Influence of meteorological factors on acute aortic events in a subtropical territory

Y. Law, Y.C. Chan*, S.W. Cheng

Division of Vascular and Endovascular Surgery, Department of Surgery, The University of Hong Kong, Queen Mary Hospital, Hong Kong

Received 22 September 2015; received in revised form 6 November 2015; accepted 16 November 2015

KEYWORDS
acute aortic dissection; acute aortic events; ambient temperature; humidity; pressure; ruptured aortic aneurysm; thunderstorm; weather

Summary Background/Objective: This study aims to examine the relationship between weather changes and acute aortic events in a subtropical territory. Methods: A linear regression analysis was performed in a pan-territory epidemiological survey for a period of 10 years on the impacts of meteorological factors (ambient temperature, atmospheric pressure, relative humidity, amount of cloud, rainfall, number of lightning strikes, presence of typhoon, and thunderstorm warning) on the daily incidences of acute aortic dissections and ruptured aortic aneurysms. Meteorological variables were retrieved on a daily basis from a well-established observatory, and the daily incidences of aortic dissections and rupture of aortic aneurysms were retrieved from the Clinical Data Analysis and Reporting System. Results: During the study period (January 2005 to December 2014), 3878 patients were identified as having acute aortic dissections, and 1174 patients had ruptured aortic aneurysms. Corresponding averaged daily incidences were 1.06 and 0.32, respectively. The incidences of aortic dissection and ruptured aortic aneurysm in a day could be predicted by ambient temperature in degrees Celsius using the following linear regression models: (1) incidence of aortic dissection = 1.548 + 0.021 \times \text{temperature}; (2) incidence of ruptured aortic aneurysm = 0.564 + 0.010 \times \text{temperature}. In addition, both high atmospheric pressure and absence of thunderstorm warning are positively associated with more aortic dissections. For rupture of aortic aneurysms, high atmospheric pressure and low relative humidity were positive predictors. In multiple regression analysis, however, ambient temperature was the only significant predictor for both acute aortic dissections and ruptured aortic aneurysms.

* This paper was presented in abstract form as Law Y, Chan YC, Cheng SW. Impact of Meteorological Factors on Acute Aortic Events at The Royal College of Surgeons of Edinburgh & The College of Surgeons of Hong Kong Conjoint Scientific Congress & 20th Asian Congress of Surgery, Hong Kong, September 2015.

Conflicts of interest: No conflicts of interest declared.

* Corresponding author. Division of Vascular and Endovascular Surgery, Department of Surgery, The University of Hong Kong, South Wing, 14th Floor K Block, Queen Mary Hospital, Pokfulam Road, Hong Kong.

E-mail address: ycchan88@hkucc.hku.hk (Y.C. Chan).

http://dx.doi.org/10.1016/j.asjsur.2015.11.002

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Please cite this article in press as: Law Y, et al., Influence of meteorological factors on acute aortic events in a subtropical territory, Asian Journal of Surgery (2016), http://dx.doi.org/10.1016/j.asjsur.2015.11.002
1. Introduction

Many studies have reported an association between cold weather and incidence rate of acute cardiovascular events such as myocardial infarction or cerebrovascular accidents. Several publications have demonstrated seasonal variation in acute aortic events such as aortic dissection and rupture of aortic aneurysm. However, these observatory studies were conducted almost exclusively in countries with severe winter conditions, and to date there are no such studies in countries with subtropical climates.

This study was based on a pan-territory survey conducted for a period of 10 years in Hong Kong, in a subtropical territory where summer and winter seasons are distinct. In the study setting, the use of household heater is not common and people are exposed to the true ambient atmospheric weather. Hong Kong is one of the most densely populated areas in Southeast Asia with 7.4 million people concentrated in 1104 km² (426 mi²), equating to an overall population density of about 6300 people/km² of land, 93.6% of whom are ethnic Han Chinese. There is usually little variation in meteorological factors across our small territory. Hong Kong has a world-renowned reliable and accurate observatory, established in 1883, which maintains well-documented, meticulous daily meteorological data-set. Hong Kong also has in service a dedicated, reliable Pan-territory electronic registry containing data on patients’ morbidity and mortality due to acute aortic events over a long period. The clinical management system (CMS) and electronic patient record (ePR), built in-house since 1991 in all the public hospitals, store essential clinical data of more than 7 million patients who attended our public hospitals.

This 10-year population-based longitudinal study is the first pan-territory survey to examine the influence of meteorological variables on acute aortic events (acute aortic dissection and ruptured aortic aneurysms) in a subtropical territory.

2. Methods

2.1. Collection of meteorological data

The Hong Kong Observatory has an accurate and reliable electronic meteorological database, which is readily available to the public through their website. From this database, data on meteorological factors such as maximum ambient temperature (°C), mean temperature (°C), minimum temperature (°C), atmospheric pressure (hPa), mean relative humidity (%), mean amount of cloud (%), number of lightning strokes, typhoon signal warning (Yes or No), and thunderstorm signal warning (Yes or No) are available on a daily basis. Retrieved data were tabulated electronically onto an SPSS spreadsheet (IBM SPSS statistics, version 22.0) on a daily basis.

2.2. Collection of clinical data on acute aortic events

For the purpose of this study, we divided acute aortic events into either acute aortic dissections or ruptured aortic aneurysms. From a centralized public health care (computerized) database of Hong Kong public hospitals (the CMS and ePR, and data extracted from the Clinical Data Analysis and Reporting System), data on regional daily incidence of (1) aortic dissection, (2) aortic dissection with operation, (3) ruptured aortic aneurysm, and (4) ruptured aortic aneurysm with operation were retrieved. Search criteria were all emergency admissions with (1) primary discharge diagnosis of aortic dissection [9th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD9) 441.0], (2) diagnosis of aortic dissection and a procedure (ICD9 38.xx and 39.xx), (3) diagnosis of ruptured aortic aneurysm (ICD9 441.1, 441.3, 441.5, 441.6), and (4) diagnosis of ruptured aortic aneurysm and a procedure (ICD9 38.xx, 39.xx, 54.xx).

The precise number of events occurring each day was then entered electronically onto an electronic spreadsheet. Thus, we have data on both the meteorological factors and the incidence of acute aortic events within every single day in the study period.

2.3. Statistical analysis

Data were analyzed on a daily basis from 00:00 AM to 23:59 PM. Meteorological factors were used as predictors of acute aortic events. The incidences of aortic dissections and ruptured aortic aneurysms were regarded as event outcomes.

A linear regression model was built using mean ambient temperature, atmospheric pressure, relative humidity, amount of cloud, number of lightning strokes, and presence or absence of typhoon signal warning or thunderstorm signal warning as independent variable and incidence of acute aortic events as dependent variables. The correlation coefficient (R) indicated the direction of correlation (positive or negative) between the two variables; correlation of determination (R²) measured the amount of variability in one variable that was shared by other; and the F ratio

Conclusion: This is the first pan-territory study to show an attributable effect of ambient temperature on acute aortic events. This paper confirms that even in a subtropical country, meteorological variables were important factors influencing acute aortic events.

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measured how much the model improved the prediction of the outcome compared with the level of inaccuracy. Factors that significantly predicted incidence of acute aortic events were subjected to multiple regression analysis.

In addition, we investigated the temperature parameters as predictors of event outcome. Temperature parameters included maximum ambient temperature, mean ambient temperature, minimum ambient temperature, mean temperature 1 day before, mean temperature 2 days before, difference in temperature compared with 1 day before, difference in temperature compared with 2 days before, percentage change in temperature compared with 1 day before, percentage change in temperature compared with 2 days before, and diurnal variation (maximum temperature − minimum temperature). Each temperature parameter was tested with linear regression to evaluate which parameter was the best predictor.

Statistical analysis was performed using SPSS version 22.0. A p value of 0.05 was considered to be statistically significant.

3. Results

During the 10-year study period (January 1, 2005, to December 31, 2014), there were 5052 acute aortic events: 3878 acute aortic dissections, of which 288 underwent surgery, and 1174 ruptured aortic aneurysms, of which 631 underwent surgery (Figures 1 and 2). The averaged daily incidences of aortic dissection and ruptured aortic aneurysm were 1.06 and 0.32, respectively.

3.1. Seasonal variations of acute aortic events

The climatic patterns of Hong Kong is summarized in Figure 3. Hong Kong has distinct seasons of a cool and dry winter from November to February, and a hot and humid summer from May to August. There was a clear seasonal difference in the incidences of aortic dissection and ruptured aortic aneurysm. More occurrences were observed in winter months and fewer occurrences in summer months. The averaged daily incidences of aortic dissection were 1.20, 1.09, 1.09, 0.98, 0.94, 0.97, 0.94, 0.98, 1.01, 1.09, 1.11, and 1.34 in January, February, March, April, May, June, July, August, September, October, November, and December, respectively (analysis of variance (ANOVA) p < 0.001; Figure 4). The averaged daily incidences of ruptured aortic aneurysm were 0.42, 0.32, 0.34, 0.33, 0.23, 0.25, 0.30, 0.31, 0.32, 0.29, 0.35, and 0.41 in January, February, March, April, May, June, July, August, September, October, November, and December, respectively (ANOVA p < 0.001; Figure 5). Season wise, the averaged daily incidences of aortic dissection were 1.22, 1.01, 0.96, and 1.07 in winter, spring, summer, and autumn, respectively (ANOVA p < 0.001; Figure 6). The averaged daily incidences of ruptured aortic aneurysm were 0.38, 0.30, 0.29, and 0.32 in winter, spring, summer, and autumn, respectively (ANOVA p < 0.001; Figure 7).

3.2. Temperature as predictor of acute aortic events

The incidence of aortic dissection and ruptured aortic aneurysm in a day could be predicted by ambient temperature in degrees Celsius using the following linear regression models:

\[
\text{Incidence(aortic dissection)} = 1.548 - 0.021 \times \text{temperature}
\]  
(1)  
(linear regression; R = −0.102, R^2 = 0.010, F = 38.13, p < 0.001; Figure 8)

\[
\text{Incidence(ruptured aortic aneurysm)} = 0.564 - 0.010 \times \text{temperature}
\]  
(2)  
(linear regression; R = −0.098, R^2 = 0.010, F = 35.16, p < 0.001; Figure 9)
Both slopes were negative, indicating that the higher the temperature, the lower the incidence. We can therefore predict the number of cases of aortic dissection or ruptured aortic aneurysm in 1 day given the specific temperature of that day. For example, at 0°C, the predicted daily incidence of aortic dissection is 1.55. For every 10°C increase, the incidence drops by 0.21. At 30°C, the daily incidence of aortic dissection is 0.92 (Equation 1).

Similarly, at 0°C, the predicted daily incidence of rupture of aortic aneurysm is 0.56. For every 10°C increase, the incidence drops by 0.10. At 30°C, the daily incidence of ruptured aortic aneurysm is 0.26 (Equation 2).

3.3. Other meteorological factors as predictors

In a similar fashion, mean atmospheric pressure (hPa), mean relative humidity (%), mean amount of cloud (%), number of lightning strokes, presence or absence of typhoon signal warning, and presence and absence of thunderstorm signal warning were analyzed using the linear regression models.

High atmospheric pressure and absence of thunderstorm warning were positively associated with increased incidence of acute aortic dissection in univariate analysis (linear regression: $R = 0.093$, $R^2 = 0.009$, $F = 31.52$,
p < 0.001 and $R = -0.043$, $R^2 = 0.002$, $F = 6.69$, $p = 0.010$ for atmospheric pressure and thunderstorm warning, respectively). In the case of ruptured aortic aneurysms, high atmospheric pressure and low relative humidity predicted increased occurrence of ruptured aortic aneurysms (linear regression: $R = 0.081$, $R^2 = 0.007$, $F = 24.22$, $p < 0.001$ and $R = -0.037$, $R^2 = 0.001$, $F = 5.08$, $p = 0.024$ for atmospheric pressure and relative humidity, respectively; Table 1). In multiple regression analysis, however, ambient temperature was the only single significant predictor for both aortic dissection and ruptured aortic aneurysm (Tables 2 and 3).

3.4. Which temperature parameters best predict acute aortic events?

Among all the temperature parameters, mean ambient temperature best predicted aortic dissection, whereas...
minimum temperature of the day best predicted rupture of aortic aneurysm, of which $R^2$ values and $F$ ratios were the highest (Tables 4 and 5).

4. Discussion

To our knowledge, this is the first study to evaluate the effects of common meteorological parameters on the occurrence of acute aortic events in a subtropical territory. In particular, through the univariate analysis, it was found that temperature, pressure, and thunderstorm warning parameters were statistically associated with acute aortic dissection, and that temperature, pressure, and relative humidity parameters were statistically associated with aortic aneurysm rupture. Results of multivariate analysis indicated that only the ambient temperature was associated with these acute aortic events. This finding was rational after careful consideration of the climate pattern. Cold winter months in our territory were associated with high atmospheric pressure and lack of rainfall and thunderstorm, whereas hot summer months are associated with low atmospheric pressure and high humidity (Figure 3). Pearson correlation indicated that the ambient temperature was negatively correlated with atmospheric pressure ($R = -0.836, p < 0.001$), and positively correlated with both relative humidity ($R = 0.235, p < 0.001$) and total rainfall ($R = 0.131, p < 0.001$). By multiple linear regression analysis, these covariate factors were excluded, leaving only ambient temperature as the single predictor of acute aortic event. The territory of Hong Kong is small with

Table 1 Meteorological factors to predict incidence of aortic dissection or ruptured aortic aneurysm by linear regression.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Aortic dissection $(R, p)$</th>
<th>Ruptured aortic aneurysm $(R, p)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean atmospheric pressure (hPa)</td>
<td>$0.093, &lt;0.001$</td>
<td>$0.081, &lt;0.001$</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>$-0.031, 0.065$</td>
<td>$-0.037, 0.024$</td>
</tr>
<tr>
<td>Amount of cloud (%)</td>
<td>$0.000, 0.997$</td>
<td>$-0.009, 0.572$</td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td>$-0.002, 0.910$</td>
<td>$-0.009, 0.587$</td>
</tr>
<tr>
<td>Number of lightning strokes</td>
<td>$-0.018, 0.301$</td>
<td>$-0.021, 0.220$</td>
</tr>
<tr>
<td>Typhoon 8 or above (Yes or No)</td>
<td>$0.004, 0.798$</td>
<td>$-0.008, 0.630$</td>
</tr>
<tr>
<td>Thunderstorm warning (Yes or No)</td>
<td>$-0.043, 0.010$</td>
<td>$-0.016, 0.338$</td>
</tr>
</tbody>
</table>

Significant $p$ values were bold.

Table 2 Multiple regression analysis for aortic dissection.

<table>
<thead>
<tr>
<th>Factors</th>
<th>$B$</th>
<th>SE $B$</th>
<th>$\beta$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-3.323</td>
<td>5.461</td>
<td>0.543</td>
<td>0.543</td>
</tr>
<tr>
<td>Mean temperature ($^\circ$C)</td>
<td>-0.017</td>
<td>0.006</td>
<td>-0.081</td>
<td>0.007</td>
</tr>
<tr>
<td>Mean pressure (hPa)</td>
<td>0.005</td>
<td>0.005</td>
<td>0.028</td>
<td>0.372</td>
</tr>
<tr>
<td>Thunderstorm</td>
<td>0.016</td>
<td>0.047</td>
<td>0.006</td>
<td>0.740</td>
</tr>
</tbody>
</table>

$R = 0.103, R^2 = 0.011, F = 12.973.$
Significant $p$ values were bold.

Table 3 Multiple regression analysis for ruptured aortic aneurysm.

<table>
<thead>
<tr>
<th>Factors</th>
<th>$B$</th>
<th>SE $B$</th>
<th>$\beta$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>2.030</td>
<td>3.008</td>
<td>&lt;0.500</td>
<td></td>
</tr>
<tr>
<td>Mean temperature ($^\circ$C)</td>
<td>-0.011</td>
<td>0.003</td>
<td>-0.106</td>
<td>0.001</td>
</tr>
<tr>
<td>Mean pressure (hPa)</td>
<td>-0.001</td>
<td>0.003</td>
<td>-0.016</td>
<td>0.638</td>
</tr>
<tr>
<td>Humidity (%)</td>
<td>-0.001</td>
<td>0.001</td>
<td>-0.019</td>
<td>0.312</td>
</tr>
</tbody>
</table>

$R = 0.099, R^2 = 0.010, F = 12.058.$
Significant $p$ values were bold.
sometimes dropping below 10 months are December and January with temperatures Goodwin et al found that the ambulatory daytime blood healthy elderly and 21 young volunteers in England, small prospective cross-seasonal study involving 25 winter and a hot and humid summer. In the winter, the Climate wise, Hong Kong has four seasons: a cool and dry population of 7.4 million, 98% of whom are Han Chinese. activity levels in the elderly group in the winter. Exposure door temperatures, lower body temperature, and higher pressures in the elderly individuals were higher in the

<table>
<thead>
<tr>
<th>Temperature parameter</th>
<th>R</th>
<th>R²</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum temperature (°C)</td>
<td>-0.098</td>
<td>0.010</td>
<td>35.08</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mean temperature (°C)</td>
<td>-0.102</td>
<td>0.010</td>
<td>38.13</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Minimum temperature (°C)</td>
<td>-0.102</td>
<td>0.010</td>
<td>38.07</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mean temperature 1 d before (°C)</td>
<td>-0.101</td>
<td>0.010</td>
<td>37.41</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Difference in temperature compared to 1 d before (°C)</td>
<td>0.003</td>
<td>0.000</td>
<td>0.04</td>
<td>0.850</td>
</tr>
<tr>
<td>Percentage change in temperature compared to 1 d before (%)</td>
<td>-0.002</td>
<td>0.000</td>
<td>0.01</td>
<td>0.921</td>
</tr>
<tr>
<td>Mean temperature 2 d before (°C)</td>
<td>-0.097</td>
<td>0.009</td>
<td>34.72</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Difference in temperature compared with 2 d before (°C)</td>
<td>0.011</td>
<td>0.000</td>
<td>0.41</td>
<td>0.523</td>
</tr>
<tr>
<td>Percentage change in temperature compared to 2 d before (%)</td>
<td>0.005</td>
<td>0.000</td>
<td>0.08</td>
<td>0.772</td>
</tr>
<tr>
<td>Diurnal variation in temperature (°C)</td>
<td>0.001</td>
<td>0.000</td>
<td>0.00</td>
<td>0.965</td>
</tr>
</tbody>
</table>

To date, the etiology of an acute aortic dissection and aneurysm rupture is poorly understood. It was thought that the moment of dissection could be precipitated by a sudden change of higher-than-normal blood pressures, and that changes in atmospheric pressure and temperature may contribute to this. The interaction between climate, temperature, and blood pressure is complex, and the rise in diastolic blood pressure secondary to the exposure to cold is reported to be a well-known physiological response caused by sympathetic reactivity. In a small prospective cross-seasonal study involving 25 healthy elderly and 21 young volunteers in England, Goodwin et al found that the ambulatory daytime blood pressures in the elderly individuals were higher in the winter than in the summer and higher in both seasons than in the young people. The seasonally related differences were particularly associated with lower outdoor and indoor temperatures, lower body temperature, and higher activity levels in the elderly group in the winter. Exposure to cold temperature leads to vasoconstriction and tachycardia, both of which contributed to increased blood pressure and cardiac load. Short- and long-term exposure to the cold weather tends to increase central aortic blood pressure and cardiac workload, especially in untreated hypertensive middle-aged men. Guinea et al reported a temperature-induced mechanical stress in rabbits at the plaque–vessel interface, which could be enough to promote plaque rupture. Cold-induced hypertension and plaque–vessel interface stress may be the cause of acute aortic events in winter.

The risk of adverse cardiovascular health effects attributable to cold temperatures seems to depend on the average annual temperature: for example, the Eurowinter Group found that, in cold periods, coronary event rates increased more in populations living in warm climates than in populations living in cold climates. This observation was similar to winter mortality resulting from cerebrovascular disease, respiratory disease, and all other causes. It was suggested that people in colder regions took more precautionary measures to outdoor temperature and they had the infrastructure, clothing, and knowledge to deal with cold weather. Thus, it is necessary to promote ways of keeping warm on cold days in subtropical warm regions like Hong Kong, where use of household heater is rare and residents lack the relevant knowledge. Whether promoting public awareness lessens the disease burden of acute aortic events could be a useful study topic in future. By contrast, cardiologists and vascular surgeons should be vigilant in combating acute aortic events in winter months as our study showed a clear surge in incidence rate.

**Table 4** Temperature parameter best predicting the incidence of aortic dissection by linear regression.

**Table 5** Temperature parameter best predicting the incidence of ruptured aortic aneurysm by linear regression.
There are of course limitations to our study. A prospective interpretation of retrospectively collected clinical data may have flaws. This study was based on hospital admissions and on the presumed accurate electronic data entry of the diagnosis. Patients who died of their acute aortic events may not have full autopsy examination to pinpoint the precise cause of death, or there may be misdiagnosis. Other acute aortic events leading to out-of-hospital deaths may not have been included.

5. Conclusion

This 10-year population-based longitudinal study is the first pan-territory survey to show an attributable effect of meteorological variables on acute aortic events. Although other health care variables also played an important part in triggering acute aortic events, this study highlighted the need for greater awareness in aortic disease prevention, particularly in advising the elderly population to keep warm during the cold season.

Acknowledgments

No financial gains or external funds received. The authors are grateful to the public electronic information obtained from the Hong Kong Observatory (http://www.hko.gov.hk/cis/climat_e.htm) with their written approval.

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