Is Greater Temperature Change within a Day Associated with Increased Emergency Hospital Admissions for Heart Failure?

Qiu et al: Diurnal Temperature Change and Heart Failure

Hong Qiu, PhD; Ignatius Tak-sun Yu, MPH; Lap Ah Tse, PhD; Linwei Tian, PhD;
Xiaorong Wang, PhD; Tze Wai Wong, MPH

School of Public Health and Primary Care, The Chinese University of Hong Kong, Hong Kong Special Administrative Region, China

Correspondence to
Ignatius Tak-Sun Yu, MPH
School of Public Health and Primary Care
The Chinese University of Hong Kong
4/F School of Public Health, Prince of Wales Hospital, Shatin, N.T., Hong Kong SAR, China.
Phone: 852-2252 8773
Fax: 852-2606 3500
E-mail: iyu@cuhk.edu.hk

DOI: 10.1161/CIRCHEARTFAILURE.113.000360

Journal Subject Codes: Etiology: [8] Epidemiology
Abstract

Background—Although the seasonal variation and the effect of cold temperature on heart failure (HF) morbidity has been well documented, it is unknown whether the temperature variation within a day, i.e. diurnal temperature range (DTR), is an independent risk factor for HF. We hypothesized that large DTR might be a source of additional environmental stress and therefore a risk factor for HF exacerbation. We aimed to test the association between DTR and HF hospitalization, and to examine the effect modifiers such as age, gender, and season.

Methods and Results—We collected daily meteorological data and emergency HF hospital admissions from 2000 to 2007 in Hong Kong. We used Poisson regression models to fit the relationship between daily DTR and emergency HF hospitalizations; after adjusting for the time trend, seasonality, mean temperature, humidity, and levels of outdoor air pollution. We confirmed the seasonal variation of HF with peak hospital admissions in winter in Hong Kong. The adverse effects of DTR on emergency HF admissions were observed on current day and lasted for the following several days. Every 1 °C increase of DTR at lag0 corresponded to 0.86% (95% CI: 0.31%, 1.43%) increment of emergency hospital admissions for HF. DTR exhibited significantly greater effect in cool season, on female and elderly patients.

Conclusions—Greater temperature change within a day was associated with increased emergency hospital admissions for HF. Health policy makers and hospitals may want to take into account the increased demand of specific facilities for susceptible population in winter with greater daily temperature variations.

Key Words: diurnal temperature range; emergency hospital admission; heart failure; temperature variation; time series study
Heart failure (HF) is a common, costly, disabling, and potentially deadly condition [1]. It is
the leading cause of hospitalization in people age 65 years and older [2]. HF is an increasing
important global public health issue, particularly in ageing societies such as Hong Kong. HF
is associated with significantly reduced physical and mental health, resulting in a markedly
decreased quality of life [3]. As a result of the costs of hospitalization, it is also associated
with high health expenditure, accounting for about 2% of all health-care expenditure [1, 4].
Coronary artery disease, valvular heart disease, hypertension, overweight, and diabetes, are
the main causes and risk factors of heart failure [5]. Despite the impressive number of
effective treatments available, patients with heart failure continue to experience progressively
worsening symptoms, frequent admission to hospital, and premature death [1]. So studies are
required to help decision-makers target resources towards implementing the prevention,
which is of most importance for the elderly population.

The environmental risk factors such as cigarette smoking [5], air pollution [6-8], low ambient
temperature [9, 10], for HF have been well documented in the literature. Weather changes [11,
12] associated HF hospitalizations has also been studied. The diurnal temperature range
(DTR), defined as the difference between maximal and minimal temperatures within one day,
is a meteorological indicator associated with global climate change which may be related to a
variety of health outcomes including cardiovascular (such as acute coronary syndrome, stroke
and coronary heart disease) and respiratory diseases [12-16]. Researchers have observed that
patients with HF exhibit attenuated thermoregulatory response [17]. Although the seasonal
variations of the mortality and morbidity of HF have been well established [9,18,19], it is
unknown whether the temperature variation within one day, i.e. DTR, is the risk factor for HF
exacerbations independent of the corresponding absolute temperature. We hypothesized that
large diurnal temperature change might be a source of additional environmental stress and
therefore a risk factor for HF exacerbation. Women or elderly would have less effective
thermoregulation and may be more sensitive to the temperature change [20]. HF patients
showed much higher hospital admissions in the winter months, which suggested us examine
the association between DTR and HF hospitalization varied by season.

Hong Kong is situated on the south coast of China. With a land area of 1,104 km² and a
population of seven million people, it is one of the most densely populated areas in the world.
Hong Kong has a subtropical climate with hot and humid summer and moderate cool winter.
The mean temperature is 27.6°C from May to October (the warm season) and 19.5°C from
November to April (the cool season). Heart Failure in Hong Kong is common and increasing
according to the information from Hospital Authority (the statutory body running all public
hospitals in Hong Kong: http://www.ha.org.hk). In this study, we aimed to test the
associations between DTR and HF hospitalizations in Hong Kong, and to study the effect
modifiers such as age, gender, and season.
Methods

Data collection

This is an ecological study using time series analysis. We collected city wide hospital admissions for all circulatory diseases and heart failure (HF) from January 2000 to December 2007 in Hong Kong. The hospital admission data were taken from the publicly funded hospitals providing 24 hour accident and emergency services and covering 90% of hospital beds in Hong Kong for local residents [8]. The patient data captured from the computerized medical record system included age, gender, date of admission, source of admission, and principal diagnosis on discharge coded with International Statistical Classification of Diseases, 9th Revision (ICD-9). We abstracted the hospital admissions through the accident and emergency services for diseases of the circulatory system (ICD-9: 390-459) and HF (ICD-9: 428). We also computed the emergency HF admissions by gender and by three age groups (age <65, 65~74, and >=75 years old) as the health outcomes. Daily admissions for influenza (ICD-9:487) were used to identify influenza epidemics, which were then treated as a potential confounder in the data analysis [21]. The present study used grouped health information (number of emergency hospital admissions on each day) collected on a routine basis in the public hospital system provided by the Hospital Authority, no specific institutional review committee approval and informed consents from subjects were required, as information on individuals was not involved.
We collected the meteorological information including the daily maximum, minimum, mean temperature and relative humidity for the same period from the Hong Kong Observatory. DTR was calculated by the maximum temperature minus the minimum temperature within the same day.

As air pollutants have been identified as risk factors for emergency HF hospitalizations [6-8], we also collected the air pollution concentrations from the Environmental Protection Department. Hourly concentrations of four criteria air pollutants (particles with an aerodynamic diameter less than 10 micron, \( \text{PM}_{10} \); nitrogen dioxide, \( \text{NO}_2 \); ozone, \( \text{O}_3 \); and sulphur dioxide, \( \text{SO}_2 \)) monitored in 10 general stations were used to generate daily mean air pollution concentrations to denote the pollution level in Hong Kong [22].

**Statistical modeling**

Generalized additive Poisson regression models were used to fit the relationship between the daily DTR and the emergency HF hospitalizations. We used the smoothing spline, \( s(.) \), to filter out seasonal patterns and long-term trends in daily hospitalizations, as well as the daily mean temperature and relative humidity [23]. We also included an adjustment for the day of the week and dichotomous variables such as public holidays and influenza outbreaks.

We followed previous studies to select a priori the model specification and the degree of freedom (\( df \)) for the time trend and other meteorological variables [22-24]. We used a \( df \) of 8 per year for the time trend, a \( df \) of 6 for the mean temperature of the current day (\( \text{Temp}_0 \)) and the
previous 3 days’ moving average (Temp_{1:3}) and a df of 3 for the current day relative humidity (Humid_0). We included the day of the week (DOW) and public holidays (Holiday) in the model as dummy variables [25]. To adjust for the confounder effect of an influenza epidemic on emergency hospital admissions, we entered a dummy variable for the weeks with a number of influenza hospital admissions exceeding the 75 percentile in a year into the core model [26]. Briefly, we set up a core model to remove the long term trends, seasonal variations and adjust for time varying confounders as follows:

\[
\log(E(Y)) = \alpha + s(t, df=8/\text{year x no. of years}) + s(Temp_{0}, df=6) + s(Temp_{1:3}, df=6) + \\
\quad s(Humid_{0}, df=3) + \beta_{1}\text{DOW} + \beta_{2}\text{Holiday} + \beta_{3}\text{influenza} \cdots \cdots \cdots \cdots \cdots \cdots (1)
\]

Here \(E(Y)\) means the expected daily emergency HF hospital admission counts on day \(t\); \(s(.)\) is the smoothing spline function for nonlinear variables. We examined the residuals of the core model to check whether there were discernable patterns and autocorrelation by means of residual plot and partial autocorrelation function (PACF) plot. The PACF of residuals of the core model (1) was smaller than 0.1 for all the lags, which meant no serial correlation in the residuals and sufficient confounder control [27]. No discernible patterns and no autocorrelation in the residuals are the criteria for an adequate core model set up which is intended to remove all potential confounders in the daily variations of health outcome. The linear effect of DTR on emergency HF admissions was then estimated for the same day and up to five days before the outcome (single-lag effect from lag_0 to lag_5). The overall
cumulative effect of DTR lasting for 0–5 days was estimated by distributed lag model [28].

To justify the assumption of linearity between the logarithm of emergency HF hospital admissions and DTR, we graphically examined the dose-response relationship derived using a smoothing function [26]. Sensitivity analyses were conducted to test such association by further adjusting for the confounding effects from air pollution. Sensitivity analysis was also conducted to test whether the DTR effect is stable by replacing the mean temperature with the minimum temperature in core model (1).

In addition to the whole period analysis, we examined the effect of DTR for the warm season (from May to October) and the cool season (November to April) separately, using half the $d_f$ of 4 per year for the time trend [29]. Modified effects of gender and age group were also examined by using the subgroups of HF hospitalizations as the health outcomes [29]. We tested the statistical significance of differences between season, gender or age group by calculating $(\beta_1 - \beta_2) / \sqrt{SE_1^2 + SE_2^2}$, where $\beta_1$ and $\beta_2$ are the estimates for the two categories (e.g., warm and cool season, or females and males), and $SE_1$ and $SE_2$ are their respective standard errors [29-31]. A factor larger than 1.96 was considered as statistically significant difference at $\alpha=0.05$ level.

The results were expressed in terms of the percentage increase (Excess Relative Risk, ERR (%)) in emergency HF hospital admissions for 1 °C increase of DTR, and respective 95% confidence intervals (CI). All analyses were conducted in the statistical environment R2.15.1
Results

Data description

From year 2000 to 2007, there has been about 20% increase in hospital admissions for heart failure. The emergency admissions for heart failure were 11,066 in year 2000, while this number increased to 13,290 in 2007. During our study period, a total of 95,897 emergency hospital admissions for HF were recorded in our study population, accounting for about 21% of emergency hospitalizations due to total circulatory diseases. On average there were 33 emergency admissions per day for HF, of which approximately 56.4% were females. The percentage of HF hospitalizations was 10.4%, 22.9% and 66.8% in the three age groups (age <65, 65–74, and >=75 years old) respectively. The daily mean emergency HF admissions were significantly higher in the cool season than those in the warm season (39 vs. 27, t-test: p-value<0.01) (Table 1). The daily mean air temperature was 23.6°C with a mean diurnal temperature range 4.0°C. The daily mean concentration of air pollutants was 53.6, 57.8, 41.6 and 20.3μg/m³ for PM₁₀, NO₂, O₃ and SO₂, respectively.

Regression results

Figure 1 shows the time series of the daily count of observed HF hospitalizations (a typical seasonal variation with peak admissions in winter months), and the predicted values fitted by
the Poisson regression core model. Dose-response curve (Figure 2) shows that the association between the risk of emergency HF hospitalizations and DTR was essentially linear. The adverse effects of DTR on emergency HF admissions were observed in our study for all the lags we examined, after adjusting for the time trend, seasonality, absolute air temperature, calendar effect and influenza epidemics. Every 1 °C increase of DTR at lag0 corresponded to 0.86% (95% CI: 0.31%, 1.43%) increase of emergency hospital admissions for HF. The overall cumulative effect of DTR lasting for 0–5 days was associated with 3.76% (95% CI: 3.36%, 4.16%) increment of emergency HF hospitalizations. The effects were significantly higher in cool season than those in warm season at lag1, lag2 and 5-day distributed lags (Figure 3).

Further adjustment for the possible confounding effects from air pollutants at the same lags resulted in decreased ERR in general, especially when adjusted for NO2, though the cumulative effect of DTR was still statistically significant (Table 2). Replacing the terms of mean temperature with the minimum temperature in core model (1) showed that the association between DTR and HF hospitalizations was also robust to the adjustment for daily minimum temperature (Table 2).

Stratified analyses by gender (Table 3) showed that DTR exposure exhibited greater effect on female HF patients than males, with the cumulative effect estimates of 4.41% (95% CI: 3.89%, 4.92%) and 2.93% (95% CI: 2.37%, 3.50%) increase of HF admissions per 1 °C
increase of DTR, respectively. At the same time, DTR exposure exhibited greater effect on
patients with age of 75 and older; the corresponding cumulative effect size was 4.13% (95%
CI: 3.66%, 4.60%) per 1 °C increase of DTR (Table 3). Results demonstrated that females and
elders were more vulnerable to the temperature change within a day.

Discussion

Although the seasonal variation of HF hospitalizations [9,19] or the association between cold
temperature and HF morbidity [10,18] has been well documented, the temperature change
within a day or DTR is still a novel environmental risk factor which should be aware of by
HF patients and caretakers. In this time series study, we compared the day-to-day variations
of DTR and the day-to-day variations of emergency HF hospitalizations, and estimated the
short-term effects of DTR on HF exacerbations. We found significantly adverse effects of
DTR on HF admissions on current day and lasting for the following several days. The effects
of DTR were robust to the adjustment for daily absolute temperature (mean or minimum) and
air pollution concentrations, and were significantly greater in the cool season. Female and
everly subjects were the subgroups that were more sensitive to the DTR effects.

Seasonal variation of HF hospital admissions was very obvious in Hong Kong (Figure 1),
displaying a significant winter-peak, as previous studies have shown not only in the northern
hemisphere [18, 19] but also in the southern hemisphere [9]. Physiological mechanisms
underlying the association between the cold temperature and greater HF hospitalizations have been well documented [18]. For example, the hemodynamic stresses and neurohumoral activation that accompany a reduction in temperature may exacerbate HF, induce myocardial ischemia and precipitate arrhythmias. Furthermore, both ischemia and arrhythmias could further increase the risk of HF decompensation. Other mechanisms may relate to the pulmonary infection in seasonal variation. Respiratory infections are more frequent in winter and could precipitate HF. The short-term cold exposure in young healthy subjects could also initiate a mild inflammatory reaction and a tendency for an increased state of hypercoagulability [32].

Several previous studies have also found the adverse effects of temperature change within a day on cardio-respiratory morbidity [12, 13] and mortality [14-16]. Plausible biological mechanisms of DTR on cardiovascular diseases have been hypothesized. Greater DTR may cause cardiovascular related diseases by increasing in blood pressure, oxygen uptake, heart rate, and cardiac workload [12]. Keatinge et al. [33] found that increases in blood platelets, red cells, and viscosity were associated with normal thermoregulatory adjustments to temperature change. Bull [34] argued that weather changes may affect either humoral or cellular immunity. Female or elderly subjects might have either lower thermoregulatory responses or weaker immunity so that they were more vulnerable to the temperature change within a day.
The impact of colder temperature on cardiovascular morbidity or mortality has been found not only in the regions with cold winter climate, but also in the regions with relatively warmer weather. Those single-location studies conducted in warmer areas with higher long-term mean temperatures tended more frequently to report detrimental effects of cold and tended to report effect estimates of greater magnitude [10, 35]. Hong Kong has a moderate cool winter with mean temperature 19.5°C (8.2 ~ 22.0°C in range) in cool season, residents may be more vulnerable to low temperature and daily temperature change. Furthermore, indoor heating system is very uncommon in Hong Kong. Hence, a decrease in the outdoor temperature can affect indoor temperature rather quickly in winter and affect the patients at risk. In contrast, during the hot and humid summer in Hong Kong (temperatures of 25°C~30°C and humidity of 70%~90% between 10th to 90th percentiles), people usually use air-conditioning indoors and engage in less outdoor activities, thus reducing the risks of temperature change. This might be the reason that we did not find the association between the DTR and HF admissions in the warm season.

Our findings provide some insight into the prevention of temperature change related emergency HF hospitalizations. Early warning system for impending large temperature change may reduce the impact of DTR on population health. Female and elderly subjects, especially the socially isolated and economically disadvantaged, should be closely monitored and offered access to heated indoor environments to reduce the great DTR exposure. They
should be given advice on appropriate clothing when a rapid drop in temperature is predicted.

Monitoring patients such as home telemonitoring during follow-up to detect deterioration in
the hope of reversing it and preventing an adverse outcome was also suggested [1].

The strength of this study relied on the reliable and comprehensive hospital admission data,
which were central-computerized source of patient data covering over 90% of the population
in Hong Kong. We included almost 100 thousands HF emergency admissions over the 8 years’
study period, which is the largest single-city study to estimate the association between DTR
and HF hospitalization up to date.

Some limitations should be noted. As in other time-series studies, we used available outdoor
monitoring data to represent the population exposure to ambient temperature, temperature
change and air pollution. Indoor temperature and personal exposure data were not available.

Exposure misclassification should not be ignored due to the widely used air-conditioning in
warm season. Another limitation was that we could not identify the re-admissions for patients
with HF according to the available data. We have to put the first onset of HF and the
re-admission patients together, and observed the increase of DTR associated with the increase
of the total hospital admissions for HF. A previous study demonstrated that in the 6-9 months
following the initial HF admission, 60% of patients had 1 or more readmissions for any cause
and HF accounted for 28% of all readmissions [36]. Further study is needed to separately
examine the association between DTR and the first onset or re-admission of HF, which may
help to identify specific target group(s) for focused prevention. Furthermore, studies in other settings with different climate and larger DTR are recommended in order to provide a better understanding of the effects of temperature change on health.

In conclusion, we found significantly short-term adverse effects of DTR on emergency HF admissions. The effects of DTR were significantly greater in the cool season. Females and elders were much more vulnerable to the temperature change. Policy makers and hospitals should take into account the increased demand of specific facilities for susceptible population in cool season with wider daily temperature variations.

Acknowledgments

The authors thank the Hospital Authority for providing hospital admissions data, the Hong Kong Observatory for providing temperature and humidity data, and the Hong Kong Environmental Protection Department for providing air pollution data.

Disclosures

None.

References


Table 1. Distribution of Emergency HF Hospital Admissions, Meteorological Factors and Air Pollution Concentrations in Hong Kong, 2000-2007 (2922 days)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Min.</th>
<th>P25</th>
<th>P50</th>
<th>P75</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Emergency Hospital Admissions (counts/day)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Circulatory Diseases</td>
<td>156.1</td>
<td>23.7</td>
<td>66</td>
<td>141</td>
<td>155</td>
<td>171</td>
<td>243</td>
</tr>
<tr>
<td>Heart failure</td>
<td>32.8</td>
<td>10.8</td>
<td>10</td>
<td>25</td>
<td>31</td>
<td>39</td>
<td>86</td>
</tr>
<tr>
<td>In cool season</td>
<td>39.2</td>
<td>10.8</td>
<td>15</td>
<td>32</td>
<td>38</td>
<td>46</td>
<td>86</td>
</tr>
<tr>
<td>In warm season</td>
<td>26.6</td>
<td>6.1</td>
<td>10</td>
<td>22</td>
<td>26</td>
<td>30</td>
<td>49</td>
</tr>
<tr>
<td>Female</td>
<td>18.5</td>
<td>6.7</td>
<td>4</td>
<td>14</td>
<td>18</td>
<td>22</td>
<td>57</td>
</tr>
<tr>
<td>Male</td>
<td>14.3</td>
<td>5.6</td>
<td>2</td>
<td>10</td>
<td>13</td>
<td>17</td>
<td>41</td>
</tr>
<tr>
<td>Age &lt; 65</td>
<td>3.4</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Age of 65~74</td>
<td>7.5</td>
<td>3.4</td>
<td>0</td>
<td>5</td>
<td>7</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>Age &gt;=75</td>
<td>21.9</td>
<td>8.3</td>
<td>4</td>
<td>16</td>
<td>20</td>
<td>26</td>
<td>65</td>
</tr>
<tr>
<td><strong>Meteorological factors</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean temperature (°C)</td>
<td>23.6</td>
<td>4.9</td>
<td>8.2</td>
<td>19.6</td>
<td>24.8</td>
<td>27.8</td>
<td>31.8</td>
</tr>
<tr>
<td>Max Temp (°C)</td>
<td>25.8</td>
<td>5.2</td>
<td>9.3</td>
<td>21.7</td>
<td>26.8</td>
<td>30.1</td>
<td>35.4</td>
</tr>
<tr>
<td>Min Temp (°C)</td>
<td>21.7</td>
<td>5.0</td>
<td>6.4</td>
<td>17.9</td>
<td>23.1</td>
<td>25.9</td>
<td>29.4</td>
</tr>
<tr>
<td>DTR (°C)</td>
<td>4.0</td>
<td>1.4</td>
<td>0.7</td>
<td>3.1</td>
<td>4.0</td>
<td>4.9</td>
<td>12.2</td>
</tr>
<tr>
<td>In cool season</td>
<td>3.9</td>
<td>1.5</td>
<td>0.7</td>
<td>2.9</td>
<td>3.9</td>
<td>4.9</td>
<td>12.2</td>
</tr>
<tr>
<td>In warm season</td>
<td>4.1</td>
<td>1.3</td>
<td>0.8</td>
<td>3.3</td>
<td>4.1</td>
<td>5</td>
<td>9.8</td>
</tr>
<tr>
<td>Humidity (%)</td>
<td>78.3</td>
<td>9.8</td>
<td>31.0</td>
<td>74.0</td>
<td>79.0</td>
<td>85.0</td>
<td>98.0</td>
</tr>
<tr>
<td><strong>Air pollution concentrations (µg/m³)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM₁₀</td>
<td>53.6</td>
<td>27.6</td>
<td>14.0</td>
<td>31.5</td>
<td>47.9</td>
<td>70.2</td>
<td>196.0</td>
</tr>
<tr>
<td>NO₂</td>
<td>57.8</td>
<td>20.6</td>
<td>14.9</td>
<td>43.2</td>
<td>55.6</td>
<td>69.0</td>
<td>168.2</td>
</tr>
<tr>
<td>O₃</td>
<td>41.6</td>
<td>25.1</td>
<td>2.3</td>
<td>22.0</td>
<td>35.2</td>
<td>56.1</td>
<td>180.0</td>
</tr>
<tr>
<td>SO₂</td>
<td>20.3</td>
<td>13.8</td>
<td>2.8</td>
<td>11.3</td>
<td>16.9</td>
<td>24.4</td>
<td>134.9</td>
</tr>
</tbody>
</table>

Abbreviation: SD, standard deviation; Pₓ, xth percentiles; Min., minimum; Max., maximum.
Table 2. Sensitivity Analyses for the Effects of DTR on Emergency HF hospital admissions by lags (lag0–lag5 and overall cumulative) (ERR% (95%CI) per 1 °C Increment of DTR)

<table>
<thead>
<tr>
<th>Lag Days</th>
<th>Effect Estimate a</th>
<th>Further adjusted by air pollutants at the same lags b</th>
<th>Effect Estimate b</th>
</tr>
</thead>
<tbody>
<tr>
<td>lag0</td>
<td>0.87 (0.31, 1.43)</td>
<td>0.91 (0.36, 1.47) 0.41 (-0.16, 0.97) 0.88 (0.32, 1.44) 0.57 (0.00, 1.15)</td>
<td>1.44 (0.89, 1.99)</td>
</tr>
<tr>
<td>lag1</td>
<td>0.89 (0.34, 1.43)</td>
<td>0.82 (0.28, 1.37) 0.52 (-0.04, 1.08) 0.78 (0.23, 1.32) 0.77 (0.20, 1.34)</td>
<td>0.48 (-0.06, 1.02)</td>
</tr>
<tr>
<td>lag2</td>
<td>0.81 (0.28, 1.34)</td>
<td>0.69 (0.16, 1.22) 0.46 (-0.09, 1.00) 0.59 (0.06, 1.12) 0.79 (0.23, 1.34)</td>
<td>0.32 (-0.20, 0.84)</td>
</tr>
<tr>
<td>lag3</td>
<td>0.86 (0.35, 1.38)</td>
<td>0.69 (0.17, 1.21) 0.32 (-0.21, 0.85) 0.62 (0.10, 1.14) 0.80 (0.26, 1.35)</td>
<td>0.43 (-0.08, 0.95)</td>
</tr>
<tr>
<td>lag4</td>
<td>0.63 (0.12, 1.14)</td>
<td>0.49 (-0.02, 1.01) 0.26 (-0.27, 0.79) 0.40 (-0.12, 0.91) 0.69 (0.15, 1.23)</td>
<td>0.56 (0.05, 1.07)</td>
</tr>
<tr>
<td>lag5</td>
<td>0.63 (0.12, 1.14)</td>
<td>0.50 (-0.01, 1.02) 0.34 (-0.19, 0.88) 0.51 (-0.01, 1.03) 0.56 (0.02, 1.10)</td>
<td>0.62 (0.10, 1.13)</td>
</tr>
<tr>
<td>Overall Cumulative</td>
<td><strong>3.76 (3.36, 4.16)</strong></td>
<td><strong>3.02 (2.63, 3.42)</strong> <strong>2.33 (1.94, 2.73)</strong> <strong>2.85 (2.45, 3.25)</strong> <strong>3.29 (2.99, 3.79)</strong></td>
<td><strong>3.16 (2.76, 3.56)</strong></td>
</tr>
</tbody>
</table>

*: Effects were estimated from core model (1); b: Effects were estimated by replacing the terms of mean temperature with the minimum temperature in core model (1); c: Overall cumulative effects of DTR lasting for 0~5 days were estimated by distributed lag models. Statistical significance was determined by *p < 0.05. Effect estimates were in bold.
Table 3. Modification of Gender and Age group on DTR Effects on Emergency HF Admissions in Hong Kong (ERR% (95%CI) per 1°C Increment of DTR)

<table>
<thead>
<tr>
<th>Lag Days</th>
<th>Stratified by gender</th>
<th>Stratified by age group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>lag0</td>
<td>1.31 (0.60, 2.02)#</td>
<td>0.29 (-0.49, 1.09)</td>
</tr>
<tr>
<td>lag1</td>
<td>0.68 (-0.01, 1.38)</td>
<td>1.15 (0.38, 1.93)</td>
</tr>
<tr>
<td>lag2</td>
<td>0.72 (0.05, 1.40)</td>
<td>0.93 (0.19, 1.69)</td>
</tr>
<tr>
<td>lag3</td>
<td>1.15 (0.50, 1.81)</td>
<td>0.49 (-0.24, 1.22)</td>
</tr>
</tbody>
</table>
| lag4     | 0.88 (0.23, 1.54) | 0.30 (-0.42, 1.03) | -0.09 (-1.50, 1.34) | 1.21 (0.23, 2.20)^
| lag5     | 0.75 (0.10, 1.41) | 0.47 (-0.26, 1.20) | -0.23 (-1.64, 1.21) | 0.97 (-0.01, 1.97)^
| Overall Cumulative | 4.41 (3.89, 4.92)# | 2.93 (2.37, 3.50) | 2.18 (1.07, 3.30) | 3.29 (2.51, 4.06)^

Overall cumulative effects of DTR lasting for 0~5 days were estimated by distributed lag models. Statistically significant effect estimates were in bold.

*: Differences between female and male group were significant at $\alpha = 0.05$; 
§: Differences between age>=75 and age<65 group were significant at $\alpha = 0.05$; 
#: Differences between age>=75 and age of 65~74 group were significant at $\alpha = 0.05$; 
^
: Differences between age of 65~74 and age<65 group were significant at $\alpha = 0.10$. 


Figure Legends

Figure 1. Observed and Predicted daily counts of Emergency HF Hospital Admissions (fitted values in red)

Figure 2. Dose-response curves between the logarithm of emergency HF hospital admission and DTR at lag01 (df=3). The estimated mean percentage of change in daily emergency HF hospital admissions is shown by the solid line, and the dotted lines represent the point-wise 95% Confidence Intervals. The lower histogram shows the distribution of DTR.

Figure 3. Modification of Season on DTR Effects on HF Admissions in Hong Kong (ERR% (95%CI) per 1 °C Increment of DTR). *: Differences between cool and warm season were significant at α=0.05.
Observed and predicted daily counts of HF
Is Greater Temperature Change within a Day Associated with Increased Emergency Hospital Admissions for Heart Failure?
Hong Qiu, Ignatius Tak-sun Yu, Lap Ah Tse, Linwei Tian, Xiaorong Wang and Tze Wai Wong

Circ Heart Fail. published online August 9, 2013;
Circulation: Heart Failure is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2013 American Heart Association, Inc. All rights reserved.
Print ISSN: 1941-3289. Online ISSN: 1941-3297

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circheartfailure.ahajournals.org/content/early/2013/08/09/CIRCHEARTFAILURE.113.000360

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation: Heart Failure can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation: Heart Failure is online at:
http://circheartfailure.ahajournals.org/subscriptions/