**INTRODUCTION**

Hypertension is a major public health burden worldwide [1]. Raised blood pressure (BP) is a leading cause of cardiovascular disease and mortality, but is also the strongest modifiable risk factor [2-4]. On the basis of scientific evidence of the beneficial effects of healthy lifestyle on BP control as well as overall health, lifestyle modifications such as a healthy diet and increased physical activity have been recommended as a first-line strategy to reduce BP [5,6]. Even for patients on antihypertensive medication, non-pharmacological treatment is still strongly recommended as a combination treatment [3,5,6].
Thus far, data on the effects of diet on BP have been acquired for some aspects of diet, such as nutrient intake (e.g., dietary fiber, polyunsaturated fats, potassium, and vitamins), food group consumption (e.g., fruits and vegetables, fish, and nuts), and dietary patterns (e.g., the Dietary Approaches to Stop Hypertension diet and the Mediterranean diet) [7-9]. Based on this evidence, health professionals have made recommendations about food consumption—both in terms of what and how much to eat—in order to prevent hypertension and to reduce BP [5,6]. However, both the prevalence of self-reported diet management and compliance with dietary recommendations are relatively low compared to compliance with antihypertensive medication or other lifestyle modifications, such as smoking cessation [10-15]. Although the BP-lowering effects of reduced sodium intake and healthy diet are well established in both normotensive and hypertensive people [9,16,17], people have still considerable difficulties preparing meals according to the recommendations, managing their diet in special situations (e.g., eating out), and modifying old habits, among other factors [16,18-20]. For successful dietary modification, there is a need for new strategies to lower potential barriers to diet management, coupled with efforts to better understand the factors influencing dietary compliance.

In recent years, interest has grown in the timing of eating beyond traditional dietary approaches focusing on foods and nutrients. A longer period of food intake each day, irregular eating, and eating at the wrong time are associated with more energy intake and poor diet quality [21-24]. Previous studies have shown that late eating was associated with lower efficacy of weight loss interventions than early eating [25], and that early time-restricted eating reduced appetite [26] and improved insulin sensitivity, BP, and oxidative stress [27]. Erratic eating patterns have been found to adversely influence obesity, diabetes, metabolic syndrome, and cardiovascular diseases [21,25,28,29]. However, that evidence was obtained from carefully controlled feeding studies with specific populations such as pregnant women or obese adults [21,22,25,27]. There is little evidence available on characteristics related to eating time, BP control, and cardiometabolic health among adults with hypertension in a real-world setting. Thus, this study aimed to investigate whether late eating is associated with BP control and cardiometabolic risk factors among Korean adults with hypertension.

**MATERIALS AND METHODS**

**Data source and study population**

This study used data from the Korea National Health and Nutrition Examination Survey (KNHANES) 2010-2018, which is an ongoing surveillance system conducted by Korea Disease Control and Prevention Agency (KCDA). This nationwide cross-sectional survey provides information on health and nutritional status.

In the KNHANES 2010-2018, there were 38,794 adults aged 30-79 years who had information on both BP and dietary intake. Among them, we excluded pregnant and lactating women (n = 539) or individuals for whom inaccurate information was obtained regarding the time of each eating episode, e.g., “do not remember” or “all morning” (n = 270). Among the remaining adults (n = 37,987), we included adults with hypertension who took antihypertensive medicine or had systolic BP of ≥140 mmHg or diastolic BP of ≥90 mmHg. Thus, a total of 13,361 adults with hypertension (6,244 men and 7,117 women) were retained in the present study.

**Dietary intake and definition of late eating**

Dietary intake was assessed using 1-day 24-hour recall. Trained dietitians collected information on dietary intake and habits. Participants were requested to report when, where, what, and how much they ate and drank on the recall day. Both the time of the day when they consumed foods and beverages (e.g., 07:40) and each eating episode (e.g., breakfast, lunch, dinner, and snack) were collected. If homemade dishes were consumed, the recipe was collected from the person who prepared the dishes. The amount of the foods and beverages participants consumed was reported using measuring aids (e.g., 2-dimensional drawings, rulers, measuring cups and spoons), and then converted into weight (g) by using the database for volume and weight of foods. All dietary recall procedures were performed using a standardized protocol involving the multiple-pass method. Dietary intake of food and nutrients was calculated using Korean food composition data developed for the KNHANES [30-32]. In addition to dietary intake, the raw data of the KNHANES included the overall diet quality score calculated using the Korean Healthy Eating Index (KHEI). The KHEI evaluates how well an individual’s diet complies with the dietary guidelines for Koreans. The KHEI consists of 14 components (8 for adequate intake, 3 for moderate intake, and 3 for balanced diet) and the score ranges from 0 to 100, with a higher score reflecting better diet quality [14,33]. More details are available elsewhere [14,32-35].

Late eating was defined by the midpoint between the times of the first and the last eating episode during the recall day, based on the operational definition applied in previous studies [25]. The median midpoint of eating episodes in our study population was 13:45; therefore, participants were divided into 2 groups according to the midpoint of their eating episodes as early eaters (before 13:45) and late eaters (after 13:45), respectively. The frequency of meals and snacks was defined by the number of eating episodes. The proportion of dietary energy intake from meals and snacks for each participant was calculated.

**Blood pressure control and cardiometabolic risk factors**

BP was measured 3 times at 5-minute intervals after resting for more than 5 minutes in a sitting position. The mean of the last 2 measurements was used in the present study. Controlled BP was defined as systolic BP < 140 mmHg and diastolic BP < 90 mmHg. Body weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively. Body mass index (BMI) was calculated as...
body weight divided by height squared (kg/m²). Waist circumference was measured to the nearest 0.1 cm at the midpoint between the lower rib cage and the iliac crest. Blood was collected after fasting for more than 8 hours. Fasting blood glucose, hemoglobin A1c, total cholesterol, triglycerides, and high-density lipoprotein-cholesterol were measured. All procedures of the health examination survey were performed by trained staff according to standardized protocols. Clinical laboratory tests were conducted in central certified laboratories. Further details on health examination are described elsewhere [30,34].

Other variables
Information on household income, occupation and shift work, health-related behaviors, past history of diseases, and medication was collected via a health interview survey. Household income was defined as the family income adjusted by the number of family members. The quartiles of monthly household income defined by the KNHANES were used in this study. Information regarding work time was obtained through the responses “working during the day (6 a.m. to 6 p.m.)” or “at different times.” In our study, those who worked at different times (e.g., night workers or 24-hour shift workers) were defined as shift workers, and the rest—including day workers and the unemployed—as non-shift workers. Smoking, drinking, and physical activity were assessed based on self-reports. Current smoking was defined as ongoing smoking behavior at the time of the survey and having smoked more than 5 packs of cigarettes in one’s lifetime. Current drinking was defined as drinking at least once a month during the last year. Physical activity was surveyed in every survey year, but the same questionnaire was not applied every year. However, information on walking was collected using the same question and protocol. Thus, the number of days walked was used as information regarding physical activity. History of diseases and information regarding disease treatment were collected through interviews. Comorbid status was defined based on the self-reported presence of any diagnosis of diabetes, dyslipidemia, stroke, myocardial infarction, or angina pectoris. Taking BP-lowering drugs on more than 20 days a month was defined as high adherence to antihypertensive medication. Details on data collection and health interview survey are available elsewhere [30,34].

Statistical analysis
Descriptive statistics on the time of eating episodes, demographic and health-related characteristics, and dietary profiles were presented as mean ± standard deviation (SD) or proportion (%). Differences in variables between late eaters and early eaters were analyzed using the Student t-test for continuous variables and the chi-square test for categorical variables.

The associations of late eating with BP control in adults with hypertension were examined using 3 logistic regression models. Model 1 was used to estimate the crude odds ratio (ORs) and the corresponding 95% confidence intervals (CIs) of late eating for controlled BP compared with early eating. Model 2 was used to estimate the adjusted OR after adjustment for gender, age, shift work, smoking, drinking, walking, BMI, comorbid status, and antihypertensive medication. Model 3 further adjusted for total energy intake and overall diet quality (i.e., the KHEI score) plus the variables included in model 2. The KHEI has been included only in the raw data of the KNHANES since 2013, and thus model 3 was performed in a smaller population (n = 8,493). We also performed multiple logistic regression analyses by gender (men or women), age (30-49, 50-64, or ≥ 65 years), shift work (yes or no), smoking (yes or no), drinking (yes or no), walking (< 3.5 or ≥ 3.5 d/wk), obesity (BMI < 23.0 or ≥ 23.0 kg/m²), comorbid status (yes or no), adherence to antihypertensive medication (high or low), overall diet quality (KHEI score < 65.8 or ≥ 65.8, using the study population mean), and whether the diet on the recall day was the same as usual or not. In subgroup analyses, multiple logistic models were adjusted for other potential confounders.

To evaluate differences in cardiometabolic risk factors between late eaters and early eaters, we presented data as means ± SDs by group and performed linear regression analyses. Crude models and adjusted models were applied, respectively. In multiple linear regression models, we adjusted variables included in model 2 of multiple logistic regression analyses as mentioned above. The results were presented as β coefficients and p-values. The data were analyzed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). All statistical tests were 2-sided, and p-values < 0.05 were considered to indicate statistical significance.

Ethics statement
All survey protocols and procedures were approved by the Institutional Review Board of the KCDA (2018-01-03-P-A, 2018-01-03-C-A). Informed consent was obtained from each participant. Further details on the KNHANES are described elsewhere [30,34].

RESULTS
Time of eating episodes and demographic and health-related characteristics
Among 13,361 adults with hypertension, 53.3% were women and the mean age was 61.8 years (Table 1). On average, the first eating episode was at 07:47 (hh:mm) and the last was at 19:43, and the median midpoint of eating time in the day was 13:45. The mean times of late eaters for all eating episodes were delayed compared with early eaters. The mean midpoint of the eating period of later eaters was nearly 2 hours later than that of early eaters. Later eaters were more often men, were younger, had a higher income, had a higher BMI, were more often shift workers, smokers and drinkers, and were less physically active than early eaters. Among all adults with hypertension, 71.4% were already aware of their hypertension, two-thirds took antihypertensive medication over 20 days per month, and 43.3% were diagnosed with any cardiometabolic diseases such as diabetes, dyslipidemia, stroke, myocardial infarction, or angina pectoris. Later eaters had relatively...
lower awareness of hypertension and antihypertensive treatment than early eaters.

**Dietary intake, the number of eating episodes, and overall diet quality**

Table 2 shows the differences in dietary profiles between late eaters and early eaters. Late eaters had more eating episodes and more energy intake than early eaters. Their meal frequency was slightly lower, but the snack frequency was much higher, and the proportion of snacking to total energy intake was higher than for early eaters. Late eaters also had lower KHEI scores than early eaters. Although some of the 14 KHEI components (i.e., meat/fish/eggs/legumes, milk/milk products, carbohydrate, and total fat) presented higher scores in late eaters and some (i.e., fruits, sweets and beverages, and balanced energy intake) showed no differences between late eaters and early eaters, all other component scores were higher in early eaters. Thus, late eaters had much poorer dietary profiles than early eaters.

**Association of late eating with blood pressure control**

Among our study participants, 50.8% had controlled BP (data not shown). Table 3 shows the ORs of late eating for BP control compared with early eating. Late eaters had a significantly lower OR for BP control in model 1 (0.82; 95% CI, 0.77 to 0.88), but this association disappeared after adjustment for other potential confounders in model 2 (OR, 1.03; 95% CI, 0.94 to 1.12) and model 3 (OR, 1.02; 95% CI, 0.90 to 1.15). Similar associations were found in subgroup analyses (Figure 1). Overall, an independent association between late eating and BP control was not found after adjusting for potential confounders.

**Associations of late eating with cardiometabolic risk factors**

Table 4 shows the associations between late eating and cardiometabolic risks, including BP, identified through linear regression analyses. In simple regression models, compared with early eaters, late eaters had significantly higher diastolic BP (3.20 mmHg), BMI (0.43 kg/m²), waist circumference (0.43 cm), triglycerides (14.70 mg/dL), and total cholesterol (3.50 mg/dL). After adjustment for potential confounders, the associations of late eating with BP, waist circumference, and total cholesterol disappeared. However, late eating still had a significant association with higher BMI (0.13 kg/m², p = 0.03) and triglycerides (6.43 mg/dL, p < 0.01). We also investigated associations between the midpoint time of the eating period during the day and cardiometabolic risk factors.
in the same multivariate models. The midpoint of the eating period had no significant association with systolic/diastolic BP or other cardiometabolic risk factors, but each 10-minute delay in the midpoint of the eating period was associated with a 1.05 mg/dL increase in the blood triglyceride concentration after adjustment for potential confounders (data not shown).

**DISCUSSION**

Using data from the KNHANES 2010-2018, we examined the associations of late eating with BP control and cardiometabolic risk factors among Korean adults with hypertension. In our study, late eating showed a negative association with BP control in a univariate model, but this association disappeared after adjustment for potential confounders. Late eating was significantly associated with higher BMI and a higher blood concentration of triglycerides, independent of potential confounders.

There have been few studies on meal timing, and none have focused on Koreans. Our study found that the average time of the first and last food intake of Korean adults with hypertension was 07:47 and 19:43, respectively, and the midpoint of the eating period was 13:45. In a study of overweight and obese adults in Spain [25], information on eating time was collected using questionnaires. The mean breakfast and dinner times were 08:31 and 21:21, respectively, and the median midpoint between breakfast and dinner was 14:54. Another study of healthy Indian adults showed that overall the median breakfast and last intake times were 06:58 and 22:45, respectively [36]. Our study participants had a slightly shorter eating duration and earlier dietary intake than participants in other studies [25,36].

**Table 2. Dietary profiles according to late eating in adults with hypertension**

| Variables                                      | Total (n=13,361) | Early eaters (n=6,680) | Late eaters (n=6,681) | p-value |
|------------------------------------------------|------------------|------------------------|-----------------------|---------|
| **Dietary intake**                             |                  |                        |                       |         |
| Energy intake, kcal/d                          | 1,889±840        | 1,826±796              | 1,952±878             | <0.001  |
| Carbohydrates (% of TE)                       | 70.3±11.2        | 71.8±10.8              | 68.9±11.3             | <0.001  |
| Protein (% of TE)                              | 14.1±4.2         | 13.8±4.1               | 14.3±4.3              | <0.001  |
| Fat (% of TE)                                  | 15.6±8.7         | 14.4±8.3               | 16.8±8.9              | <0.001  |
| Sodium, mg/d                                   | 3,885±2,858      | 3,731±2,733            | 4,039±2,969           | <0.001  |
| **Frequency of eating occasions (total)**      | 5.3±1.8          | 5.1±1.7                | 5.4±1.8               | <0.001  |
| **Meals**                                      | 2.8±0.5          | 2.8±0.4                | 2.7±0.5               | <0.001  |
| **Snacks**                                     | 2.5±1.7          | 2.3±1.7                | 2.7±1.7               | <0.001  |
| **Meal energy density (% of TE)**              |                  |                        |                       |         |
| Meals                                          | 82.9±15.1        | 84.5±14.8              | 81.2±15.3             | <0.001  |
| Snacks                                         | 17.1±15.1        | 15.5±14.8              | 18.8±15.3             | <0.001  |
| **Healthy eating index (score)**               | 65.8±12.4        | 66.4±12.1              | 65.2±12.6             | <0.001  |
| **Adequacy**                                   |                  |                        |                       |         |
| Breakfast (0-10)                               | 8.7±3.0          | 9.3±2.2                | 8.1±3.4               | <0.001  |
| Mixed grains (0-5)                             | 2.6±2.2          | 2.7±2.2                | 2.4±2.2               | <0.001  |
| Total fruits (0-5)                             | 2.5±2.2          | 2.5±2.3                | 2.5±2.2               | 0.386   |
| Fresh fruits (0-5)                             | 2.7±2.4          | 2.6±2.4                | 2.7±2.4               | 0.622   |
| Total vegetables (0-5)                         | 3.7±1.4          | 3.8±1.4                | 3.7±1.4               | 0.001   |
| Fresh vegetables (0-5)                         | 3.4±1.6          | 3.5±1.7                | 3.4±1.6               | 0.005   |
| Meat, fish, egg, and legumes (0-10)            | 6.6±3.3          | 6.5±3.3                | 6.7±3.3               | <0.001  |
| Milk and its products (0-10)                   | 2.6±4.1          | 2.5±4.0                | 2.8±4.2               | <0.001  |
| **Moderation**                                 |                  |                        |                       |         |
| Saturated fatty acids (0-10)                   | 8.8±2.9          | 9.0±2.6                | 8.6±3.1               | <0.001  |
| Sodium (0-10)                                  | 6.9±3.3          | 7.1±3.3                | 6.7±3.4               | <0.001  |
| Sweets and beverages (0-10)                    | 9.5±1.8          | 9.5±1.8                | 9.4±1.9               | 0.140   |
| **Balance**                                    |                  |                        |                       |         |
| Carbohydrates (0-5)                            | 1.9±2.1          | 1.8±2.0                | 2.1±2.1               | <0.001  |
| Total fat (0-5)                                | 2.8±2.2          | 2.6±2.2                | 3.0±2.2               | <0.001  |
| Energy intake (0-5)                            | 3.1±2.2          | 3.1±2.2                | 3.1±2.2               | 0.351   |

Values are presented as mean±standard deviation.
TE, total energy intake; KNHANES, Korea National Health and Nutrition Examination Survey.
1Student t-test.
2Information on healthy eating index and its components was available only for participants in the KNHANES 2013-2018.
Although there was no independent association between late eating and BP control among our study population of adults with hypertension, our findings concerning late eating, higher BMI, and higher triglyceride concentrations are consistent with previous studies on the detrimental effects of late eating on cardiometabolic risks and cardiovascular diseases [21,25,29,37,38]. Later circadian timing of food intake is reportedly associated with increased BMI and percentage of body fat, regardless of more traditional risk factors (e.g., the amount or content of dietary intake and physical activity) [25,37]. Late eaters had a higher blood concentration of triglycerides, lower insulin sensitivity, a higher concentration of leptin in the morning, and more obesogenic behaviors (e.g., eating when stressed, eating while watching TV, etc.) than early eaters [25]. The timing and distribution of dietary intake during the day seem to be related to human health. A British birth cohort showed that high energy intake late in the evening was associated with higher hypertension incidence and greater increases in BP over 10 years [29]. A carefully controlled inpatient study reported that nighttime eaters gained more weight than non-nighttime eaters after adjustment for baseline weight and follow-up time [21]. In a weight loss intervention trial, later eaters had a lower success rate and a lower rate of weight loss than early eaters [25].

In addition to later circadian timing of eating, there is evidence supporting the beneficial influence of shortening eating duration and early eating on human health [26,27,39,40]. Controlled feeding trials found that early time-restricted feeding (eating from 08:00 to 14:00 [26] and 6-hour feeding with dinner before 15:00 [27]) increased fullness and decreased the desire to eat [26], increased fat oxidation [26], and improved BP [27], insulin sensitivity [27], oxidative stress levels, and metabolic flexibility [26,27]. In a trial that only shortened eating duration (10-11 hours) for overweight adults with prolonged eating periods (>14 hours), subjects experienced body weight reduction, expressed more subjective sleep satisfaction, and reported feeling more energetic. Eating

| Variables                        | Total (n) | BP control (%) | OR for BP control (95% CI)¹   |
|----------------------------------|----------|---------------|------------------------------|
|                                  |          |               | Model 1                     |
| Meal timing                      |          |               | Model 2                     |
| Early eaters                     | 6,680    | 3,561 (53.3)  | 1.00 (reference)            |
| Late eaters                      | 6,681    | 3,228 (48.3)  | 0.82 (0.77, 0.88)           |
| Gender                           |          |               | Model 3                     |
| Men                              | 6,244    | 3,052 (48.9)  | 1.00 (reference)            |
| Women                            | 7,117    | 3,737 (52.5)  | 0.86 (0.78, 0.95)           |
| Age (yr)                         | 13,361   |               | 1.00 (0.99, 1.00)           |
| Shift working                    |          |               | 1.00 (0.99, 1.01)           |
| No                               | 11,993   | 6,124 (51.1)  | 1.00 (reference)            |
| Yes                              | 1,099    | 524 (47.7)    | 1.13 (0.96, 1.33)           |
| Current smoking                  |          |               | 1.14 (0.91, 1.44)           |
| No                               | 11,010   | 5,721 (52.0)  | 1.00 (reference)            |
| Yes                              | 2,211    | 991 (44.8)    | 1.12 (0.98, 1.28)           |
| Current drinking                 |          |               | 1.14 (0.94, 1.38)           |
| No                               | 6,802    | 3,665 (53.9)  | 1.00 (reference)            |
| Yes                              | 6,422    | 3,044 (47.4)  | 1.05 (0.95, 1.16)           |
| Walking, no. of days             | 13,087   |               | 1.02 (1.00, 1.03)           |
| Body mass index (kg/m²)          | 13,333   |               | 1.02 (1.00, 1.04)           |
| Comorbid status                  |          |               | 0.99 (0.97, 1.01)           |
| No                               | 7,581    | 3,134 (41.3)  | 1.00 (reference)            |
| Yes                              | 5,780    | 3,655 (63.2)  | 1.05 (0.96, 1.15)           |
| Adherence to antihypertensive medication |        |               | 1.05 (0.93, 1.18)           |
| Low                              | 4,318    | 331 (7.7)     | 1.00 (reference)            |
| High                             | 9,043    | 6,458 (71.4)  | 30.94 (27.05, 35.39)        |
| Total energy intake (100 kcal)   | 13,361   |               | 187.86 (133.32, 264.70)     |
| Healthy Eating Index (10 score)  | 8,493    |               | 1.00 (0.99, 1.00)           |

Data include number of participants, proportion of controlled blood pressure within each group, and OR (95% CI) of late eating for BP control. BP, blood pressure; OR, odds ratio; CI, confidence interval.

¹Model 1 shows crude ORs; Model 2 was adjusted for gender, age, shift work, smoking, drinking, walking, body mass index, comorbid status, and adherence to antihypertensive medication; Model 3 was additionally adjusted for total energy intake and healthy eating index plus the variables included in model 2.
Figure 1. Subgroup analyses for associations of late eating with blood pressure control in hypertensive adults. ORs after adjustment for gender, age, shift work, smoking, drinking, walking, BMI, comorbid status, and adherence to antihypertensive medication. Data are presented as OR and 95% CI. The Korean Healthy Eating Index was available for the KNHANES 2013-2018 participants, and thus subgroup analyses for diet quality were performed using data of adults in 2013-2018 (n=8,493). OR, odds ratio; CI, confidence interval; KNHANES, Korea National Health and Nutrition Examination Survey.

Table 4. Associations of late eating with cardiometabolic risk factors in adults with hypertension

| Variables | Cardiometabolic risk factors, mean±SD | Parameter estimate for cardiometabolic risk factors (p-value) |
|-----------|--------------------------------------|----------------------------------------------------------|
|           | Early eaters | Late eaters | Crude model | Adjusted model¹ |
| Systolic blood pressure (mmHg) | 134.2±16.8 | 133.6±16.6 | -0.61 (0.035) | -0.38 (0.161) |
| Diastolic blood pressure (mmHg) | 79.0±11.8 | 82.2±12.3 | 3.20 (<0.001) | 0.19 (0.261) |
| BMI (kg/m²) | 24.9±3.3 | 25.3±3.5 | 0.43 (<0.001) | 0.13 (0.029) |
| Waist circumference (cm) | 86.1±9.1 | 86.5±9.5 | 0.43 (0.008) | -0.09 (0.273) |
| Fasting glucose (mg/dL) | 107.6±27.1 | 107.7±27.1 | 0.13 (0.790) | 0.20 (0.643) |
| Hemoglobin A1c (%) | 6.1±0.9 | 6.1±1.0 | -0.02 (0.218) | 0.01 (0.547) |
| Triglycerides (mg/dL) | 150.4±100.0 | 165.1±134.8 | 14.70 (<0.001) | 6.47 (0.003) |
| Total cholesterol (mg/dL) | 188.4±38.7 | 191.9±39.1 | 3.50 (<0.001) | 0.77 (0.253) |
| HDL cholesterol (mg/dL) | 48.2±12.0 | 48.1±11.9 | -0.12 (0.569) | -0.23 (0.270) |

SD, standard deviation; BMI, body mass index; HDL, high-density lipoprotein.

¹Adjusted models included gender, age, shift work, smoking, drinking, walking, BMI, comorbid status, and adherence to antihypertensive medication. For BMI, BMI was excluded in the adjusted model; for fasting glucose or hemoglobin A1c, antidiabetic treatment (drug use or insulin injection) was additionally added in the adjusted model; for blood lipid levels, lipid-lowering medication was additionally added in the adjusted model.
time also seems to be related to the composition and function of the human gastrointestinal microbiota [40]. These time-based dietary interventions usually focus on limiting the eating hours in the day (e.g., shortening the eating period or shifting the eating window to early in the day) without intentionally altering dietary quality or quantity. Time-based dietary approaches appear to be relatively easy to follow and adapt. In clinical feeding trials, time-restricted interventions not only have a high level of compliance and a low dropout rate [27,41], but also have few or no adverse effects [26,27,41], and thus have been proposed as a sustainable and effective strategy for dietary modification.

Several mechanisms may explain how time-related dietary characteristics, including late-eating, affect overall health [27,39,42-44]. One possible explanation is that early time-restricted eating may decrease dietary energy intake, even if people do not pay attention to calorie intake [39,43]. A decrease in calorie intake induces a decrease in body weight, thereby improving health conditions [43]. However, later circadian time-of-eating appears to play a role in body composition even after controlling for total calorie intake and other possible confounders [37]. Sutton et al. [27] found that early time-restricted feeding improved insulin sensitivity, BP, oxidative stress, and appetite even without weight loss, in their randomized, crossover, isocaloric and eucaloric controlled feeding trial. This impact of eating time on human health has been explained by several other mechanisms [42,45,46]. Previous studies found that circadian rhythms may regulate human metabolism (e.g., thermic effect of food, gluconeogenesis, glycolysis, protein or lipid synthesis, lipid oxidation, and mitochondrial function), maintain homeostasis, and also coordinate the process of nutrition [42]. This suggests that humans are optimized for food intake in the morning rather than later in the day, and that eating at the wrong time (i.e., eating at times misaligned with the circadian rhythm) can lead to circadian disruption, contributing to metabolic dysfunction and adverse impacts on health in spite of no change in food intake or physical activity [42,44]. Disrupted circadian rhythms are found in later life and also in disease conditions [46]. Scheduled meals (i.e., right-time eating aligned with the circadian rhythm) can entrain the circadian system and restore circadian rhythms [46]. However, further studies are still required in order to better understand the link between eating time and human health, because there is not enough information regarding which eating time periods and lengths of eating times are more beneficial for human health.

In Korea, one-third of adults aged 30 years or older are estimated to have hypertension. The rates of treatment and control of hypertension rapidly improved relative to the past, but there has been no substantial change for the last decade [47]. The increased control rate of hypertension may be due to increased antihypertensive drug treatment [47]. The low proportion of dietary management [14] and the low level of dietary adherence to guidelines for hypertension prevention and treatment are still problematic [16]. Moreover, our previous study found a distinct gap between normotensive adults’ attitudes towards hypertension treatment and the current health-related behaviors of adults with hypertension [16]. Although pharmacological treatment is a major contributor to reducing BP, dietary modification can also improve cardiovascular health [43]. Thus, efforts are needed to seek an easy-to-adapt and promising strategy for diet modification.

This study is the first attempt to show the characteristics of the eating time of Korean adults with hypertension and to examine the associations of eating time with BP control and cardiometabolic risk factors. We used the data from KNHANES, a nationwide study, and thus were able to include diverse adults with hypertension residing across Korea. We believe our findings are meaningful because they show an unfavorable association between late eating and some cardiometabolic health factors, even after adjustment for confounders such as pharmacological treatment. Despite these strengths, this study has some limitations to be considered. First, this study analyzed cross-sectional data. Thus, our findings do not demonstrate a causal relationship between late eating and BP control and cardiometabolic risk factors among adults with hypertension. Second, we defined late eating by using 1-day 24-hour recall data, which may not reflect individuals’ usual eating patterns in terms of time. To partly overcome the limitation of single-day dietary assessments, we additionally performed the same analyses only for adults with hypertension who reported that the amount of food they ate on the recall day was similar to the amount of food they usually ate (Supplementary Material 1), and the associations between late eating and cardiometabolic risk factors remained unchanged. Nonetheless, caution is still needed when interpreting these results. Lastly, although 24-hour recall data of the KNHANES contain information on the time when each participant consumed food, the dietary assessment of the KNHANES was originally intended to measure the dietary intake of foods and nutrients, not to capture the time of the day in detail. Thus, our data lack details on eating time, such as time-stamped ingestion data, which recent studies have collected using innovative smartphone apps [36,39].

In conclusion, this study did not find an independent association between late eating and BP control among Korean adults with hypertension, but found an inverse association between late eating and cardiometabolic health, independent of confounders. Our findings support the suggestion that a time-based dietary approach can be used as a useful strategy to improve the prognosis of adults with hypertension. Further research is needed to clarify the causal relationship between late eating and health and to understand the impact of other attributes related to meal timing (e.g., eating period and the eating time window) on health.

**SUPPLEMENTARY MATERIALS**

Supplementary material is available at http://www.e-epih.org/.

**CONFLICT OF INTEREST**

The authors have no conflicts of interest to declare for this study.
REFERENCES

1. Kearney PM, Whelton M, Reynolds K, Muntner P, Whelton PK, He J. Global burden of hypertension: analysis of worldwide data. Lancet 2005;365:217-223.

2. Lackland DT, Weber MA. Global burden of cardiovascular disease and stroke: hypertension at the core. Can J Cardiol 2015;31:569-571.

3. Olsen MH, Angell SY, Asma S, Boutouyrie P, Burger D, Chirinos JA, et al. A call to action and a lifestyle strategy to address the global burden of raised blood pressure on current and future generations: the Lancet Commission on hypertension. Lancet 2016;388:2665-2712.

4. Stampfer MJ, Hu FB, Manson JE, Rimm EB, Willett WC. Primary prevention of coronary heart disease in women through diet and lifestyle. N Engl J Med 2000;343:16-22.

5. Whelton PK, Carey RM, Aronow WS, Casey DE Jr, Collins KJ, Dennison Himmelfarb C, et al. 2017 ACC/AHA/ABC/ACP/AANS/ASPS/ASRA/IDSA/SICP/ASA/SNIS/S到底 guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. Circulation 2018;138:e1948-e294.

6. Lee HY, Shin J, Kim GH, Park S, Ilm SH, Kim HC, et al. 2018 Korean Society of Hypertension Guidelines for the management of hypertension: part II-diagnosis and treatment of hypertension. Clin Hypertens 2019;25:504-509.

7. O’Shaughnessy KM. Late eating and blood pressure control. J Adv Nurs 1999;29:832-839.

8. Hori M, Kitai M, Watanabe K, Ishii J, Saito T, Tanaka K, et al. Compliance with dietary guidelines among hypertensive patients. Hypertens Res 2006;29:388-393.

9. Srinath Reddy K, Katan MB. Diet, nutrition and the prevention of hypertension and cardiovascular diseases. Public Health Nutr 2004;7:167-186.

10. Kyngäs H, Lahdenperä T. Compliance of patients with hypertension and associated factors. J Adv Nurs 1999;29:832-839.

11. Khan MS, Bawany FI, Mirza A, Hussain M, Khan A, Lashari MN. Frequency and predictors of non-compliance to dietary recommendations among hypertensive patients. J Community Health 2014;39:732-736.

12. Kwan MW, Wong MC, Wang HH, Liu KQ, Lee CL, Yan BP, et al. Compliance with the Dietary Approaches to Stop Hypertension (DASH) diet: a systematic review. PLoS One 2013;8:e78412.

13. Adiouch S, Lelong H, Kesse-Guyot E, Baudry J, Lampuré A, Galan P, et al. Compliance with nutritional and lifestyle recommendations in 13,000 patients with a cardiometabolic disease from the Nutrinet-Santé Study. Nutrients 2017;9:546.

14. Shim JS, Oh K, Jung SJ, Kim HC. Self-reported diet management and adherence to dietary guidelines in Korean adults with hypertension. Korean Circ J 2020;50:432-440.

15. Hellstroem I, Brands MW, Daniels SR, Karanja N, Elmer PJ, Sacks FM, et al. Dietary approaches to prevent and treat hypertension: a scientific statement from the American Heart Association. Hypertension 2006;47:296-308.

16. Adams OP, Carter AO. Knowledge, attitudes, practices, and barriers reported by patients receiving diabetes and hypertension primary health care in Barbados: a focus group study. BMC Fam Pract 2011;12:135.

17. Russell BE, Gurrola E, Ndumele CD, Landon BE, O’Malley JA, Keegan T, et al. Perspectives of non-Hispanic Black and Latino patients in Boston’s urban community health centers on their experiences with diabetes and hypertension. J Gen Intern Med 2010;25:504-509.

18. DeAndrade S, El Rayess F, Goldman R. Perspectives on hypertension in the New England Cape Verdean community. J Racial Ethnic Health Disparities 2018;5:162-169.

19. Gluck ME, Venti CA, Salbe AD, Krakoff J. Nighttime eating: commonly observed and related to weight gain in an inpatient food intake study. Am J Clin Nutr 2008;88:900-905.

20. Gontijo CA, Balieiro LC, Teixeira GP, Fahmy WM, Crispim CA, Maia YC. Effects of timing of food intake on eating patterns, diet quality and weight gain during pregnancy. Br J Nutr 2020;123:922-933.
24. Rothschild J, Hoddy KK, Jambazian P, Varady KA. Time-restricted feeding and risk of metabolic disease: a review of human and animal studies. Nutr Rev 2014;72:308-318.

25. Dashti HS, Gómez-Abellán P, Qian J, Esteban A, Morales E, Scheer FA, et al. Late eating is associated with cardiometabolic risk traits, obesogenic behaviors, and impaired weight loss. Am J Clin Nutr 2020;113:154-161.

26. Ravussin E, Beyl RA, Poggiogalle E, Hsia DS, Peterson CM. Early time-restricted feeding reduces appetite and increases fat oxidation but does not affect energy expenditure in humans. Obesity (Silver Spring) 2019;27:1244-1254.

27. Sutton EF, Beyl R, Early KS, Cefalu WT, Ravussin E, Peterson CM. Early time-restricted feeding improves insulin sensitivity, blood pressure, and oxidative stress even without weight loss in men with prediabetes. Cell Metab 2018;27:1212-1221.

28. Maugeri A, Kunzova S, Medina-Inojosa JR, Agodi A, Barchitta M, Homolka M, et al. Association between eating time interval and frequency with ideal cardiovascular health: results from a random sample Czech urban population. Nutr Metab Cardiovasc Dis 2018;28:847-855.

29. Almoosawi S, Prynne CJ, Hardy R, Stephen AM. Time-of-day of energy intake: association with hypertension and blood pressure 10 years later in the 1946 British Birth Cohort. J Hypertens 2013;31:882-892.

30. Korea Centers for Disease Control and Prevention. 2016-2018 Guidelbook for using the data from Korea National Health and Nutrition Examination Survey; 2020 [cited 2021 Sep 1]. Available from: https://knhanes.kdca.go.kr/knhanes/sub03/sub03_02_05.do.

31. National Institute of Agricultural Sciences. Korean standard food composition table (version 9.1); 2019 [cited 2021 Sep 1]. Available from: http://koreanfood.rda.go.kr/eng/ftcFoodSrchEng/engMain.

32. Korea Centers for Disease Control and Prevention. Guidelines for nutrition survey: Korea National Health and Nutrition Examination Survey 6th (2013-2015); 2015 [cited 2021 Sep 1]. Available from: https://knhanes.kdca.go.kr/knhanes/sub04/sub04_02_02.do?classType=4.

33. Yun S, Oh K. Development and status of Korean Healthy Eating Index for adults based on the Korea National Health and Nutrition Examination Survey. Public Health Wkly Rep 2018;11:1764-1772 (Korean).

34. Kweon S, Kim Y, Jang MJ, Kim Y, Kim K, Choi S, et al. Data resource profile: the Korea National Health and Nutrition Examination Survey (KNHANES). Int J Epidemiol 2014;43:69-77.

35. Shim JS, Shim SY, Cha HJ, Kim J, Kim HC. Socioeconomic characteristics and trends in the consumption of ultra-processed foods in Korea from 2010 to 2018. Nutrients 2021;13:1120.

36. Gupta NJ, Kumar V, Panda S. A camera-phone based study reveals erratic eating pattern and disrupted daily eating-fasting cycle among adults in India. PLoS One 2017;12:e0172852.

37. Kelly AW, Phillips AJ, Czeisler CA, Keating L, Yee K, Barger LK, et al. Later circadian timing of food intake is associated with increased body fat. Am J Clin Nutr 2017;106:1213-1219.

38. Kupek E, Lobo AS, Leaf DB, Bellisle F, de Assis MA. Dietary patterns associated with overweight and obesity among Brazilian schoolchildren: an approach based on the time-of-day of eating events. Br J Nutr 2016;116:1954-1965.

39. Gill S, Panda S. A smartphone App reveals erratic diurnal eating patterns in humans that can be modulated for health benefits. Cell Metab 2015;22:789-798.

40. Kaczmarek JL, Musaad SM, Holscher HD. Time of day and eating behaviors are associated with the composition and function of the human gastrointestinal microbiota. Am J Clin Nutr 2017;106:1220-1231.

41. Wilkinson MJ, Manoogian EN, Zadourian A, Lo H, Fakhouri S, Shoghi A, et al. Ten-hour time-restricted eating reduces weight, blood pressure, and atherogenic lipids in patients with metabolic syndrome. Cell Metab 2020;31:92-104.

42. Świątkiewicz I, Wozniak A, Taub PR. Time-restricted eating and metabolic syndrome: current status and future perspectives. Nutrients 2021;13:221.

43. Gabel K, Hoddy KK, Haggerty N, Song J, Kroeger CM, Trepanowski JF, et al. Effects of 8-hour time-restricted feeding on body weight and metabolic disease risk factors in obese adults: a pilot study. Nutr Healthy Aging 2018;4:345-353.

44. Chellappa SL, Vujovic N, Williams JS, Scheer FA. Impact of circadian disruption on cardiovascular function and disease. Trends Endocrinol Metab 2019;30:767-779.

45. Jiang P, Turek FW. Timing of meals: when is as critical as what and how much. Am J Physiol Endocrinol Metab 2017;312:E369-E380.

46. Kessler K, Pivovarova-Ramich O. Meal timing, aging, and metabolic health. Int J Mol Sci 2019;20:1911.

47. Korean Society of Hypertension. Korea hypertension fact sheet 2018 [cited 2019 Aug 5]. Available from: http://www.koreanhypertension.org/reference/guide?mode=read&tidno=4166 (Korean).