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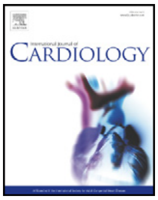

# Weather, pollution, and acute myocardial infarction in Hong Kong and Taiwan

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ABSTRACT

*Background:* Several previous studies examined the association between acute myocardial infarction (AMI) incidence and temperature and/or air pollution. Results of these studies have been inconsistent and few studies have been done in cities with sub-tropical or tropical climates.
*Methods:* Daily data on AMI hospitalizations, mean temperature and humidity, and pollutants, were collected for 2000–2009 for three warm-climate Asian cities. Poisson Generalized Additive Models were used to regress daily AMI counts on temperature, humidity, and pollutants while controlling for day of the week, long-term trends and seasonal effects. Smoothing splines allowing non-linear associations were used for temperature and humidity while pollutants were modeled as linear terms.
*Results:* A 1 °C drop below a threshold temperature of 24 °C was significantly ($p<.0001$) associated with AMI hospitalization increases of 3.7% (average lag 0–13 temperature) in Hong Kong, 2.6% (average lag 0–15) in Taipei, and 4.0% (average lag 0–11) in Kaohsiung. No significant heat effects were observed. Among pollutants same day nitrogen dioxide (NO$_2$) levels were the strongest predictors in all three cities, with a 10 mg/m$^3$ increase in NO$_2$ being associated with a 1.1% rise in AMI hospitalization in Hong Kong, and a 10 ppb rise being associated with 4.4% and 2.6% rises in Taipei and Kaohsiung, respectively.
*Conclusions:* Cool temperatures and higher NO$_2$ levels substantially raised AMI risk in these warm-climate cities and the effect sizes we observed were stronger than those found in previous studies. More attention should be paid to the health dangers of cold weather in warm-climate cities.

## 1. Introduction

Numerous studies have looked at short-term associations between meteorological factors and cardiovascular mortality/morbidity and/or pollution and mortality/morbidity. Most have found that mortality and hospitalization rates tend to be higher during periods of extreme high and low temperatures [1–5], and with periods of high pollutant levels [6–12], although the specific pollutant(s) involved in the higher risk varies between studies.

A few studies have looked specifically at associations between mortality and/or hospitalization from acute myocardial infarction (AMI) and meteorological parameters. A recent systematic review [13] found 13 studies which used a time-series approach to examine short term associations between temperature and AMI risk. Eight of the 12 of these studies which included data from the winter season found a significant increased risk of AMI at colder temperatures, while significant increased AMI risk at higher temperatures were reported by 7 studies [13]. As noted by the review authors these studies tended to use inconsistent methodologies: only 3 of the studies adjusted for daily pollutant levels, 6 of the studies only considered temperature as a linear effect, and only 7 of the 13 considered the possibility of lagged effects of temperature [13]. A systematic review of the effects of air pollution on the incidence of AMI found 19 studies which had looked at the short-term association of air pollution with AMI on a daily time-scale [14]. The authors concluded that although the results of these studies were inconsistent but generally provided evidence of a short-term effect of pollutants on MI risk [14]. The majority of the reviewed studies appear to have used solid methodology with confounding by temperature, season and long term trends and the possibility of delayed effects being considered. However, very few of the reviewed studies on either temperature [13] or air pollution [14] were conducted in cities with sub-tropical or tropical climates, and none in sub-tropical or tropical areas of Southeast Asia.

Here we examine the association between temperature, humidity and air pollutant levels with AMI hospitalization in three Asian cities, two, Hong Kong and Taipei, Taiwan, with sub-tropical climates, and one, Kaohsiung, Taiwan, with a tropical climate. We use time-series regression methods and consider the possibility of both non-linear and lagged effects for meteorological parameters.

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## 2. Methods

### 2.1. Data

For Hong Kong data on all hospital admissions with primary discharge diagnosis of AMI (ICD-9 410.xx) from 2000 to 2009 were obtained from the Hong Kong Hospital Authority, while data on mean daily temperature and mean relative humidity were obtained from the Hong Kong Observatory and data on daily pollutant levels, including respirable suspended particulates with diameter<=10 μm ($PM_{10}$), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$) and ozone ($O_3$) were obtained from the Hong Kong Environmental Protection Department. The number of flu consultation per 1000 consultations for Hong Kong General Outpatient Clinics was obtained from the Hong Kong Department of Health website and was used as a proxy for influenza epidemics. For Taipei and Kaohsiung AMI hospitalization data were obtained from Taiwan's National Health Research Institute, meteorological data were obtained from Taiwan's Central Weather Bureau and the pollutant data from the Taiwanese Department of Environmental Protection Administration. Influenza data were not available for the Taiwanese cities. The authors of this manuscript have certified that they comply with the Principles of Ethical Publishing in the International Journal of Cardiology.

### 2.2. Statistical analysis

Separate Poisson Generalized Additive Models (GAMs) [15] for time-series were used to model the data for the 3 cities, with AMI hospitalizations as the response variable. Meteorological predictors included daily mean temperature and mean relative humidity. Long-term time trends were controlled using a smooth function of day of study, 1….3653, with a maximum of 10 degrees of freedom (1 per year). Seasonality was controlled for using a smooth function of day of year, 1,…, 365 (or 366 for leap years) with a maximum of 4 df, and day of week was controlled using indicator variables. Temperature, humidity, and pollutants, including $NO_2$, $SO_2$, and $PM_{10}$ were initially modeled using non-linear polynomial constrained distributed lag models [16], with maximum lag = 28 for meteorological parameters and maximum lag = 5 for pollutants, with these choices being based on previous studies [17]. The df for lag structure = 4, and df for each smooth term describing association between predictor and response = 4. The choice of maximum lags was based on the results of previous studies. The results of these models were then used to determine the appropriate number of lags to consider for each variable. R version 2.10.0 was used for all analyses [18]. The R package mgcv [15] was used to fit the GAMs in conjunction with the dlnm package [16] which was used for the distributed lag modeling. The 'quasipoisson' option was used for the distribution family to allow for the possibility of overdispersion (variance greater than the mean) of the outcome variable [19]. A stratified analysis was also performed for incident cases and recurrent cases. For these analyses cases were classified as incident if the case was the first for an individual patient in the dataset and recurrent if they had a previous MI recorded in the dataset. Thus all cases classified as recurrent were in fact recurrent, but some cases classified as incident may have actually been recurrent if the prior MI had occurred before January 1, 2000. The following sensitivity analyses were also performed: (1) Using only lags 0–7 for temperature and humidity; and (2) excluding MI cases for which the patient stayed in the hospital for less than 3 days.

## 3. Results

### 3.1. Descriptive

Descriptive statistics for daily values of the study variables are shown in Table 1. Hong Kong had the largest number of AMI cases, with a total of 49,524 over the study period and a daily median of 13, followed by Taipei and Kaohsiung with total AMI cases equal to 25,720 and 9084, and daily medians of 7 and 2, respectively. In Hong Kong AMI admissions were highest December–January, declined each month until bottoming out in June, remained low through October before rising again in November. Taipei shows a somewhat different pattern with admissions peaking January–March (with a slight dip in February) declining in April, bottoming out May–September, then rising slightly and remaining stable October–December. In Kaohsiung admissions peak January–February, begin declining in March, bottom out April–October, and begin rising again November–December. Hong Kong and Taipei had similar climates although Taipei showed slightly more temperature variation, particularly on the high end. Taipei was also somewhat drier. Kaohsiung was warmer and drier and showed considerably less temperature variation on the cool end. Among pollutants, $PM_{10}$ levels were similar in Hong Kong and Taipei, but much higher in Kaohsiung. $NO_2$ and $SO_2$ levels are more difficult to compare since they are measured using $mg/m^3$ in Hong Kong and parts per million (ppm) in Taiwan, and the conversion between the two depends on air temperature. However across the range of temperatures experienced in these cities, Hong Kong had slightly higher $NO_2$ levels (converted median = 28.9 ppm at 25 C) than either Taipei or Kaohsiung, while Hong Kong's $SO_2$ levels (converted median = 6.09 ppm at 25 °C) were in between those of Kaohsiung and Taipei.

### 3.2. Poisson time-series regression models

#### 3.2.1. Hong Kong

The results of the distributed lag models indicated that the lower mean temperature was associated with lower AMI risk on the same day but higher risk over subsequent lags with significant excess risk starting at lag 1, peaking at lag 4, and continuing through lag 13. A similar pattern was noted for humidity, but the association was considerably weaker. For pollutants, in single pollutant models, higher $NO_2$ levels were significantly associated with higher AMI risk at lag 0, while higher $SO_2$ and PM10 were non-significantly associated with higher AMI risk over several lags, and higher O3 levels were non-significantly associated with lower risk. In two pollutant models with $NO_2$ all other pollutants became non-significant. A model was then fit with smooth terms with maximum 4 df for average of lags 0–13 for mean temperature and mean relative humidity, a linear term for lag 0 $NO_2$, and the other confounders. The results of this model indicated that lag 0–13 mean temperature had a non-linear association with AMI risk rising slowly below 27 °C, then more rapidly below 24 °C (Fig. 1a). There was no evidence of an increase in AMI risk at high temperatures. The association between humidity and AMI was non-significant, negative and linear. Therefore the final model

**Table 1**
Descriptive statistics for study variables.

| | HK | | Taipei | | Kaohsiung | |
|---|---|---|---|---|---|---|
| Variable | Median (IQR) | 5th percentile–95th percentile | Median (IQR) | 5th percentile–95th percentile | Median (IQR) | 5th percentile–95th percentile |
| AMI hospitalizations | 13 (10–16) | 7–22 | 7 (5–9) | 3–12 | 2 (1–3) | 0–5 |
| Male AMI | 8 (6–10) | 4–14 | 5 (3–7) | 2–10 | 2 (1–3) | 0–4 |
| Female AMI | 5 (3–7) | 2–10 | 2 (1–3) | 0–4 | 1 (0–1) | 0–2 |
| AMI<=64 | 3 (2–5) | 1–7 | 3 (2–4) | 0–6 | 1 (0–1) | 0–3 |
| AMI 65–74 | 3 (2–5) | 1–7 | 2 (1–2) | 0–4 | 0 (0–1) | 0–2 |
| AMI 75+ | 6 (4–8) | 2–12 | 2 (1–3) | 0–5 | 1 (0–1) | 0–3 |
| Mean temp °C | 24.8 (19.5–27.8) | 14.6–29.8 | 24.0 (19.4–28.1) | 14.3–30.8 | 26.6 (22.5–28.7) | 17.9–30.3 |
| Mean relative humidity (%) | 79 (73–85) | 58–92 | 74.1 (68–81) | 59.8–89.5 | 73.0 (69.0–77.8) | 62.0–85.7 |
| $NO_2$ $\mu g/m^3$ (HK) ppb (Taiwan) | 54.5 (42.4–68.0) | 27.6–94.7 | 26.6 (21.7–32.0) | 13.2–42.7 | 23.5 (16.6–31.5) | 10.2–40.5 |
| $SO_2$ $\mu g/m^3$ (HK) ppb (Taiwan) | 16.5 (11.1–23.3) | 7.0–41.3 | 3.7 (2.6–5.0) | 1.5–7.1 | 7.9 (6.0–9.9) | 3.6–13.8 |
| PM10 $\mu g/m^3$ | 47.8 (31.5–69.6) | 20.9–102.1 | 46.4 (34.7–62.8) | 23.4–94.5 | 74.5 (45.1–103.3) | 28.6–141.4 |