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Daytime cold exposure and salt intake based on nocturnal urinary sodium excretion: A cross-sectional analysis of the HEIJO-KYO study

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HIGHLIGHTS

- We measured ambient temperature and nocturnal sodium excretion among 860 elderly.
- Colder daytime ambient temperature was associated with higher salt intake.
- Higher sodium excretion rate was associated with higher nighttime blood pressure.

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ABSTRACT

Increased cardiovascular incidence in winter is partly explained by higher blood pressure due to cold exposure. Although higher salt intake induced by cold exposure has been reported in mice, the association remains unclear in humans. To investigate the association between salt intake and cold exposure in winter, a cross-sectional study was conducted among 860 elderly subjects (mean ± standard deviation: 72.0 ± 7.1 years).

We determined ambient temperature at every 10 min according to indoor temperature measured in the subjects' home, outdoor temperature, and self-administered diary logging time spent outdoors. Salt intake was estimated by nocturnal sodium excretion rate of overnight urine collection. A 1 °C lower daytime ambient temperature was significantly associated with a higher urinary sodium excretion rate by 0.07 mmol/h in the subsequent night independent of age, sex, body weight, alcohol intake, calcium channel blocker use, diabetes, household income, estimated glomerular filtration rate, daytime physical activity ($p = 0.02$). After further adjustment for outdoor temperature and day length, the lowest tertile groups of ambient daytime temperature (10.1 ± 2.3 °C) showed the nocturnal urinary sodium excretion rate was higher by 14.2% (7.62 vs. 6.54 mmol/h) compared with the highest tertile group (19.3 ± 1.8 °C). Higher sodium excretion rate was associated with higher nighttime ambulatory blood pressure ($p < 0.01$) and its lower nocturnal dipping ($p < 0.01$). Significant association between higher salt intake and daytime cold exposure partly explain the mechanism of higher blood pressure in winter, and suggest that a reduction of cold exposure might be effective to decrease salt intake.

1. Introduction

Higher mortality in winter than other seasons is worldwide phenomenon [1–4]. Increased mortality from ischemic heart diseases and stroke in winter [5–7] is partly explained by a higher blood pressure (BP) due to cold exposure [8,9].

As an index of cold exposure, outdoor temperature is convenient because it is usually available from meteorological office. However, it may diverse from the really-exposed temperature, because it poorly correlate with indoor temperature especially in cold climate [10]. Ambient temperatures defined as indoor temperature while the participants stayed at home and outdoor temperature while the participants were out of their home showed the strongest association with ambulatory BP than outdoor temperature and indoor temperature [10,11].

Higher salt intake estimated using 24 h urinary sodium excretion is associated with higher BP from within-population and cross-population analyses in the INTERSALT study [12,13]. Systematic review from randomized controlled studies demonstrated effectiveness of a low-salt diet in decreasing BP [14]. Meta-analysis of prospective cohort studies including over 100,000 participants showed that higher salt intake is significantly associated with greater incidence of stroke and total cardiovascular disease (CVD) [15].

Higher salt intake induced by cold exposure was reported in mice [16,17], and it may also explain the higher BP due to cold exposure. However, the influence of cold exposure on salt intake in human has

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not reported. The association between ambient temperature and salt intake may provide important evidence to develop a suitable environment for reduction of salt intake to prevent CVD.

To quantify the association between ambient temperature and salt intake, we conducted the cross-sectional study among 880 elderly participants. We estimated salt intake from the nocturnal urinary sodium excretion because of the high correlation between 24 h and overnight sodium excretion in an Asian population [18,19].

2. Methods

2.1. Participants

From September to April in 2010, 2011, 2012, and 2013, we recruited 880 home-dwelling males and females, aged 60 years or more for HEIJO-KYO (Housing Environments and Health Investigation among Japanese Older People in Nara, Kansai Region), a prospective community-based cohort study. The study protocol has been previously described [20]. Of all 880 participants, we excluded 20 participants with missing of indoor temperature or overnight urine collection during the colder season (October–April), 860 were remained for analysis (Fig. 1). All participants provided a written informed consent and the study protocol was approved by the Nara Medical University Ethics Review Board.

2.2. Study protocol

The participants' characteristics, including age, gender, smoking, household income, and drinking habits, and medication use were obtained using a standardized questionnaire. After the waist circumference at the level of the umbilicus in the standing position, an overnight fasting venous sample was obtained. At noon, we started measurements of indoor temperature, ambulatory BP and actigraphy for 48 h. The participants were instructed to collect overnight urine at the second night. We revisited each participant at home to retrieve instruments and collect their diaries logging bedtime, rising time, duration in bedroom, and time spent outdoors.

2.3. Nocturnal urinary sodium excretion

After discarding the last void at bedtime, participants were asked to collect urine until the first morning void. The sodium concentration was measured using an ion-selective electrode method in a commercial laboratory (SRL Co. Inc., Tokyo, Japan). The total nocturnal urinary sodium excretion (mmol) and nocturnal urinary sodium excretion rate (mmol/h) were calculated from the total urine volume, the sodium concentration, and the duration of urine collection.

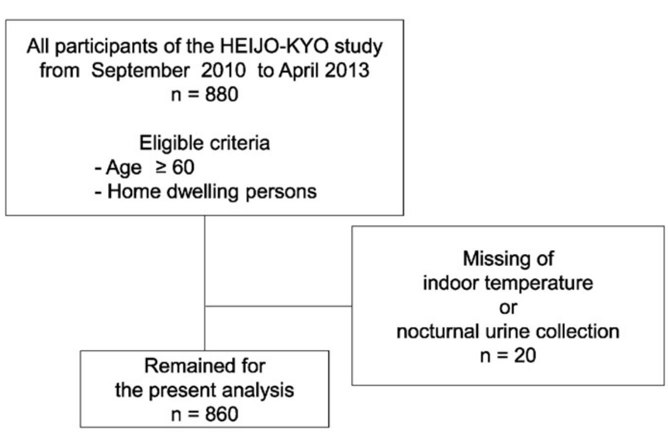

Fig. 1. Flow chart of participants.

2.4. Daytime ambient temperature

Indoor temperature was measured in the living room and bedroom 60 cm above the floor. Bed temperature was measure at center of the bed 50 cm from the headboard. These temperatures were measured at 10 min intervals using a Thermochron iButtons (DS1922L; Maxim Integrated, Dallas, TX, USA) with an accuracy of ±0.5 °C from −10 °C to +65 °C and a 0.0624 °C resolution. Outdoor temperature was also measured at 10 min intervals and was provided by the local meteorological office in Nara (latitude, 34° N). We defined the ambient temperature as indoor temperature (temperature in the living room or bedroom) while the participants were at living room or bedroom, and the outdoor temperature while the participants were out of their homes. The at-home and out-of-home periods were determined according to the participants' self-reported diaries logging the time spent outdoors and the time spent at living room and bedroom. The mean ambient temperature during the last daytime (rising–bedtime) before the nocturnal urine collection was calculated.

2.5. Ambulatory BP and physical activity

Physical activity was determined at 1 min epochs using an actigraph (Actiwatch 2; Respironics Inc., Murrysville, PA, USA) worn on the non-dominant arm. Ambulatory BP was measured using a validated device (TM-2430; A&D Co. Ltd., Tokyo, Japan) on the non-dominant arm at 30 min intervals. We calculated the mean of two days for the daytime systolic BP (blood pressure), nighttime systolic BP, and dipping [(daytime systolic BP − nighttime systolic BP) / (daytime systolic BP) × 100].

2.6. Other measurements

Venous blood samples were analyzed using a standard clinical chemical analysis to determine the concentration of creatinine, glycated hemoglobin (HbA1c), and fasting plasma glucose. Diabetes was defined based on medical history, the current administration of anti-diabetic treatment, or fasting plasma glucose of at least 126 mg/dl and HbA1c of at least 6.5% (National Glycohemoglobin Standardization Program value). The estimated glomerular filtration rate (eGFR) was calculated by the Japanese Society of Nephrology—Chronic Kidney Disease Practice Guide formula: $\text{eGFR (ml/min/1.73 m}^2) = 194 \times [\text{serum creatinine (mg/dl)}]^{-1.094} \times [\text{age (years)}]^{-0.287}$. The result was multiplied by a correction factor of 0.739 for women. Data of the day length from sun rise to sunset in Nara on the measurement days were obtained from National astronomical Observatory of Japan. The habitual intake of soup and fruit were asked using self-administered questionnaire as follows: "How many cups of Miso soup and other kind of soup do you have in a week?", "How often do you take fruit in a week?", and "Please select your quantity of your usual fruit intake from 1) small size, 2) standard portion size, and 3) large portion size". The product of the fruit intake frequency in a week and the size (1 to 3) was calculated.

2.7. Statistical analysis

For continuous variables with a normal distribution, the mean ± standard deviation was reported. For variables not distributed normally, the median and interquartile ranges were reported. The associations of variables with the nocturnal urinary sodium excretion rate were assessed using univariate and multivariate linear regression models. Multivariate adjusted mean values among tertile groups of daytime ambient temperature were compared using ANCOVA (analysis of covariance).

We assessed associations of nocturnal urinary sodium excretion rate with daytime ambient temperature as continuous variables (Table 2) and tertile groups (Table 3).

We explored the variables as potential confounders with marginal to significant association ($p < 0.20$) in the univariate model. In the