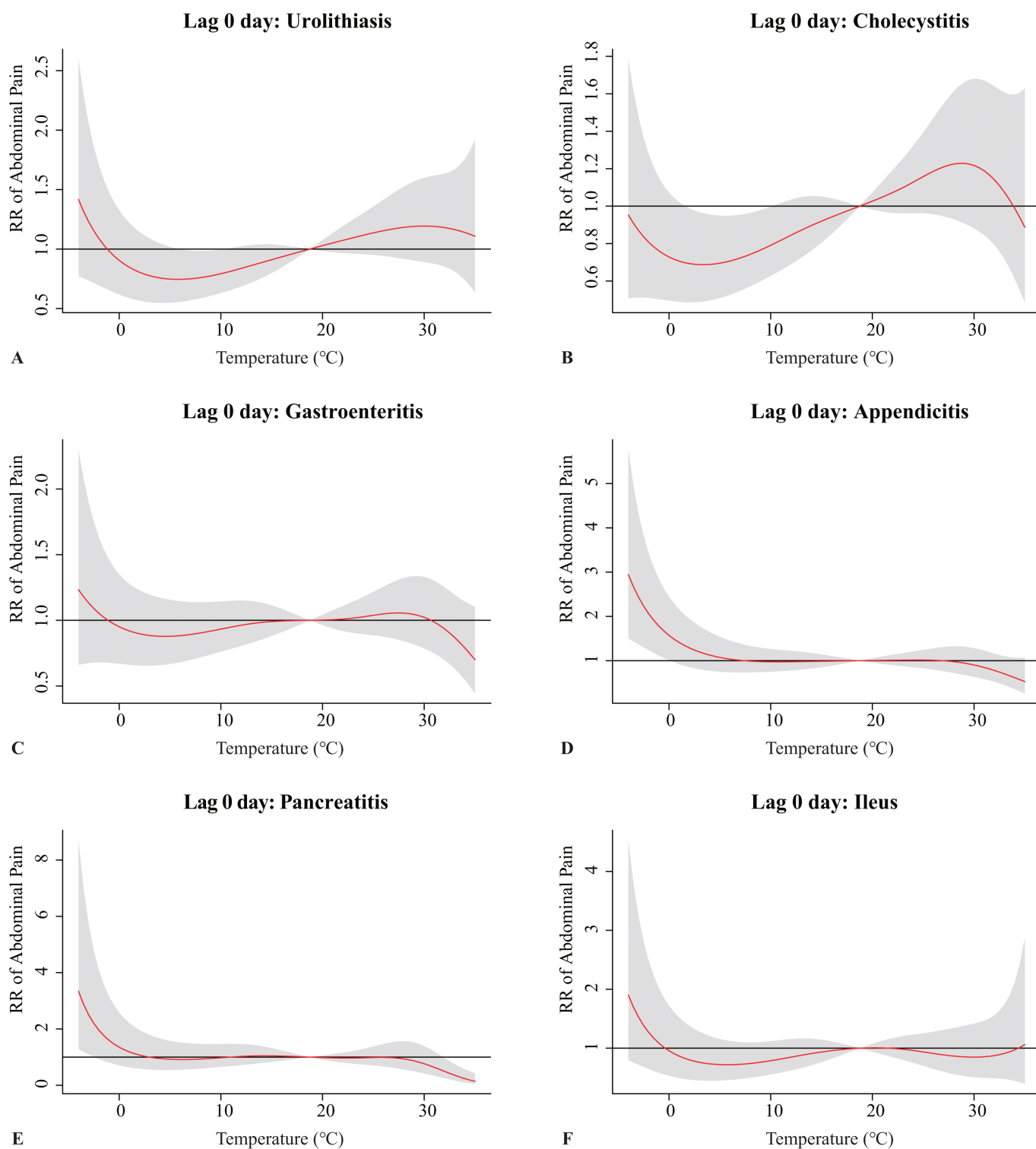


Figure 3. The E-R curves of daily mean temperature and RR of daily EDVs for abdominal pain at Lag 0 day, stratified by preliminary diagnoses. Daily mean temperatures are shown on the abscissa, and the RRs of the EDVs for abdominal pain are shown on the ordinate. The red lines represent the RRs, and the gray areas represent the 95% CIs for the risk estimates. (A)–(F) The E-R curves of the six diseases at Lag 0 day. The 6 diseases above are urolithiasis, cholecystitis, gastroenteritis, appendicitis, pancreatitis, and ileus, respectively. CI, confidence interval; EDVs, emergency department visits; E-R, exposure-response; RR, relative risk.

it may lead to redistribution of blood flow, which in turn leads to reduced blood supply to the gastrointestinal tract, triggering abdominal pain.^[32] We suppose that the body's core temperature will not easily change at a low ambient temperature, because people always wear more clothes to keep warm on cold days.

However, a study in Finland showed no significant correlation between air temperature and the incidence of nonspecific abdominal pain.^[33] This may be because the temperatures in Finland are low (mean annual temperature, 3.9°C) compared to Wuhan, China (median annual temperature, 19°C); therefore, people

there are accustomed to cold weather. In hot weather, the redistribution of blood toward the core triggers ischemia, reperfusion injury, and oxidative stress in multiple organs and systems and thus may result in more EDVs.^[34,35]

Urolithiasis (ICD-10, N20.9), cholecystitis (ICD-10, K81.0), and appendicitis (ICD-10, K35), which usually manifest as acute or severe abdominal pain, are the main causes of abdominal pain in EDVs. Several studies have investigated the effect of temperature on the incidence of these diseases. First, our analysis revealed that mildly cold temperatures decrease the risk of EDVs for urolithiasis. Heat stress and dehydration are considered to be significant in terms of urinary concentration, low urine volume, and concentration of relatively insoluble salts such as calcium oxalate, which may lead to stones.^[36,37] When the temperature is relatively low, the heat stress and dehydration effects are weakened. Second, a higher incidence of cholecystitis in summer has been observed in many studies, and stones underlie the majority of cases.^[38–40] In summer, the loss of fluid promotes the formation of stones, and the higher possibility of gram-negative bacterial bloodstream infections facilitates inflammation.^[38,39,41] The decrease in the levels of high-density lipoprotein and increase in the levels of low-density lipoprotein related to ambient temperature may also explain the higher incidence of gallstones, because the presence of gallstones is a sign of alterations in cholesterol synthesis.^[23,42] At moderately low temperatures, the probability of fluid loss and bacterial infection is relatively low, which may partly explain the lower risk of EDVs for cholecystitis. Third, we found that the risk of EDVs for appendicitis increased in extremely cold weather, which was similar to former research.^[43] Low temperature may induce vasoconstriction, lead to local ischemia of the appendix, and subsequently participate in the occurrence and development of appendicitis.

Previous research has suggested that sex hormones and a more pronounced response of sympathetic activity may account for differences in temperature sensitivity between women and men.^[44–46] However, in sex stratification, we did not find any differences in temperature reactivity. This may be due to the fact that different menstrual cycles may obscure the group differences, and confounding factors at the individual level are not controlled. Future studies should explore these potential mechanisms in detail. In age stratification, we observed minor risk differences between the younger, middle-aged, and elderly groups during moderately hot weather. The risk in the former group was slightly higher than that in the latter group. Many studies have come to a contrary conclusion, showing that temperature variation impairs elders more, with the explanation that aging results in physiological changes in thermoregulation and homeostasis, in more comorbidities and prevalence of chronic diseases.^[47] We ascribe this controversy to the different outcomes we chose. Temperature variations in elderly centers, mainly in the cardiovascular system, are a source of higher mortality. The EDVs for abdominal pain are mainly digestive system diseases and sometimes urinary system diseases, which are acute but mostly nonfatal, and the smaller proportion of older adults visiting for abdominal pain in our study (41.8% vs 58.2%) can also serve as evidence. Younger people tend to have more outdoor activities, more exposure to ambient temperature changes, and more susceptibility to temperature variations, even though they generally have better thermoregulation ability and heat tolerance than older people.^[34,48]

The most significant innovation of our study is that we conducted a stratification study according to the CETS.^[49] Our study shows that relatively cold air temperatures will significantly diminish the relative risk of abdominal pain for those with L2 grade, whereas moderately high temperatures will increase the risk of

abdominal pain for those with L3 grade. Severe abdominal pain caused by serious diseases, like strangulating obstruction, gastrointestinal perforation, and acute obstructive suppurative cholangitis, will be tagged with L2.^[49] There are some studies that support our discovery. First, low temperatures may slow down gram-negative bacterial bloodstream infections, which can cause septic shock.^[41,50–52] Second, exposure of the entire body to cold temperatures can activate tension of the sympathetic nerve, which will, in turn, inhibit gastrointestinal activities, thus alleviating abdominal pain.^[53] Third, more fluid loss at higher temperatures may aggravate shock and hypotension.^[52,54] However, we were not provided with the patients' accurate final diagnoses. It is difficult to reach a definite conclusion as to whether ambient temperature is correlated with visits for these diseases; therefore, further research on the correlation between ambient temperature and specific diseases is required. Triage is required by nurses before doctors' diagnoses in emergency departments, and nurses have few objective indicators for reference unless diseases have already affected patients' basic vital signs. Thus, when facing patients with abdominal pain, extreme and unbearable pain complained of by patients subjectively is the main reason for nurses to triage patients to a higher grade, causing erroneous triages in which there is more overtriage than undertriage.^[55] In our study, we found that the EDVs for abdominal pain of L2 grade will significantly lessen on cold days. Thus, we propose that more attention and medical resources can be directed toward other emergency symptoms such as chest pain, headache, and trauma on cold days. However, in relatively hot seasons, abdominal pain symptoms should not be neglected, as the risk of abdominal pain at the L3 level increases during mildly hot weather.

Limitations

Our study has some limitations. First, we were unable to measure personal exposure, which may have resulted in exposure misclassification. Second, because the emergency department is usually busy and overcrowded, some people with mild abdominal pain may choose to leave before being diagnosed by doctors, which results in an unavoidable loss of sample size. Third, we did not record pre-existing diseases or other health factors that may impair tolerance to temperature variation. However, the design of our time series might ease this problem because these factors can be considered constant at the city level.^[56,57] Fourth, the data of our study were from 1 city and 1 hospital and had a relatively short time span as well as a relatively early collection time; thus, its general application might be limited. Our study is the first step in investigating the correlation between ambient temperature and EDVs for abdominal pain. Studies with larger and more updated samples are required.

Conclusion

Our study revealed that low temperatures decreased the incidence of EDVs for abdominal pain, whereas high temperatures increased the risk, especially on Lag 0 day. Male, middle-aged, and elderly (≥ 45 years old) patient visits will be significantly fewer in lower ambient temperatures. Younger people (< 45 years old) were more likely to be affected by temperature variations. We also found that extremely and moderately cold weather seemed to diminish the EDVs for abdominal pain with L2 on CETS. However, mildly hot weather had the opposite effect on L3 patients. For conditions that may present with abdominal pain, such as urolithiasis and cholecystitis, the risk of developing the disease decreases with decreasing temperatures. We believe that our findings add epidemiological evidence on how temperature

affects human health and help guide hospitals to take precautions on days with extreme temperatures, helping them maintain order in emergency departments.

Conflict of interest statement

The authors declare no conflict of interest.

Author contributions

Lin M participated in methodology, software, investigation, visualization, and writing the original draft. Ni S participated in resources, investigation, and writing the original draft. Jin X contributed to supervision, project administration, and funding acquisition.

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Ethical approval of studies and informed consent

This study followed the principles of the Declaration of Helsinki as revised in 2013. This study was approved, and written informed consent was waived by the Medical Ethics Committee of Zhongnan Hospital (registration number: 2021018K; date: April 28, 2021), owing to the deidentification of participants.

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References

- [1] Liu J, Varghese BM, Hansen A, et al. Hot weather as a risk factor for kidney disease outcomes: a systematic review and meta-analysis of epidemiological evidence. *Sci Total Environ*. 2021;801:149806. doi:10.1016/j.scitotenv.2021.149806
- [2] Lin YK, Sung FC, Honda Y, Chen YJ, Wang YC. Comparative assessments of mortality from and morbidity of circulatory diseases in association with extreme temperatures. *Sci Total Environ*. 2020;723:138012. doi:10.1016/j.scitotenv.2020.138012
- [3] Kline O, Prunicki M. Climate change impacts on children's respiratory health. *Curr Opin Pediatr*. 2023;35(3):350–355. doi:10.1097/mop.0000000000001253
- [4] Wang Y, Liu Y, Ye D, et al. Temperatures and health costs of emergency department visits: a multisite time series study in China. *Environ Res*. 2021;197:111023. doi:10.1016/j.envres.2021.111023
- [5] Louis S, Carlson AK, Suresh A, et al. Impacts of climate change and air pollution on neurologic health, disease, and practice: a scoping review. *Neurology*. 2023;100(10):474–483. doi:10.1212/wnl.000000000000201630
- [6] Faurie C, Varghese BM, Liu J, Bi P. Association between high temperature and heatwaves with heat-related illnesses: a systematic review and meta-analysis. *Sci Total Environ*. 2022;852:158332. doi:10.1016/j.scitotenv.2022.158332
- [7] Yang X, Xu X, Wang Y, Yang J, Wu X. Heat exposure impacts on urban health: a meta-analysis. *Sci Total Environ*. 2024;947:174650. doi:10.1016/j.scitotenv.2024.174650
- [8] Hoegh-Guldberg O, Jacob D, Taylor M, et al. The human imperative of stabilizing global climate change at 1.5°C. *Science*. 2019;365(6459):eaaw6974. doi:10.1126/science.aaw6974
- [9] Qian Z, He Q, Lin HM, et al. High temperatures enhanced acute mortality effects of ambient particle pollution in the “oven” city of Wuhan, China. *Environ Health Perspect*. 2008;116(9):1172–1178. doi:10.1289/ehp.10847
- [10] Wang Y, Liu Y, Ye D, et al. High temperatures and emergency department visits in 18 sites with different climatic characteristics in China: risk assessment and attributable fraction identification. *Environ Int*. 2020;136:105486. doi:10.1016/j.envint.2020.105486
- [11] Guo C, Ge E, Lee S, et al. Impact of heat on emergency hospital admission in Texas: geographic and racial/ethnic disparities. *J Expo Sci Environ Epidemiol*. 2023;34(6):927–934. doi:10.1038/s41370-023-00590-6
- [12] Xu Z, Watzek JT, Phung D, Oberai M, Rutherford S, Bach AJE. Heat, heatwaves, and ambulance service use: a systematic review and meta-analysis of epidemiological evidence. *Int J Biometeorol*. 2023;67(10):1523–1542. doi:10.1007/s00484-023-02525-0
- [13] Oberai M, Xu Z, Bach AJE, Phung D, Watzek JT, Rutherford S. Preparing for a hotter climate: a systematic review and meta-analysis of heatwaves and ambulance callouts in Australia. *Aust N Z J Public Health*. 2024;48(1):100115. doi:10.1016/j.anzjph.2023.100115
- [14] Hooker EA, Mallow PJ, Oglesby MM. Characteristics and trends of emergency department visits in the United States (2010–2014). *J Emerg Med*. 2019;56(3):344–351. doi:10.1016/j.jemermed.2018.12.025
- [15] Hitti E, Geha M, Hadid D, Bachir R. The disease spectrum of adult patients at a tertiary care center emergency department in Lebanon. *PloS One*. 2019;14(5):e0216740. doi:10.1371/journal.pone.0216740
- [16] Kim JJ, Kwok ESH, Cook OG, Calder LA. Characterizing highly frequent users of a large Canadian urban emergency department. *West J Emerg Med*. 2018;19(6):926–933. doi:10.5811/westjem.2018.9.39369
- [17] Pöyry H, Kiviniemi M, Raappana A, et al. The most common diagnoses and costs of paediatric emergency department visits: a population-based cohort study. *Acta Paediatr*. 2022;111(1):169–170. doi:10.1111/apa.16087
- [18] Magnúsdóttir MB, Róbertsson V, Þórgírmsson S, Rósmundsson P, Agnarsson Ú, Haraldsson Á. Abdominal pain is a common and recurring problem in paediatric emergency departments. *Acta Paediatr*. 2019;108(10):1905–1910. doi:10.1111/apa.14782
- [19] Ghazani M, FitzGerald G, Hu W, Toloo GS, Xu Z. Temperature variability and gastrointestinal infections: a review of impacts and future perspectives. *Int J Environ Res Public Health*. 2018;15(4):766. doi:10.3390/ijerph15040766
- [20] Lin S, Sun M, Fitzgerald E, Hwang SA. Did summer weather factors affect gastrointestinal infection hospitalizations in New York state? *Sci Total Environ*. 2016;550:38–44. doi:10.1016/j.scitotenv.2015.12.153
- [21] Zhao Q, Li S, Coelho MSZS, Saldiva PHN, Huxley RR, Guo Y. High ambient temperature and risk of hospitalization for gastrointestinal infection in Brazil: a nationwide case-crossover study during 2000–2015. *Sci Total Environ*. 2022;849:157836. doi:10.1016/j.scitotenv.2022.157836
- [22] Eze JI, Scott EM, Pollock KG, Stidson R, Miller CA, Lee D. The association of weather and bathing water quality on the incidence of gastrointestinal illness in the west of Scotland. *Epidemiol Infect*. 2014;142(6):1289–1299. doi:10.1017/s0950268813002148
- [23] Malig BJ, Wu XM, Guirguis K, Gershunov A, Basu R. Associations between ambient temperature and hepatobiliary and renal hospitalizations in California, 1999 to 2009. *Environ Res*. 2019;177:108566. doi:10.1016/j.envres.2019.108566
- [24] Chu L, Phung D, Crowley S, Dubrow R. Relationships between short-term ambient temperature exposure and kidney disease hospitalizations in the warm season in Vietnam: a case-crossover study. *Environ Res*. 2022;209:112776. doi:10.1016/j.envres.2022.112776
- [25] Mou P, Qu H, Guan J, Yao Y, Zhang Z, Dong J. Extreme temperature events, functional dependency, and cardiometabolic multimorbidity: insights from a national cohort study in China. *Ecotoxicol Environ Saf*. 2024;284:117013. doi:10.1016/j.ecoenv.2024.117013
- [26] Qian K, Sun Q, Li Y, Chen J. Association of ambient temperature on acute ischemic stroke in Yancheng, China. *BMC Public Health*. 2024;24(1):1879. doi:10.1186/s12889-024-19423-8
- [27] Gasparrini A, Armstrong B, Kenward MG. Distributed lag non-linear models. *Stat Med*. 2010;29(21):2224–2234. doi:10.1002/sim.3940
- [28] Song J, Lu J, Wang E, et al. Short-term effects of ambient temperature on the risk of premature rupture of membranes in Xinxiang, China: a time-series analysis. *Sci Total Environ*. 2019;689:1329–1335. doi:10.1016/j.scitotenv.2019.06.457

- [29] Luo G, Liu Q, Zhang Z, Jin X. A retrospective study of patients complaining of nontraumatic acute abdominal pain, admitted in the emergency department of an urban hospital in China. *Emerg Crit Care Med*. 2023;3(4):149–155. doi:10.1097/ec9.0000000000000083
- [30] Strigo IA, Carli F, Bushnell MC. Effect of ambient temperature on human pain and temperature perception. *Anesthesiology*. 2000;92(3):699–707. doi:10.1097/00000542-200003000-00014
- [31] Wang LJ, Yin H, Di YH, Liu YF, Liu JP. Human local and total heat losses in different temperature. *Physiol Behav*. 2016;157:270–276. doi:10.1016/j.physbeh.2016.02.018
- [32] Samen CDK, Sutton OM, Rice AE, et al. Correlation between temperature rise after sympathetic block and pain relief in patients with complex regional pain syndrome. *Pain Med*. 2022;23(10):1679–1689. doi:10.1093/pm/pnac035
- [33] Ilves I, Fagerstrom A, Herzig KH, Juvonen P, Miettinen P, Paajanen H. Seasonal variations of acute appendicitis and nonspecific abdominal pain in Finland. *World J Gastroenterol*. 2014;20(14):4037–4042. doi:10.3748/wjg.v20.i14.4037
- [34] Ebi KL, Capon A, Berry P, et al. Hot weather and heat extremes: health risks. *Lancet*. 2021;398(10301):698–708. doi:10.1016/s0140-6736(21)01208-3
- [35] Ma YX, Zhang YF, Cheng BW, et al. A review of the impact of outdoor and indoor environmental factors on human health in China. *Environ Sci Pollut R*. 2020;27(34):42335–42345. doi:10.1007/s11356-020-10452-5
- [36] Johnson RJ, Sánchez-Lozada LG, Newman LS, et al. Climate change and the kidney. *Ann Nutr Metab*. 2019;74(Suppl 3):38–44. doi:10.1159/000500344
- [37] Peerapen P, Thongboonkerd V. Kidney stone prevention. *Adv Nutr*. 2023;14(3):555–569. doi:10.1016/j.advnut.2023.03.002
- [38] Zangbar B, Rhee P, Pandit V, et al. Seasonal variation in emergency general surgery. *Ann Surg*. 2016;263(1):76–81. doi:10.1097/Sla.0000000000001238
- [39] Yoshimoto H, Yamakawa K, Umemura Y, et al. Seasonal variation and severity of acute abdomen in Japan: a nine-year retrospective analysis. *J Pers Med*. 2021;11(12):1346. doi:10.3390/jpm11121346
- [40] Kimura Y, Takada T, Strasberg SM, et al. TG13 current terminology, etiology, and epidemiology of acute cholangitis and cholecystitis. *J Hepatobiliary Pancreat Sci*. 2013;20(1):8–23. doi:10.1007/s00534-012-0564-0
- [41] Schwab F, Gastmeier P, Hoffmann P, Meyer E. Summer, sun and sepsis—the influence of outside temperature on nosocomial bloodstream infections: a cohort study and review of the literature. *PloS One*. 2020;15(6):e0234656. doi:10.1371/journal.pone.0234656
- [42] Mathew AV, Yu J, Guo Y, et al. Effect of ambient fine particulate matter air pollution and colder outdoor temperatures on high-density lipoprotein function. *Am J Cardiol*. 2018;122(4):565–570. doi:10.1016/j.amjcard.2018.04.061
- [43] Sulu B, Günerhan Y, Palanci Y, İşler B, Çağlayan K. Epidemiological and demographic features of appendicitis and influences of several environmental factors. *Ulus Travma Acil Cerrahi Derg*. 2010;16(1):38–42.
- [44] Barcelon E, Chung S, Lee J, Lee SJ. Sexual dimorphism in the mechanism of pain central sensitization. *Cells*. 2023;12(16):2028. doi:10.3390/cells12162028
- [45] Fernández-Peña C, Reimúndez A, Viana F, Arce VM, Señarís R. Sex differences in thermoregulation in mammals: implications for energy homeostasis. *Front Endocrinol (Lausanne)*. 2023;14:1093376. doi:10.3389/fendo.2023.1093376
- [46] Neves EB, Salamunes ACC, de Oliveira RM, Stadnik AMW. Effect of body fat and gender on body temperature distribution. *J Therm Biol*. 2017;70:1–8. doi:10.1016/j.jtherbio.2017.10.017
- [47] Yu W, Vaneckova P, Mengersen K, Pan X, Tong S. Is the association between temperature and mortality modified by age, gender and socio-economic status? *Sci Total Environ*. 2010;408(17):3513–3518. doi:10.1016/j.scitotenv.2010.04.058
- [48] Li Y, Cheng Y, Cui G, et al. Association between high temperature and mortality in metropolitan areas of four cities in various climatic zones in China: a time-series study. *Environ Health*. 2014;13:65. doi:10.1186/1476-069x-13-65
- [49] Donglei Shi XL, Zhou Y, the taskforce of expert. Experts consensus on the implementation of the emergency triage system. *Chin Emerg Med*. 2018;27(6):599–604
- [50] González-Fernández C, Basauri A, Fallanza M, Bringas E, Oostenbrink C, Ortiz I. Fighting against bacterial lipopolysaccharide-caused infections through molecular dynamics simulations: a review. *J Chem Inf Model*. 2021;61(10):4839–4851. doi:10.1021/acs.jcim.1c00613
- [51] Tang A, Shi Y, Dong Q, et al. Prognostic differences in sepsis caused by gram-negative bacteria and gram-positive bacteria: a systematic review and meta-analysis. *Crit Care*. 2023;27(1):467. doi:10.1186/s13054-023-04750-w
- [52] Shields R. The absorption and secretion of fluid and electrolytes by the obstructed bowel. *Br J Surg*. 1965;52(10):774–779. doi:10.1002/bjs.1800521019
- [53] Wu J, Hu Z, Han Z, Gu Y, Yang L, Sun B. Human physiological responses of exposure to extremely cold environments. *J Therm Biol*. 2021;98:102933. doi:10.1016/j.jtherbio.2021.102933
- [54] Dow RW, Lindenauer SM. Acute obstructive suppurative cholangitis. *Ann Surg*. 1969;169(2):272–276. doi:10.1097/00000658-196902000-00015
- [55] Zhiting G, Jingfen J, Shuihong C, Minfei Y, Yuwei W, Sa W. Reliability and validity of the four-level Chinese emergency triage scale in mainland China: a multicenter assessment. *Int J Nurs Stud*. 2020;101:103447. doi:10.1016/j.ijnurstu.2019.103447
- [56] Zeger SL, Irizarry R, Peng RD. On time series analysis of public health and biomedical data. *Annu Rev Public Health*. 2006;27:57–79. doi:10.1146/annurev.publhealth.26.021304.144517
- [57] Bhaskaran K, Gasparrini A, Hajat S, Smeeth L, Armstrong B. Time series regression studies in environmental epidemiology. *Int J Epidemiol*. 2013;42(4):1187–1195. doi:10.1093/ije/dyt092

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