The Effect of Ambient Temperature and Barometric Pressure on Ambulatory Blood Pressure Variability

Megan Jehn, Lawrence J. Appel, Frank M. Sacks, and Edgar R. Miller III, for the DASH Collaborative Research Group

Background: The effect of ambient temperature on cardiovascular disease has previously been studied. Less known are the effects of climate on blood pressure (BP) regulation, specifically, the role of temperature on BP variability.

Methods: We investigated the effect of temperature and barometric pressure on ambulatory BP variability in 333 men and women with above-optimal BP or stage 1 hypertension participating in the Dietary Approaches to Stop Hypertension (DASH) multicenter feeding trial. Each subject consumed the same diet for 3 weeks. Daytime, nighttime, and 24-h BP were recorded by ambulatory BP monitoring (ABPM). Climatologic data were obtained from local meteorologic centers.

Results: After adjustment for body mass index (BMI), age, sex, baseline clinic systolic BP, and clinical center, systolic BP variability was inversely associated with 24-h temperature ($P = .005$) and daytime temperature ($P = .006$). There was no observed association between BP variability and barometric pressure. There was a significant trend of increasing nighttime systolic BP and diastolic BP with increasing temperature, but these results did not persist after adjustment for confounding variables.

Conclusions: During periods of cold weather, an increase in BP variability may complicate the diagnosis and management of hypertension and may contribute to the high cardiovascular mortality observed in the winter. Am J Hypertens 2002;15:941–945 © 2002 American Journal of Hypertension, Ltd.

Key Words: Ambulatory blood pressure monitoring, temperature, atmospheric pressure, blood pressure variability.

Seasonal variations in the incidence of cardiovascular disease, including acute myocardial infarction and cerebrovascular disease have been reported. Typically, there is an increased incidence of cardiovascular events in colder months. In addition to seasonal patterns, diurnal patterns in cardiovascular events are also evident with an increased incidence during the morning and a gradual nocturnal decline.

It is a common clinical observation that hypertensive patients require less pharmacologic treatment in the summer compared with the winter. Seasonal variation in blood pressure (BP) has been reported in numerous studies including persons both with and without hypertension, as well as patients with end-stage renal disease and children. Blood pressure is higher in the winter and lower in the summer according to measurements obtained in both the clinic and ambulatory settings. This seasonal variation in BP has been directly attributed to changes in temperature.

To the best of our knowledge, the effect of climate on ambulatory BP variability (variability of individual BP readings) has only been examined in one previous study, which reported significantly higher BP variability in winter than in summer (1.5 mm Hg differences in SD). Previously, it has been difficult to assess the influence of climate on BP and BP variability because of the potential for confounding from lifestyle factors, particularly diet. The objective of this study is to determine the influence of temperature and barometric pressure on ambulatory BP variability in the setting of a controlled feeding study.
Methods

The study population consisted of 333 individuals who had participated in the Dietary Approaches to Stop Hypertension (DASH) trial and who had their BP measured by 24-h ambulatory monitoring. DASH was a multicenter, randomized feeding study comparing the effects of different dietary patterns among adults with higher than optimal BP or stage 1 hypertension. Detailed information about the design and methods of this study has been published elsewhere. The DASH study was approved by Institutional Review Boards at each clinical site. All participants provided written informed consent.

Study Population

Subjects aged 22 years or older with an average clinic-based systolic BP (SBP) \(<160\text{ mm Hg}\) and diastolic BP (DBP) between 80 and 95 mm Hg were eligible. All participants were fed a control diet for a 3-week run-in period before randomization. During the last week of run-in, all participants underwent ambulatory BP monitoring (ABPM).

The DASH trial was conducted at four centers (Baltimore, MD, Boston, MA, Baton Rouge, LA, and Durham, NC). Participants in the DASH study were enrolled sequentially into the trial in cohorts. The first cohort enrolled in January 1995, and the last group enrolled in January 1996. The present study included only those participants who had successfully completed ABPM. In addition, participants who had unusual sleep schedules \(n = 19\) were excluded from analyses.

Diets

The DASH trial tested three dietary patterns; however, the ABP measurements that were used in this report were taken before randomization, during a 3-week run-in period, when all participants were fed the “control diet” that is typical of what many Americans eat. During run-in, participants were monitored to prevent weight loss or weight gain.

Ambulatory BP Monitoring

Ambulatory BP was recorded at the end of the run-in period with the Space Labs 90207 device (Spacelabs Inc., Redmond, WA). Before beginning the recording period, DASH technicians took two random-zero sphygmomanometer (RZ-BP) measurements using standardized protocol. The monitors were programmed to take readings every 30 min for the 24-h period after placement.

After 24 h, patients returned to the clinic, and the data from the monitors were downloaded using Spacelabs software 90121. Only ABPM data that contained 14 acceptable readings between 6:00 AM and midnight were considered satisfactory. The data were edited to exclude outlier readings and ensure that no more than 24 h of readings were included for each participant.

Outcomes

Daytime, nighttime, and 24-h BP variability, as measured by ABPM, were the primary outcome variables in this study; mean levels of ambulatory BP were secondary outcome variables. For each individual, the average of all ambulatory BP measurements was used as the mean BP level. The BP variability was defined as the standard deviation of the measurements over the same period. Means and standard deviations of SBP and DBP were also calculated for the time spent awake and asleep, determined by the self-reported study average waking (7:00 AM) and sleeping times (10:00 PM).

Climatologic Data

Daily outdoor temperature and barometric pressure data were obtained from the National Climatic Data Center (North Carolina) for each of the four clinic locations. For this study, temperature is reported in degrees Celsius and atmospheric pressure was measured in millibars (mbar). Temperature records were available eight times daily (every 3 h) through 1996. Barometric pressure records were available eight times daily through 1995 and once per day through 1996. Climatologic records were abstracted for the corresponding days that participants underwent ABPM. Mean daytime temperature and pressure, and mean nighttime temperature and pressure were calculated based on the same study-average sleeping and waking times used to calculate awake and asleep BP.

Statistical Analysis

The baseline data presented are expressed as means ± SD. The influence of temperature on SBP and DBP variability was explored by categorizing temperature and barometric pressure into quartiles and testing for trend. To assess the independent association of temperature and barometric pressure with ambulatory BP and BP variability, separate multiple linear regression models were constructed adjusted for age, sex, race, clinical center, BMI, and baseline BP (for analyses of BP variability) as adjustment variables. For all statistical tests, \(P < .05\) was considered statistically significant. All calculations were performed by the investigator at Johns Hopkins using Stata Statistical Software (version 6.0, College Station, TX).

Results

The 333 participants ranged in age from 21 to 75 years (mean 45.1 ± 10.4 years); 53.1% were men and 56.2% were African American. As expected, mean BP and BP variability were higher while participants were awake (136 ± 11/87 ± 9 mm Hg) than while they were asleep (120 ± 10/73 ± 9 mm Hg).

The BP and BP variability by quartile of mean 24-h temperature are displayed in Table 1. In univariate analyses, as temperature increased from the lowest quartile to the highest, SBP variability decreased \((P < .001)\). The
same pattern was evident for daytime SBP variability ($P = .006$), but not for nighttime SBP variability ($P = .49$). Both nighttime SBP and DBP increased with increasing temperature ($P = .03$ and $P = .01$, respectively). Absolute levels of daytime and 24-h BP were unrelated to temperature in univariate analyses. The magnitude of the effect of temperature on BP variability did not differ by age (data not presented).

Table 2 displays BP levels and BP variability by quartile of mean 24-h barometric pressure. There was a slight decrease in 24-h and daytime BP variability and an increase in nighttime BP variability with increasing quartiles of barometric pressure. However, no statistically significant results were observed.

To explore the association between climate and BP, multiple linear regression analyses were further used. In analyses adjusted for age, site, BMI, race, and baseline BP, mean 24-h SBP variability was significantly and inversely related to mean 24-h temperature ($\beta = -0.04$, 95% confidence interval $-0.08$, $-0.01$) and mean daytime SBP variability was significantly and inversely related to daytime temperature ($\beta = -0.04$, 95% confidence interval $-0.06$, $-0.01$). The significant inverse correlation between mean 24-h SBP variability and mean 24-h temperature is illustrated graphically in Fig. 1 ($r = -0.11$, $P = .04$).

### Discussion

In the setting of a controlled feeding study, in which 333 individuals with above-optimal BP or stage 1 hypertension ate a common diet, we documented an inverse association...
between temperature and SBP variability. This association existed for daytime BP variability (with daytime temperature) and 24-h BP variability (with 24-h temperature) and persisted after adjusting for other known factors that influence BP such as age, sex, BMI, race, and baseline BP.

The effect of temperature on BP variability has been assessed in one previous study. Consistent with our study, the Hypertension and Ambulatory Recording Venetia Study (HARVEST) documented higher variability in daytime SBP values during winter compared to summer with a reported winter-to-summer difference in SD of 1.53 mm Hg ($P < .0001$). In our study, the observed difference in daytime SBP variability from the lowest to highest quartile of temperature was 1.5 mm Hg ($P = .006$). Although the HARVEST trial also reported a significant winter-to-summer difference in nighttime SBP and DBP variability, our study did not replicate these findings. We found significant effects of temperature on daytime and 24-h SBP variability and no effect on nighttime SBP or DBP variability.

In other studies, seasonal effects of temperature on the absolute level of BP have been documented. In contrast, we did not observe an effect of temperature on the absolute level of daytime or 24-h SBP or DBP. We did observe a trend of increasing nighttime SBP and DBP with increasing temperature, but this relationship did not persist in further analyses adjusting for potential confounders. Our results of an independent association between temperature and BP variability, and no consistent relationship between temperature and absolute level of BP are supported by the common finding that BP variability is often not associated with the absolute level of BP.

The association between barometric pressure and BP, particularly BP variability, has been studied less frequently. Overall, the relationship between BP and barometric pressure has been inconsistent, and studies have been limited by small sample sizes. Barometric pressure was negatively associated with BP in a small study of 13 hypertensives. In addition to BP, one recent study reported a v-shaped association between barometric pressure and cardiovascular disease. Although very precise measures of barometric pressure were used in the present study, there was little variability in barometric pressure data, making it difficult to detect an association.

Several mechanisms, including activation of the sympathetic nervous system, may explain the increase in BP variability associated with cold temperature. Catecholamine secretion may occur in response to cold stress. This enhanced sympathetic outflow can increase BP by increasing both heart rate and, more importantly, peripheral vascular resistance.

The DASH trial used strict trial eligibility requirements for BP, particularly DBP, narrowing the range of BP values to be analyzed. This restricted range of BP may explain our inability to detect an independent relationship between temperature and the absolute level of BP. Otherwise, the primary limitation of this report is its cross-sectional analyses. Subjects were recruited sequentially and BP was measured at different times of the year for different subjects. Analyzing measurements of BP over a 24-h period with corresponding changes in hourly climatic data on an individual basis, which was not done in these analyses, could potentially provide a better understanding of the role of climate on BP regulation.

Our study differed from previous ones by using ABPM data from four separate clinical centers during 1 year. As

![Regression of mean 24-h systolic blood pressure (SBP) variability and mean 24-h temperature.](image)

$\begin{align*}
\text{FIG. 1.} & \quad \text{Regression of mean 24-h systolic blood pressure (SBP) variability and mean 24-h temperature.} \\
\end{align*}$
such, the study provided a wide range of temperature data to be studied. The ABPM readings should also be more sensitive than clinic measurements to the effects of climate because BP measurements were partially obtained in an outdoor environment. Still, the effect of temperature may be attenuated because the majority of time is commonly spent indoors sheltered from the environment. In addition, previous studies have not been able to eliminate the possibility that seasonal changes in dietary and lifestyle factors may explain the observed seasonal variation in BP. In the present study, all study participants consumed the same diet with a fixed sodium level for 3 weeks. Also, participants were instructed not to alter their physical activity habits, thereby reducing the influence of lifestyle factors on BP variability.

Our results may have two major implications. First, increases in BP variability may complicate the diagnosis and management of hypertension, especially during cold periods. Second, an increase in variability means that higher BP may occur transiently during cold weather, independent of the average BP. This phenomenon may explain in part why cardiovascular events occur more frequently in the winter months than in the summer months.

References