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Research Letter

ASSOCIATIONS OF BLOOD PRESSURE WITH GEOGRAPHICAL LATITUDE, SOLAR RADIATION, AND AMBIENT TEMPERATURE: RESULTS FROM THE CHILEAN HEALTH SURVEY, 2009–2010

Mean blood pressure and the prevalence of hypertension vary widely throughout the world (1). Geographical latitude has been cited as a possible explanation for this variance (2–5), with increasing distance from the equator being associated with higher blood pressures. However, these statements are often not referenced (3) or refer to data from a post-hoc analysis of the International Study of Sodium, Potassium, and Blood Pressure (INTERSALT) (2, 4), which was published as a hypothesis paper in which the authors did not adequately report the methodology so as to allow others to assess the validity of the results (6). In other studies in which similar findings were reported, the differences observed were either explained by factors such as salt intake (7) or were confounded by other significant differences in characteristics such as renal function, diabetes prevalence, lifestyle, and diet (8–12). Ambient temperature and number of daylight hours have also been reported to affect blood pressure and the prevalence of hypertension (13–15).

Chile is the longest country in the world; it runs almost perfectly north to south for 4,250 km (Web Figure 1, available at http://aje.oxfordjournals.org/). It also has a genetically homogeneous population. These factors combined make it an ideal country in which to study the associations of latitude, solar radiation, and ambient temperature with blood pressure (16–19).

METHODS

In the 2009–2010 Chilean National Health Survey, investigators used a multistage, stratified probability design to produce a representative sample of the Chilean population. A total of 5,069 Chileans older than 18 years of age participated, 4,634 of whom had their blood pressure measured (91%) (20). All survey visits were conducted according to a standardized protocol, occurred in the morning at the subjects' homes, and were completed over the course of 12 months. All subjects fasted before the collection of blood tests. The ethical committee of the Pontificia Universidad Católica de Chile approved this study.

Brachial blood pressure was measured 3 times after 5 minutes of rest using a validated oscillometric monitor (Omron HEM742; Omron Corporation, Kyoto, Kansai, Japan) (21). The averages of these 3 readings are presented. Hypertension was defined as having a systolic blood pressure of 140 mm Hg or higher, having a diastolic blood pressure of 90 mm Hg or higher, and/or taking antihypertensive medication (22). The presence of chronic kidney disease was defined as an estimated glomerular filtration rate of less than 60 mL/min/1.73 m^2 (23, 24). Diabetes was defined as having a fasting glucose concentration greater than 7.0 mmol/L, a hemoglobin A1c concentration of 48 mmol/mol or higher, or a self-reported diagnosis (25).

Annual solar radiation data (MJ/m^2/day) and ambient temperatures (°C) were obtained from the Chilean Solar Radiation Laboratory (26) and Meteorological Office (www.meteochile.gob.cl), respectively, and were averaged to show mean daily values. Chile is divided into 3 distinct geographical zones: north, central, and south, which in turn are divided into a total of 15 administrative regions. Latitude, solar radiation, and temperature data were ascribed to survey participants by region of residence.

Statistical analyses

Linear regression was used to examine the relationships of blood pressure with geographical latitude, solar radiation, and temperature. Poisson regression was used to determine the prevalence ratios for hypertension. Variables included in the analyses were those that were available and had previously been reported to be associated with blood pressure in the literature. These included age, sex, family income, smoking status, fruit and vegetable consumption, salt consumption, excessive alcohol consumption (a score ≥2 on the Escala Breve de Beber Anormal, a drinking short scale that has been previously validated in the Chilean population; 27), sedentary free time, body mass index, diabetes, prior cardiovascular events, estimated glomerular filtration rate, and month of survey. All of the variables used in the analyses had fewer than 5% of the values missing and were therefore treated as missing completely at random with case-wise deletion. Analyses were performed using SPSS, version 21.0 (IBM, Chicago, Illinois).

RESULTS

The latitude limits and the average solar radiation levels and temperatures for the 3 geographical zones are shown in Web Table 1. There were high inverse correlations between geographical latitude and solar radiation ($r = -0.952$; $P < 0.001$) and between geographical latitude and ambient temperature ($r = -0.970$; $P < 0.001$). When the cohort was divided into quartiles of exposure (latitude, radiation and temperature), systolic blood pressure, diastolic blood pressure, and prevalence of hypertension demonstrated a graded association with the exposure variable. The exposure variables were thus analyzed as continuous variables.

Blood pressure

Both systolic and diastolic blood pressures significantly increased from north to south (Web Table 2). The unadjusted

Table 1. Unadjusted and Adjusted Associations of Geographical Latitude, Solar Radiation, Ambient Temperature, Systolic Blood Pressure, and Diastolic Blood Pressures With the Prevalence of Hypertension, Chilean National Health Survey, 2009–2010

Variable and Model	Systolic Blood Pressure, mm Hg		P Value	R^2	Diastolic Blood Pressure, mm Hg		P Value	R^2	PR for Hypertension		P Value
	β	95% CI			β	95% CI			β	95% CI	
Geographical latitude, degree of latitude											
Unadjusted	0.194	0.117, 0.271	<0.001		0.080	0.043, 0.118	<0.001		1.012	1.007, 1.017	<0.001
Adjusted[a]	0.102	0.041, 0.163	0.001	0.389	0.030	−0.006, 0.065	0.098	0.190	1.007	1.000, 1.014	0.044
Solar radiation, MJ/m^2/day											
Unadjusted	−0.533	−0.744, −0.322	<0.001		−0.197	−0.301, −0.094	<0.001		0.970	0.955, 0.985	<0.001
Adjusted[a]	−0.257	−0.424, −0.091	0.001	0.389	−0.059	−0.156, 0.038	0.234	0.189	0.986	0.960, 1.108	0.149
Ambient temperature, °C											
Unadjusted	−0.510	−0.714, −0.306	<0.001		−0.216	−0.316, −0.115	<0.001		0.970	0.957, 0.983	<0.001
Adjusted[a]	−0.248	−0.409, −0.087	0.003	0.399	−0.05	−0.161, 0.028	0.166	0.196	0.986	0.968, 1.003	0.111

Abbreviations: CI, confidence interval; PR, prevalence ratio.
[a] Adjusted for age, sex, family income, smoking status, fruit and vegetable consumption, salt consumption, free sedentary time, excessive alcohol consumption (score ≥2 on the Escala Breve de Beber Anormal), body mass index, prior cardiovascular events, diabetes, estimated glomerular filtration rate, and month of survey.

and adjusted associations of systolic blood pressure and diastolic blood pressure with latitude, radiation, and temperature are shown in Table 1. Only systolic blood pressure was associated with geographical latitude, solar radiation, and ambient temperature in the adjusted analyses. There was very little difference in the variability of blood pressure explained by the 3 models, with very similar R^2 values (Table 1). Exclusion of patients on antihypertensive medication did not materially alter the results.

Prevalence of hypertension

The presence of hypertension in the entire cohort was 33.8%, and it increased from north (29.3%) to south (37.4%) ($P < 0.001$; Web Table 2). Geographical latitude was positively associated with the prevalence of hypertension in the unadjusted analyses and solar radiation and ambient temperature were inversely associated, but only the association with geographical latitude remained significant in the adjusted models (Table 1).

DISCUSSION

We have demonstrated relationships of systolic blood pressure with geographical latitude, solar radiation, and ambient temperature. The prevalence of hypertension also increased with increasing distance from the equator, although the relationships with solar radiation and ambient temperature are less clear.

There is emerging evidence to suggest that the relationship between geographical latitude and blood pressure could be mediated by solar radiation (4, 28–30). The release of preformed cutaneous nitric oxide into the circulation (2, 4) and increased vitamin D synthesis have been postulated to be potential mediators (31). Further support for our findings comes from the seasonality of blood pressure, with blood pressure being generally higher in the months with fewer hours of light (13, 32). However, this observation is confounded by the difference in temperature that also occurs as the seasons change, with higher temperatures being associated with lower blood pressure (13). Indeed, in our study, ambient temperature was also associated with systolic blood pressure.

Our study has a number of limitations. In addition to its cross-sectional design, there remains the potential for residual confounding from the ecological assignment of the exposure variables, as well as the clustering of participants within administrative regions and poor (e.g., self-reported salt intake, sedentary time) or no (e.g., sleep pattern, room temperature) measures of potential confounders.

In summary, this work provides data to suggest that higher blood pressure and an increased prevalence of hypertension are associated with increasing distance from the equator and with lower levels of solar radiation and ambient temperatures. The potential mechanism(s) for these relationships require further investigation and need to be taken into account in comparative studies on hypertension.

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