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Long-term projections of temperature-related mortality risks for ischemic stroke, hemorrhagic stroke, and acute ischemic heart disease under changing climate in Beijing, China

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ABSTRACT

Background: Changing climates have been causing variations in the number of global ischemic heart disease and stroke incidences, and will continue to affect disease occurrence in the future.
Objectives: To project temperature-related mortality for acute ischemic heart disease, and ischemic and hemorrhagic stroke with concomitant climate warming.
Methods: We estimated the exposure-response relationship between daily cause-specific mortality and daily mean temperature in Beijing. We utilized outputs from 31 downscaled climate models and two representative concentration pathways (RCPs) for the 2020s, 2050s, and 2080s. This strategy was used to estimate future net temperature along with heat- and cold-related deaths. The results for predicted temperature-related deaths were subsequently contrasted with the baseline period.
Results: In the 2080s, using the RCP8.5 and no population variation scenarios, the net total number of annual temperature-related deaths exhibited a median value of 637 (with a range across models of 434–874) for ischemic stroke; this is an increase of approximately 100% compared with the 1980s. The median number of projected annual temperature-related deaths was 660 (with a range across models of 580–745) for hemorrhagic stroke (virtually no change compared with the 1980s), and 1683 (with a range across models of 1351–2002) for acute ischemic heart disease (a slight increase of approximately 20% compared with the 1980s). In the 2080s, the monthly death projection for hemorrhagic stroke and acute ischemic heart disease showed that the largest absolute changes occurred in summer and winter while the largest absolute changes for ischemic stroke occurred in summer.
Conclusions: We projected that the temperature-related mortality associated with ischemic stroke will increase dramatically due to climate warming. However, projected temperature-related mortality pertaining to acute ischemic heart disease and hemorrhagic stroke should remain relatively stable over time.

1. Introduction

Cardiovascular diseases (CVD) have represented a major global health concern since the 21st century and they are currently the leading cause of non-communicable deaths (Alwan et al., 2011). In 2013, cardiovascular deaths accounted for almost a third of all deaths globally (17.3 million deaths). Moreover, the annual CVD mortality is projected to reach 22.2 million by 2030 (Alwan et al., 2011). Specifically, ischemic heart disease, ischemic stroke, and hemorrhagic stroke continue to cause the greatest incidence of cardiovascular and circulatory deaths in most countries, with 8.14 million, 3.27 million, and 3.17 million deaths in 2013, respectively (Alwan et al., 2011). A report published by WHO indicated that approximately 80% of the cardiovascular deaths in 2003 occurred in developing countries. A relatively large proportion of these cases occurred in China (Aje and Miller, 2009). In China, the prevalence of CVD has risen sharply, and between 1990 and 2013, the number of CVD deaths dramatically increased, from 2.5 million to 3.7 million. Notably, the overall health profile has also changed

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substantially since 1990. In 1990, stroke and ischemic heart disease were ranked as the 2nd and 7th leading causes of death, respectively. In 2013, these two diseases became the two leading causes of loss of life in China. Indeed, together they accounted for 15.2% of disability adjusted life years (DALYs) (Yang et al., 2013). Indeed, ischemic heart disease, ischemic stroke, and hemorrhagic stroke accounted for over 80% of all CVD deaths in 2013 (Zhou et al., 2016).

There are many well-defined risk factors associated with ischemic heart disease and stroke. Both heat and cold may increase the risk of cardiovascular mortality and morbidity (Braga et al., 2002; Phung et al., 2016; Turner et al., 2012; Yang et al., 2015). Indeed, recent studies have shown that temperature is a risk factor for ischemic heart disease, ischemic stroke and hemorrhagic stroke (Smith, 2011). Global average temperatures have been rising for the past half-century, and the associated trend of global warming has accelerated in recent decades. An increase in the global mean surface temperature of 0.3 °C to 4.8 °C has been projected for 2081–2100 relative to 1986–2005 (Stocker et al., 2014). The changing climate has already resulted in variations in the number of incidences of ischemic heart disease and stroke, and this pattern is likely to continue, thereby affecting the burden of diseases in the future. In order to effectively prevent an increase in the prevalence of ischemic heart disease and stroke, a strategy based upon estimating the effects of climate change on these diseases is required.

In summary, we projected the future temperature-related mortality of acute ischemic heart disease, ischemic stroke, and hemorrhagic stroke as a consequence of global warming over time. We projected temperature-related mortality for the three CVD diseases in the 2020s, 2050s, and 2080s in Beijing using 31 downscaled models and two RCPs. We also aimed to provide a nuanced approach to variation and uncertainty characterization in relation to future temperature-related mortality by incorporating a range of scenarios pertaining to both demographic and climate changes.

2. Methods

We initially estimated the exposure-response relationship between the recorded figures for daily mortality caused by ischemic stroke, hemorrhagic stroke, and acute ischemic heart disease and the daily mean temperature in Beijing. We acquired downscaled temperature projections from 31 climate models under RCP4.5 and RCP8.5. These data were then combined to estimate future net temperature along with the prevalence of heat- and cold-related deaths. The results were contrasted with the baseline period.

2.1. Exposure-response relationship

2.1.1. Data

Historical data pertaining to deaths and mean temperature values (Tmean, average of 24-hour observations) for 2008 to 2013 were collected in Beijing. Daily mortality data were acquired from the Chinese Center for Disease Control and Prevention. Daily death counts resulting from ischemic stroke (ICD-10 code: I63, total of 30,042 cases during the study period), hemorrhagic stroke (ICD-10 codes: I61, total of 26,047 cases during the study period) and acute ischemic heart disease (ICD-10 code: I20-I22, I24, total of 48,853 cases during the study period) were accumulated. Daily Tmean data and other meteorological information were acquired from the China Meteorological Data Sharing Service System for Beijing (station number: 54511). In order to incorporate the possible influence of air pollution, $PM_{2.5}$ information from 2008 until 2012 and O_3 information from 2009 until 2011 were acquired from the Beijing Meteorological Bureau, which provides daily $PM_{2.5}$ and O_3 concentrations from the Beijing Baolian station.

2.1.2. Statistical analysis

We implemented a Poisson regression model combined with a distributed lag non-linear model (DLNM) to evaluate the influence of temperature on mortality (Armstrong, 2014, 2006). We controlled for the day of the week as a categorical variable and accounted for the season and long-term trends with a natural cubic spline with 7 df/year for time, as the estimated effects of temperature were stabilized.

The exposure-response curve was modeled with a natural cubic spline with three internal knots placed at equally spaced values, and the lag-response curve with a natural cubic spline with the three internal knots placed at equally spaced values in the log scale. We selected a lag of 14 days to model the effects of temperature on mortality since previous studies implied that the effects of temperature on heat typically display lag effects, which potentially lead to mortality displacement (Braga et al., 2002; Guo et al., 2011). The minimum mortality risk temperatures (MMT) of 23.6 °C, 24.9 °C, and 23.8 °C for ischemic stroke, hemorrhagic stroke, and acute ischemic heart disease, respectively, were derived from the overall cumulative exposure-response association and used as the reference temperatures to calculate relative risks. The analyses were performed using R Statistical Software (version 3.2.3) and the DLNM package.

2.2. Future temperature projections

Future temperature projections were developed using downscaled outputs from 31 global scale general circulation models (GCMs) (implemented in the Intergovernmental Panel on Climate Change Fifth Assessment report) in conjunction with two representative concentration pathways (Van Vuuren et al., 2011).

The fifth Intergovernmental Panel on Climate Change (IPCC) report introduced a group of new scenarios termed RCPs. The scenarios are the result of contributions from integrated assessment modelers, climate modelers, terrestrial ecosystem modelers, and emission inventory experts (Stocker et al., 2014; Van Vuuren et al., 2011). Two RCP scenarios were chosen during this study: RCP4.5 represents a medium emission scenario and RCP8.5 alludes to a high emission scenario (Van Vuuren et al., 2011). RCP4.5 has been described as a stabilization scenario in which the total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level (Van Vuuren et al., 2011). RCP8.5 differs by incorporating increasing greenhouse gas emissions over time, which leads to a forcing level near the 90th percentile of the baseline CO_2 emissions range (Moss et al., 2008).

The climate model outputs from the WCRP CMIP5 multi-model dataset (http://cmip-pcmdi.llnl.gov/cmip5/) (Taylor et al., 2012) were further downscaled to 1/8-degree resolution with bias-correction and spatial disaggregation. The method used here was also described in a previous study (Li et al., 2016). The 31 resultant temperature projections for daily Tmean values from 2010 to 2099 are based on three 30-year time intervals (the 31 GCMs are detailed in Table S2), which include the 2020s (2010–2039), the 2050s (2040–2069), and the 2080s (2070–2099). The 1980s (1970–1999) were used as a baseline interval. The baseline period in this study is defined as the climatology over 30 years (1970–1999 mean) using a historical run (1850–2005) in CMIP5 (rather than a particular year). This approach has been widely adopted for temperature projections in IPCC5. In order to smooth out and minimize the role of unpredictable natural variability the baseline period was composed of 30-year periods. We also included a near-term period from the 2020s (2010–2039). It was not possible to use a base period later than the 1990s (1980–2009) without having an overlap between the baseline and future periods (this was deemed undesirable). In order to ensure consistency with other studies we chose the 1980s (instead of the 1990s) as a base period (Li et al., 2013, 2015, 2016).

2.3. Population

Population data for Beijing in 2010 was acquired from the Beijing Municipal Bureau of Statistics (Bureau, 2013). Two population projection scenarios were used to estimate the number of deaths in the