Observational Study

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Association of meteorological factors with pediatric acute appendicitis in China

A 7-year retrospective analysis

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Abstract

Acute appendicitis (AA) affects between 7% and 8% of the world population and is one of the most common general surgical emergencies. The concept of seasonal patterns in the incidence of AA remains controversial. Thus, this study aimed to investigate whether meteorological factors are related to variations in the rate of pediatric AA cases at the Children's Hospital in Chongqing, China.

In total, in this retrospective survey, 3436 children younger than 18 years who had been hospitalized with AA from January 1, 2008 to December 31, 2013 were enrolled, and the meteorological factors during this period were collected.

Patients with AA showed a male/female ratio of 1.81:1; the highest incidence age ranged from 6 to 12 years old ($P<.0001$). The highest incidences of pediatric AA occurred in summer and autumn, with a peak in September and a trough in February. Pearson correlation analysis showed that the monthly mean temperature ($r=0.357$, $P=.001$), monthly mean relative humidity ($r=-0.357$, $P=.001$), and monthly mean sunshine duration ($r=0.235$, $P=-0.031$) were relatively weak correlated with pediatric AA. Multiple linear regression analysis indicated that pediatric AA occurrence was positively affected by monthly mean temperature ($P<.0001$) and negatively affected by monthly mean humidity ($P<.0001$) and monthly sum of sunshine ($P<.0001$), while monthly mean air pressure ($P=.092$), monthly wind speed ($P=.143$) and monthly precipitation ($P=.297$) were marginally associated with pediatric AA.

Pediatric AA is associated with climatic factors. Specifically, pediatric AA is more likely related to the following meteorological conditions of: high temperature (20°C–30°C), low humidity, and less sunshine.

Abbreviations: AA = acute appendicitis.

Keywords: association, meteorological factors, pediatric acute appendicitis

1. Introduction

Acute appendicitis (AA) affects between 7% and 8% of the world population and is one of the most common general surgical emergencies.[1] Some scholars have reported that the causes of appendicitis are luminal obstruction, several infectious agents, genetic factors, and environmental influences such as air pollution, ozone, and so on.[2–6] The etiology of AA is still unclear. Some infectious and noninfectious diseases, including cardiovascular and psychological diseases, have been reported to be linked to meteorological factors.[7–10] Some reports have presented a correlation between the incidence of AA and seasonal changes,[11,12] but the correlations between countries with different types of climates are unclear.[13–16]

Gastrointestinal diseases may spread directly to the appendix, which may cause blood flow disorder and inflammation of the appendix, accelerating the occurrence and development of AA.[17] Research shows that appendicitis is associated with viral infection, and the virus has seasonal epidemics.[18] Clinically, we found that the number of pediatric with appendicitis was high in summer and autumn. This leads us to investigate whether appendicitis has a significant seasonality.

Children are 4 times more likely to have appendicitis than the entire population.[19] Given the unique physiological and metabolic features of children and their relatively immature immune system, they are more susceptible to environmental meteorological factors than adults; hence, all kinds of diseases related to climate occur more easily in children.[20] In 2012, the World Health Organization reported that climate-related pneumonia, diarrhea, and malaria are the leading causes of death among children under 5 years of age; an increasing number of studies have focused on the effects of climate on children's health.[21] However, whether seasonal patterns is associated with the incidence of AA remains unclear. Therefore, the purpose of

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this study was to investigate the association between meteorological factors and variations in the rate of pediatric AA cases at Children's Hospital in Chongqing, China and to provide guidance for the prevention of appendicitis.

2. Methods

2.1. Patient data

The study procedure was approved by the Independent Ethics Committee of Chongqing Medical University. The study was conducted in the surgical department of Children's Hospital of Chongqing Medical between January 1, 2008 and December 31, 2014. In this 7-year period, 3436 children aged younger than 18 years who had been hospitalized with AA coded as K56.100 were enrolled. The diagnostic criteria for appendicitis meet the international diagnostic criteria.[22] The exclusion criteria were as follows: chronic appendicitis, other diseases complicated with appendicitis, and family address was not in an urban area or in the Chongqing neighborhood. The patients' general characteristics including age, sex, place of residence, date of onset, admission diagnosis, and discharge diagnosis were collected.

2.2. Meteorological data

Meteorological data from 2008 to 2014 were retrieved from the Chongqing Meteorological Service. We examined meteorological factors including monthly mean temperature, monthly mean air pressure, monthly mean relative humidity, monthly mean wind speed, monthly sum of sunshine and monthly precipitation level.

2.3. Data analysis

We used Microsoft Excel 2013 to create a database and SPSS version 22.0 (IBM, China) to analyze the data. The Mann-Whitney *U* and Kruskal–Wallis tests were used for analyses of normally and non-normally distributed variables. Continuous variables were shown as mean ± standard deviation; categorical variables were shown as numbers or percentages. Significance of differences in gender, sex, and onset time were compared using a Chi-squared test. Significance of differences in meteorological factors with AA were determined using one-way analysis of variance or Kruskal–Wallis *H* test when appropriate. Pearson's and multiple linear regression analyses were used to assess the relationship between incidence of pediatric AA (dependent variable: Y) and climate factors (independent variable: X). We used the Chi-squared goodness of fit test to examine the temperature variation in the pediatric AA incidence rates. *P* values were considered significant if they were <.05.

3. Results

3.1. Patient data

The overall number of AA patients conforming to the inclusion criteria from January 1, 2008, to December 31, 2014, was 3,436. There were 537 patients younger than 3 years old, 1110 between 3 and 6 years old, 926 between 6 and 9 years old, 652 between 9 and 12 years old, and 211 patients were older than 12 years old (Fig. 1A). The highest incidence age range was 6 to 12 years old ($P < .0001$). There were 2213 (64.41%) male and 1223 (35.59%) female patients (male-to-female ratio, 1.81:1) (Fig. 1B).

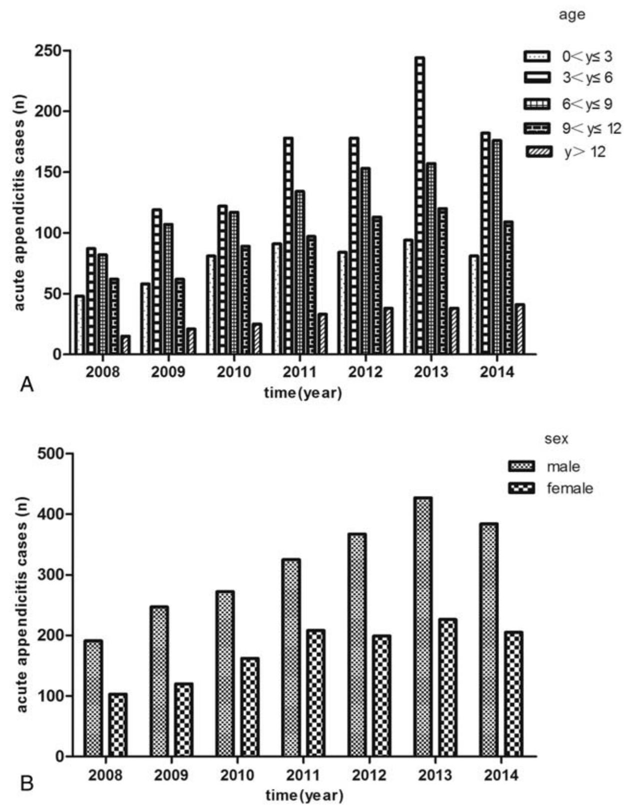

Figure 1. Age and gender distributions of acute appendicitis from 2008 to 2014. (A) Age distribution and acute appendicitis cases. (B) Gender distribution and acute appendicitis cases.

3.2. Overview of the monthly and seasonal cycles of acute appendicitis

The monthly and seasonal rates of AA cases presenting to the Children's Hospital from January 2008 to December 2014 were evaluated. The Chi-squared goodness of fit test was used to examine the periodicity of AA, revealing obvious month differences ($P < .0001$) and seasonal differences ($P < .0001$) in the incidence of AA. There was a peak in September ($P < .0001$), and the lowest incidence was observed in February ($P < .0001$) during this 7- year period (Fig. 2A). Seasonal peaks occurred in summer and autumn ($P < .0001$) (Fig. 2B).

3.3. Correlation between the incidence of AA cases and meteorological factors

Chongqing is located in a subtropical inland area of the northern hemisphere and has a subtropical monsoon humid climate; the annual temperature fluctuation is substantial, humidity is high, and sunshine is minimal. The Kolmogorov–Smirnov test was performed on the number of appendicitis cases per month during the 7 years, and the asymptotic significance of the normal distribution was 0.552 ($P > .05$), suggesting that the monthly cases of AA follows a normal distribution. Monthly meteorological data are shown in Table 1. Monthly variation of climatic factors and AA cases from 2008 to 2014 are shown in Fig. 3A–F.

Pearson correlation analysis found that the monthly mean temperature ($r = 0.357$, $P = .001$), monthly mean air pressure ($r = -0.303$, $P = .005$), monthly mean relative humidity

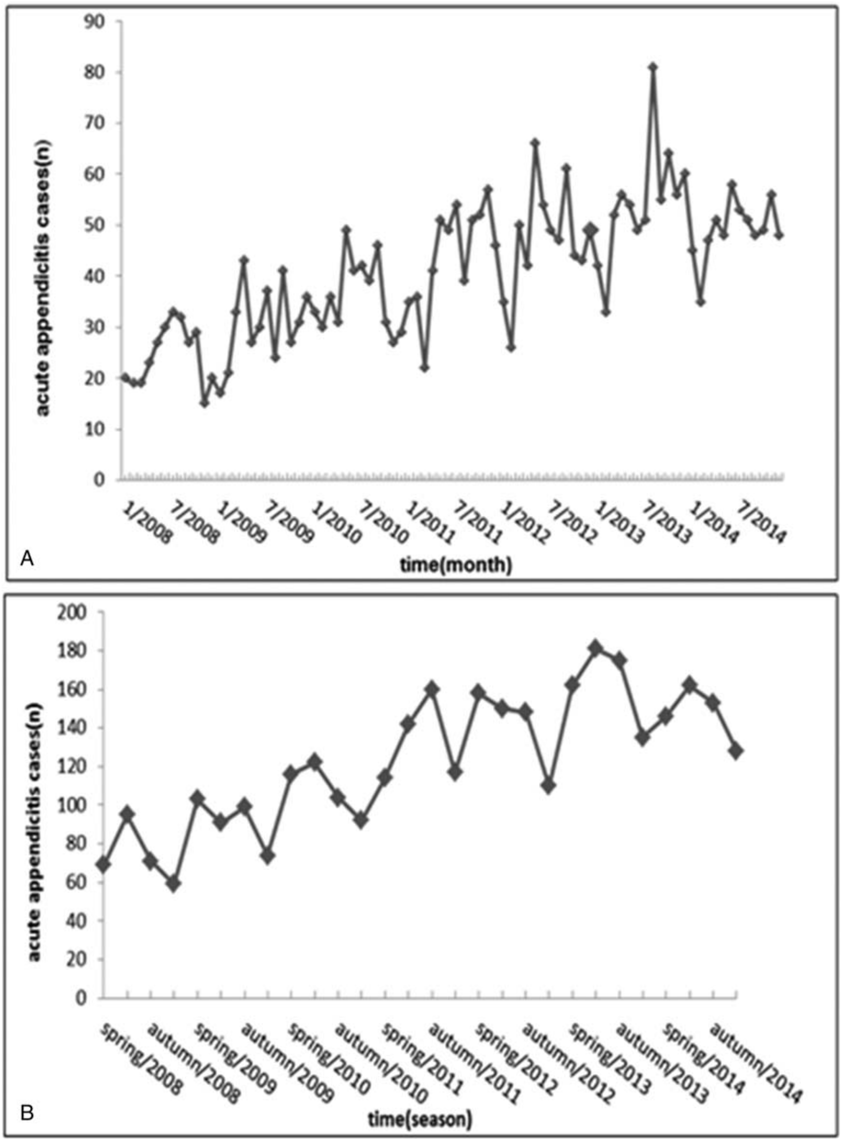

Figure 2. Incidence time distribution of acute appendicitis from 2008 to 2014. (A) Monthly distribution and acute appendicitis cases. (B) Seasonal distribution and acute appendicitis cases.

Table 1

Meteorological data in Chongqing from 2008 to 2014.

	Temperature, mean (SD), °C	Air pressure, mean (SD), hPa	Relative humidity, mean (SD), (%)	Wind speed, mean (SD), m/s	Sum of sunshine, hours	Precipitation, mm
January	7.48 (1.39)	992.88 (1.56)	80.70 (5.67)	1.18 (0.07)	3.58	4.05
February	10.20 (1.93)	987.78 (3.38)	76.27 (5.63)	1.26 (0.09)	7.53	5.21
March	14.82 (1.67)	985.98 (2.29)	71.49 (7.38)	1.44 (0.08)	16.61	12.85
April	19.09 (1.16)	981.95 (1.50)	73.26 (8.26)	1.35 (0.09)	20.14	24.37
May	22.48 (0.93)	978.21 (1.09)	75.41 (5.60)	1.40 (0.10)	19.86	28.33
June	25.50 (1.40)	974.21 (1.34)	77.22 (7.36)	1.36 (0.14)	21.65	51.00
July	29.50 (0.98)	971.74 (1.15)	67.90 (5.53)	1.59 (0.16)	37.15	21.82
August	28.92 (1.63)	974.89 (1.10)	67.21 (11.38)	1.56 (0.19)	37.52	33.72
September	24.76 (1.27)	980.25 (1.34)	75.01 (5.87)	1.50 (0.16)	20.60	30.73
October	19.30 (0.72)	987.23 (0.64)	82.11 (3.80)	1.23 (0.08)	10.71	22.10
Novembere	14.33 (1.14)	989.83 (1.68)	83.03 (3.89)	1.26 (0.16)	5.34	13.11
December	9.28 (0.36)	992.79 (2.33)	82.06 (4.86)	1.28 (0.10)	3.89	5.93

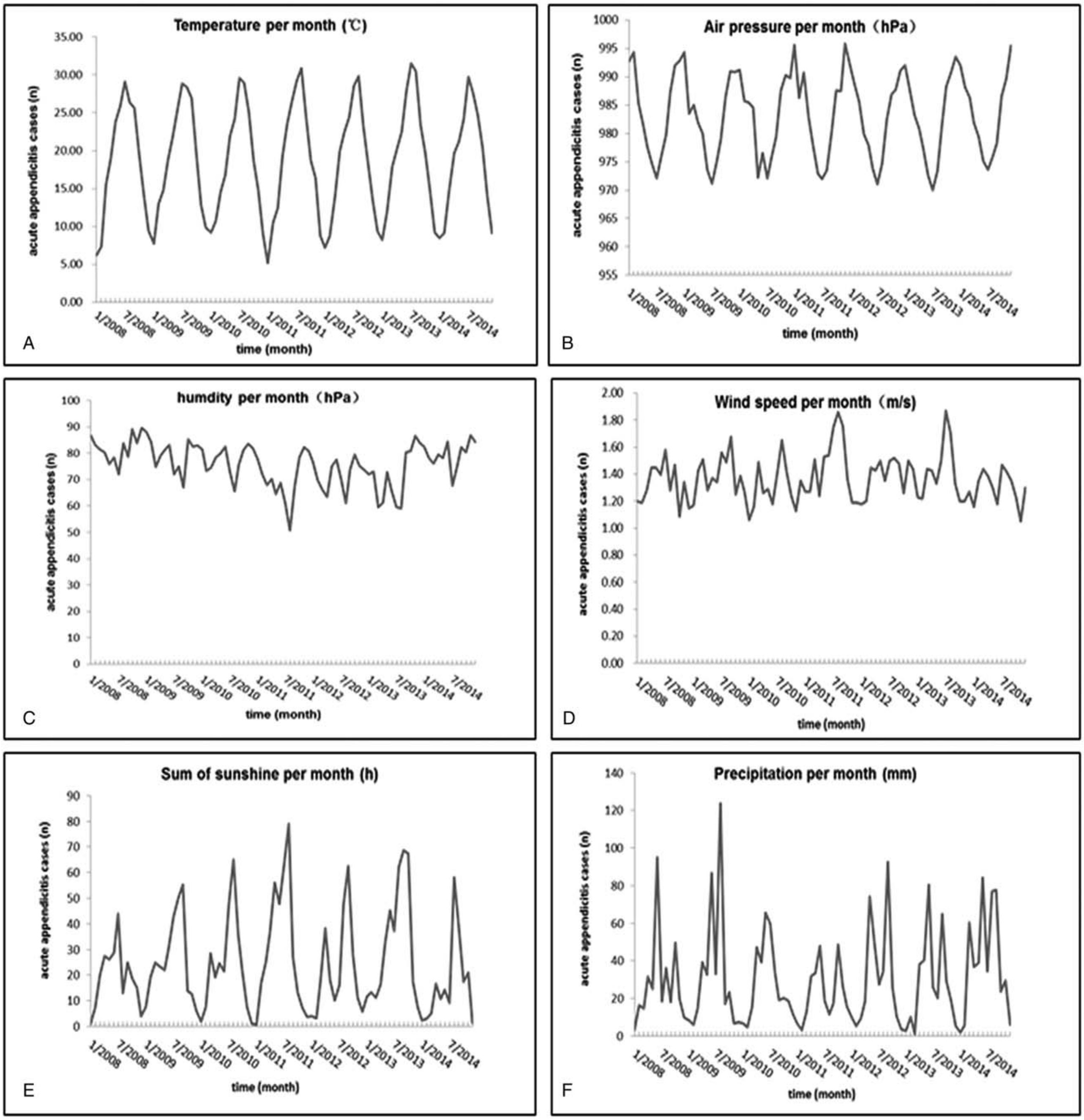

Figure 3. Distribution of meteorological data in Chongqing from 2008 to 2014. (A) Temperature per month and acute appendicitis cases. (B) Air pressure per month and acute appendicitis cases. (C) Humidity per month and acute appendicitis cases. (D) Wind speed per month and acute appendicitis cases. (E) Sum of sunshine per month and acute appendicitis cases. (F) Precipitation per month and acute appendicitis cases.

($r=-0.357$, $P=.001$), monthly sum of sunshine ($r=0.235$, $P=-.031$), monthly precipitation ($r=0.229$, $P=.036$), and wind speed ($r=-0.242$, $P=.027$) were associated with AA (Table 2).

In stepwise regression analysis of the correlation between the incidence of AA and the meteorological factors, the monthly number of AA was the dependent variable (Y), whereas the monthly mean temperature, monthly mean relative humidity, monthly average atmospheric pressure, monthly sum of sunshine, monthly average wind speed, and monthly precipitation level were the independent variables (X); the alpha level was 0.05. There was a good degree of matching between the cases and the regression model ($R=0.571$, $R^2=0.326$, adjusted $R^2=0.301$), and the regression equation was significant ($F=12.905$, $P<.0001$). Monthly average temperature ($P<.0001$), monthly sunshine duration ($P<.0001$) and mean average humidity ($P<.0001$) significantly affected the incidence of appendicitis in children; thus, the monthly average temperature positively affects the incidence of pediatric AA, whereas the monthly total sum of sunshine and average humidity negatively affects the incidence. Monthly mean wind speed ($P=.141$), mean air

Table 2

Pearson correlation analysis of the relationship between the monthly number of acute appendicitis cases and meteorological factors.

	Pearson correlation analysis	
Meteorological factors	*r* Value	*P* value
Temperature	0.357	.001
Sum of sunshine	0.235	.031
Humidity	−0.357	.001
Air pressure	−0.303	.005
Precipitation	0.229	.036
Wind speed	0.242	.027

pressure ($P=.454$), and monthly precipitation ($P=.132$) had no significant influence on the incidence of appendicitis in children. Statistical analysis results are shown in Table 3.

3.4. Correlation between temperature variation and AA cases

Mean monthly temperatures in Chongqing ranged from 6°C to 30°C. The Chi-squared goodness of fit test showed significant temperature difference at 20°C–30°C ($P<.0001$), indicating that the incidence of AA in children is more frequent during this temperature (Fig. 4).

4. Discussion

In this retrospective study, we investigated whether meteorological factors are related to variations in the rate of pediatric AA. Here, we enrolled 3436 AA cases over a period of more than 7 years with ages ranging from 3 months to 18 years. Meteorological data are provided by the Chongqing Meteorological Service. Our findings revealed that high temperature was positively associated with AA, whereas the sum of sunshine and precipitation per month were negatively associated.

AA is one of the most common general surgical emergencies with an incidence of 80–100/100,000.[1,23] The causes of appendicitis are 3-fold: appendicular obstruction, bacterial infections, and reflexes. For various reasons, gastric and intestinal dysfunction can cause spasmodic contractions of the appendix and appendix artery.[24] Others, such as eating infected food, constipation, rapid running and mental stress, might lead to intestinal disorders, blood circulation, and appendix emptying impediments, creating the conditions susceptible for bacterial infection.[13] Common pathogens are *Escherichia coli* and anaerobic bacteria.

During the 7- year period, fluctuation ranges of meteorological data included temperatures of 5.21 °C −31.51 °C, air pressures of 969.99 to 995.84 hPa, sum of sunshine of 3.58–37.52 hours,

Table 3

Multiple linear regression analysis of the relationship between the monthly number of acute appendicitis cases and meteorological factors.

	Multiple linear regression analysis		
Meteorological factors	*B* value	*t* Value	*P* value
Temperature	1.442	4.792	<.0001
Sum of sunshine	−0.698	−4.268	<.0001
Humidity	−1.263	−4.764	<.0001

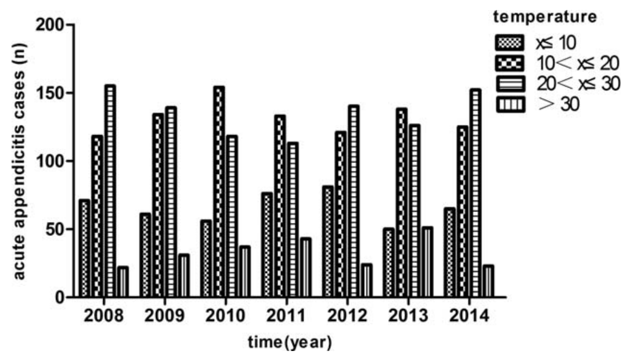

Figure 4. Temperature and number of cases of acute appendicitis from 2008 to 2014.

precipitation of 4.05–51.00 mm, humidity of 50.71%–89.65%, and wind speeds of 1.05–1.87 m/s. We examined the association of climatic factors such as monthly mean temperature, monthly mean humidity, monthly sum of sunshine, monthly mean air pressure, monthly mean wind speeds and monthly precipitation with the occurrence of pediatric AA. We found that AA has an obvious time periodicity. During this 7-year period, AA showed a male/female ratio of 1.81:1, which is consistent with other research findings that men have a higher prevalence,[23] peaking at ages 6 to 12 years. In general, higher rates of AA cases were associated with higher monthly mean temperatures (20 °C–30 ° C), monthly mean lower humidity, and less sunshine per month (Table 1, Fig. 2).

The concept of seasonal patterns in the incidence of AA remains controversial. First, our analysis showed that AA occurred particularly in summer months; we found evidence of a peak from May to September, similar to other reports from warmer countries (United States,[25] Canada,[26] Iran,[27] and Nigeria.[15]) This finding is similar to the findings by Reinisch et al,[11] Ilves et al,[28] and Stein et al.[14] Additionally, the possible relationship between warmer temperatures and a higher incidence of perforation rate of AA was emphasized by Wei et al,[29] but they were limited by the use of pooled average monthly meteorological data and unpublished exact temperature data.[1,15,25–27] These findings are in contrast to data from other epidemiological studies reporting that more AA and complicated AA cases were observed in winter.[11,30] Wei et al. found that the incidence of AA peaked from May to July in Taiwan,[29] whereas in Nigeria, the peak incidence was observed from June to August.[15] The reasons for increased incidence of AA at high temperatures are unclear, but it considered to be due to the effect of dehydration, lower number of bowel movements, infections of the lymphoid tissue in the appendix, and effects of diet and humidity.[28] Another possible explanation is a lack of accuracy of season and month divisions among countries with different geographical climates. In the same months in different countries and regions, there are some differences in meteorological factors such as temperature, humidity, and sunshine. For example, the temperature in Israel in the summer is similar to the temperature in Taiwan from May to July and the temperature in Nigeria from June to August. It has been reported that air pollution may be exacerbated when the ambient temperature is high.[31–33] Kaplan et al[34] reported that appendicitis may be caused by exposure to polluted air and recommended taking measures to improve air quality to reduce the incidence of appendicitis. In addition, the peak incidence of enteric bacterial infections was found in England from June to July, and enteric infections could cause lymphoid hyperplasia resulting in clogging of the appendix.[35]

Moreover, we found that monthly mean humidity ($P < .0001$) and monthly sum of sunshine ($P < .0001$) had a negative effect on the incidence of AA in children. Moreover, in a study from Nigeria, the incidence of the AA was reported to be related with humidity.[15] However, Ilves et al[28] and Bal et al[36] reported the absence of relationship between AA and humidity. However, the mechanism continues to be unclear. Ilves et al hypothesized that different extrinsic factors such as allergens and viral and bacterial infections might play an important role in the etiology of AA.[28] Only one study reported that the sum of sunshine did not affect the incidence of AA.[29] One possible explanation was that summer temperatures are very high, usually 30°C–45°C in Chongqing, and children usually reduce their outdoor activities. Another explanation was that eating cold and dirty food can lead to bowel dysfunction, impeding blood circulation and emptying of the appendix, and creating the conditions susceptible for bacterial infection. Clearly, additional studies are needed. Air pressure, wind speed, and precipitation did not affect the incidence of appendicitis. Other related meteorological studies have not been reported.

This study has several limitations. We might not prove this theory because of the retrospective nature of the study and the limited number of patients. We used monthly mean meteorological data; thus the statistical results lag and daily or weekly data could be used for statistics. Furthermore, other meteorological factors were not taken into consideration. Other regions would be interesting to investigate prospectively in China.

In summary, our study provides baseline data that are relevant to the epidemiology of pediatric AA in Chongqing. There was seasonal variation of pediatric AA. We found that high temperature was positively associated with AA, whereas the sum of sunshine and precipitation per month were negatively associated. On the other hand, pediatric-related medical and health institutions can actively carry out disease mission education to children for early disease identification, thereby avoiding delays in treatment and reducing the incidence of serious complications. Moreover, specialized departments to meet medical demands during peak seasons should be strengthened. American researchers have developed Google Big Data, a computer model that records the onset of influenza and is capable of predicting the peak period of regional influenza outbreaks more than 7 weeks in advance to warn health authorities and the public about the possibility of seasonal influenza outbreaks.[37] The present study uses a combination of multidisciplinary knowledge, such as pediatrics, epidemiology, statistics, and meteorology, to explore the correlation between pediatric diseases and meteorological factors, to study the big data for other major, multiple, and high-risk diseases, and to provide methodological reference, which is conducive to the development of regional population health research and the implementation of precise medical health strategy.

5. Conclusion

Pediatric AA is associated with climatic factors. Specifically, AA is more likely to be related to the following meteorological conditions: higher temperature (20°C–30°C), low humidity, and less sunshine. This study could provide a theoretical basis for the prevention and pathogenesis of AA.

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Author contributions

Conceived and designed the experiments: Yao Zhang and Xiang Feng Lyu
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Analyzed the data: Quan Kang
Wrote the paper: Yao Zhang
Modify articles: Qing Luo and Quan Kang
Conceptualization: Yao Zhang, Quan Kang, Xing Zi Dong, Xin Tian Zhao, Nan Sheng Xie.
Data curation: Xiang Feng Lyu.
Formal analysis: Qing Luo, Xiang Feng Lyu, Xing Zi Dong.
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Methodology: Yao Zhang, Nan Sheng Xie.
Project administration: Nan Sheng Xie.
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Writing – original draft: Qing Luo, Yao Zhang.
Writing – review & editing: Qing Luo, Quan Kang.

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