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Dietary Sodium, Potassium, and Blood Pressure in Normotensive Pregnant Women: the National Health and Nutrition Examination Survey

Abbi D. Lane-Cordova[1], **Lara R. Schneider**[2], **William C. Tucker**[1], **James W. Cook**[3], **Sara Wilcox**[1], **Jihong Liu**[2]

[1]Department of Exercise Science, University of South Carolina, Columbia, SC, USA

[2]Department of Epidemiology, Arnold School of Public Health, University of South Carolina, Columbia, SC, USA

[3]Department of Obstetrics and Gynecology, School of Medicine, University of South Carolina, Columbia, SC, USA

Abstract

Dietary sodium, potassium, and sodium-to-potassium ratio are linearly associated with blood pressure (BP) in non-pregnant adults. Earlier investigations suggested null or inverse associations of BP and sodium during normotensive pregnancy; findings have not been confirmed in race/ethnically diverse women or while accounting for potassium. Our purpose was to evaluate associations of BP with sodium and potassium and sodium-to-potassium ratio in race/ethnically diverse normotensive pregnant women. We used cross-sectional BP and dietary data from 984 women in multiple cycles of the National Health and Nutrition Examination Survey (mean age=27.6±0.2 years). We tested for differences in BP across quartiles of sodium intake using Kruskal-Wallis tests and linear regression to evaluate associations of sodium, potassium, and the sodium-to-potassium ratio with systolic and diastolic BP. We adjusted for potential confounding variables: age, race/ethnicity, education, marital status, BMI, smoking, and month of pregnancy. Systolic and diastolic BP were similar across quartiles of sodium intake: Quartile 1 (lowest sodium intake): 107/59; Quartile 2: 106/59; Quartile 3: 108/60; Quartile 4 (highest sodium intake): 108/58 mmHg, $p>0.60$ for all. Sodium (b=0.16, 95%CI: −0.20, 0.52) and potassium (b=0.18, 95%CI: −0.24, 0.60) and the sodium-to-potassium ratio (b= −0.54, 95%CI: −1.55, 0.47) were not associated with systolic or diastolic BP. Results were similar in stratified analyses.

• BP was similar among quartiles of sodium or potassium intake, even in analyses stratified by race/ethnicity and trimester of pregnancy

• There was no association of sodium or potassium with BP

• BP may be insensitive to dietary sodium and potassium during normotensive pregnancy

Corresponding Author: Abbi Lane-Cordova, 921 Assembly St, room 238, Columbia, SC 29201, Phone: 803-777-7568, lanecord@mailbox.sc.edu, Fax: 803-777-4783.

Conflicts of Interest
None.

Keywords

pregnancy; blood pressure; diet; sodium; potassium; nutrition

Introduction

Sodium is directly associated with blood pressure and potassium is inversely associated with blood pressure in non-pregnant adults (Jackson et al. 2018). The sodium-to-potassium ratio is also directly and linearly associated with blood pressure in non-pregnant adults (Jackson et al. 2018). Associations have been observed in non-pregnant adults, including reproductive-aged women, when sodium and potassium were quantified by diet recall or urinary excretion, and persisted after accounting for key covariables, such as sex, age, and race/ethnicity (Jackson et al. 2018; Zhang et al. 2013).

In contrast, sufficient dietary sodium may be important for promoting the plasma volume expansion necessary for adequate perfusion of the uteroplacental unit during pregnancy (Robinson 1958; Scaife and Mohaupt 2017). In a study in which dietary sodium was experimentally manipulated, salt-loading, achieved by enriching the diet with an additional 0.12g sodium/kg bodyweight for one week, led to a ~3 mmHg reduction in blood pressure in normotensive pregnant women (Gennari-Moser et al. 2014). However, the study did not account for counter-effects of dietary potassium and only included 19 white women in the first trimester of pregnancy. Another recent study of 701 women at the midpoint of pregnancy had contrasting findings; the authors reported that normotensive pregnant women who drank water with high salinity had significantly higher systolic (+ ~4 mmHg) and diastolic (+ ~2 mmHg) blood pressures compared to normotensive pregnant women who drank mainly rain water (Scheelbeek et al. 2016). Elevated blood pressure during pregnancy, i.e., systolic pressure >120 mmHg but below the threshold for hypertension, has been linked to future maternal hypertension, underscoring the importance of identifying modifiable factors that contribute to subtle differences in pregnancy blood pressure even within a normotensive range (Dunietz et al. 2017).

Given the fact that black women experience salt-sensitive hypertension at higher rates than white women and considering the known race/ethnic differences in rates of hypertensive disorders of pregnancy (Farquhar et al. 2015; Ghosh et al. 2014), associations of sodium and potassium with blood pressure during pregnancy may be modified by race/ethnicity. To the best of our knowledge, the effect of race/ethnicity on these associations has not been investigated. Further, blood pressure decreases until the midpoint of pregnancy and then rises back to pre-pregnancy levels in the third trimester during a normotensive pregnancy (Ochsenbein-Kolble et al. 2004), so associations of sodium, potassium, and the sodium-to-potassium ratio with blood pressure could also vary by trimester.

The purpose of our study was to evaluate associations of dietary intake of sodium, potassium, and the sodium-to-potassium ratio with blood pressure in normotensive pregnant women. We hypothesize that sodium, potassium, and the sodium-to-potassium ratio will not be associated with blood pressure in the full cohort of normotensive pregnant women, but that subgroup analyses will reveal a direct association of sodium with blood pressure in pregnant black women with blood pressure in the normotensive range.

Subjects and Methods

Participants

Participants in NHANES were selected using a multistage, stratified probability sampling approach. This approach is conducive to the generation of nationally representative estimates. We used data from the NHANES cycles 1999–2000 through 2013–2014 for this study (2013a). Data collected in NHANES include interview, physical examination, and a urine pregnancy test. NHANES is publicly available, and our study was determined to be exempt by the University of South Carolina Institutional Review Board.

We included pregnant women in our study. Pregnancy was verified with a urine pregnancy test. We excluded women who identified as pregnant but had a negative (n=2) or inconclusive (n=3) urine pregnancy test and excluded women who reported that they were 10 or more months pregnant (n=350). Of the 1,060 remaining women, 76 women (~7%) were classified as hypertensive during pregnancy based on average blood pressure or current use of antihypertensive medications. Given that our objective was to determine associations of sodium, potassium, and the sodium-to-potassium ratio with blood pressure in normotensive pregnant women, we omitted the 76 women with hypertension for our main analyses. Our final cohort included 984 women. We did not include a non-pregnant control group because the associations of sodium and potassium with blood pressure have been established and well-described in non-pregnant women in NHANES (Jackson et al. 2018).

Blood Pressure

Systolic and diastolic blood pressure (SBP and DBP, respectively) were measured after a 5-min seated rest using a sphygmomanometer. First, the participant's maximum inflation level was determined, then 3 additional BP readings were obtained (2013b). We included the average of the three SBP and DBP readings in our analysis. Hypertension was defined as average BP of ≥130/≥90 or current use of antihypertensive medications (Whelton et al. 2018).

Dietary Intake

Dietary sodium, potassium, and total intake were obtained from two days of interview data. According to the procedure manual: "Estimates of total intake of energy, nutrients, and nonnutrient food components from foods and beverages that were consumed during the 24-hour period before the interview (midnight to midnight)" were collected by trained non-dietician interviewers using a 24-hr recall and detailed food frequency questionnaire (2016) and analyzed by comparing to standards established and available via a national database (USDA 2015). We included an average of total values over the two days of dietary interview data, publicly available from NHANES, in our analysis.

Covariates

Information regarding age, race/ethnicity, smoking status, income, and marital status were obtained with surveys (2014a) Height and weight were measured as previously described in NHANES. Body mass index (BMI) was calculated as the weight in kilograms (kg) divided by height in meters squared (m^2) (2014b).

Statistical Analyses

Demographic and health characteristics were compared across quartiles of sodium intake using Kruskal-Wallis tests or chi-square tests for categorical variables. Differences in mean BP by quartiles of exposure were determined using Kruskal-Wallis tests, unadjusted and adjusted for age and race/ethnicity.

We used linear regression to test for associations of sodium, potassium, and sodium-to-potassium ratio with BP, unadjusted and adjusted, in separate analyses. Covariables included in adjusted models included: age, race/ethnicity, BMI, education, smoking, month of pregnancy, and marital status.

We used logistic regression to test for associations of dietary sodium or potassium intake or sodium-to-potassium ratio with odds of having hypertension in adjusted analyses as described above. In exploratory analyses, we repeated our adjusted linear regression analyses in the women identified as hypertensive to evaluate whether associations were similar in the women with hypertension during pregnancy.

Because of the effect of pregnancy progression on blood pressure (Ochsenbein-Kolble et al. 2004) and the race/ethnic disparity in rates of hypertension (Mozaffarian et al. 2015) and salt-sensitivity of blood pressure (Tu et al. 2014), we conducted two sensitivity analyses. First, we tested for differences in mean blood pressure among quartiles of sodium intake stratified by trimester of pregnancy. Next, we conducted the linear regression analyses stratified by race/ethnicity. To improve statistical power and because of low numbers of “Other Hispanic” women, we classified women as Hispanic if they received a designation of Mexican-American or Other Hispanic in the NHANES codebook.

A p-value of <0.05 was considered significant, and data are means and standard error unless otherwise noted. STATA version 14.0 (College Station, TX) was used for analyses.

Results

Participants

The cohort’s mean sodium intake was 3619 ± 51 mg/day (median 3372 mg/day, mean potassium intake was 3046 ± 43 mg/day (median 2883 mg/day), and the mean sodium-to-potassium ratio was 1.31 ± 0.02 (median 1.21). There was a greater proportion of Mexican-American women in the lowest quartile of sodium intake and a greater proportion of black women in the higher quartiles of sodium intake. Potassium intake, sodium-to-potassium ratio, and total caloric intake all increased with quartile of sodium intake. Almost 10% of all women in the cohort were current smokers, with no difference in the proportion of current smokers among quartiles of sodium intake. Proportion of women with a significant history of smoking (>100 cigarettes in lifetime) increased with quartile of sodium intake. Complete characteristics of participants by quartiles of sodium intake are shown in Table 1.

Blood Pressure

There was no difference in unadjusted mean SBP or DBP between quartiles of sodium or potassium intake or sodium-to-potassium ratio, Table 1. There was no difference in age and race/ethnicity-adjusted mean SBP or DBP between quartiles of sodium or potassium intake or sodium-to-potassium ratio, Figure 1A-C. Results persisted after additional adjustment for BMI. There was no consistent difference in SBP or DBP by quartile of sodium intake in analyses stratified by trimester of pregnancy, Supplementary Table S1[1].

Linear Regression

There was no association of sodium, potassium, or the sodium-to-potassium ratio with SBP or DBP in unadjusted or adjusted analyses, Table 2. The lack of association persisted when we examined associations by quartile of exposure *(not shown).* In regression analyses stratified by race/ethnicity, sodium intake was modestly associated with DBP only in Mexican-American/Other Hispanic women, but this association was not observed after controlling for extreme outliers, Supplementary Table S2[2].

Neither sodium intake (*b*=0.79, 95%CI: 0.59, 1.16), potassium intake (*b*=0.80, 95%CI: 0.50, 1.25), nor the sodium-to-potassium ratio (*b*=0.85, 95%CI: 0.20, 2.44) were associated with odds of hypertension in adjusted analyses. The women with hypertension had an average sodium intake of 3588 ± 207 mg per day, which was not different from mean sodium intake in normotensive women (p=0.93). In women with hypertension, mean blood pressure was 130 ± 2 / 72 ± 3 mmHg. Sodium was not associated with systolic blood pressure in women with hypertension, *b*=5.4 (95% CI: −3.3, 1.4; p=0.19) or diastolic blood pressure *b*=2.0 (95% CI: −5.2, 9.3; p=0.57) in adjusted analyses.

Discussion

The main finding of our study was that unadjusted and age and race/ethnicity-adjusted SBP and DBP were not different between different quartiles of sodium or potassium intake or quartiles of the sodium-to-potassium ratio in normotensive pregnant women. Further, dietary sodium and potassium were not associated with SBP or DBP or with odds of hypertension in pregnant women, even after adjustment for potential confounders, including age, BMI, race/ethnicity, and month of pregnancy. The lack of association persisted across race/ethnic groups. Taken together, our data suggest that blood pressure is not influenced by sodium or potassium intake during normotensive pregnancy.

Sodium causes increased blood pressure in non-pregnant humans through vascular, central/neural, or renal mechanisms, but the effects of these pathways on blood pressure are blunted during pregnancy (Laffer et al. 2016; Skinner et al. 1972). Acute salt-loading augments blood pressure in non-pregnant adults mainly due to the resultant increase in plasma volume and cardiac output that is not offset by a reduction peripheral resistance (Laffer et al. 2016). During pregnancy, plasma volume increases by up to 50% by the end of the first trimester (Fu 2018). However, the reduction in peripheral resistance that occurs during pregnancy offsets the increase in cardiac output so that blood pressure is maintained near pre-pregnancy levels (Fu 2018). We likely observed a "ceiling effect", i.e., plasma volume was already at maximum or further volume loading in normotensive pregnant women attributable to sodium intake did not affect blood pressure because of the pre-existing, profound reduction in peripheral resistance.

Another potential mechanism by which sodium is linked to blood pressure in non-pregnant adults is via sympatho-excitation (Stocker et al. 2013). In normotensive pregnancy, sympathetic activity and vasoconstriction are dissociated, so a sympathetic stimulus does not translate into higher total peripheral resistance or higher blood pressure in normotensive pregnant women (Jarvis et al. 2012; Zuspan et al. 1964). Thus, sympatho-excitatory effects of sodium are less likely to cause an increase blood pressure in normotensive pregnant women. Renal disease and inadequate renin-angiotensin-aldosterone system responses to dietary salt manipulation have been associated with salt sensitivity of blood pressure in non-pregnant adults (Farquhar et al. 2015). Renin and aldosterone are upregulated to support plasma volume expansion during normotensive pregnancy, but the angiotensin type 1 receptor (AT_1) and its pressor effect is desensitized (Verdonk et al. 2014). Because pressor effects of the AT_1 receptor are blunted and renin and aldosterone levels are already elevated, dietary sodium might have little or no effect on the renal pathway in normotensive pregnancy. Future studies should determine how long after delivery the dissociation of sodium, potassium, and blood pressure are detectable in women with a recent normotensive pregnancy.

Notably, other investigations found that blood pressure during pregnancy was directly related to sodium intake in women with preeclampsia (Yilmaz et al. 2017). The association of sodium and blood pressure did not reach significance in our study, but our sample size was quite small. Maternal features of preeclampsia, such as: excess sympathetic activation (Schobel et al. 1996) or more efficient neurovascular transduction (Zuspan et al. 1964), vascular damage (Chambers et al. 2001), renal dysfunction and heightened angiotensin II sensitivity (Wallukat et al. 1999), overlap with factors that contribute to salt-sensitivity of blood pressure in non-pregnant adults. Salt-sensitivity of blood pressure and angiotensin II sensitivity were observed years after delivery in women with a history of preeclampsia (Saxena et al. 2010).

These findings suggest altered mechanisms of blood pressure control during and after pregnancy in women with hypertensive disorders. Women with a past hypertensive disorder of pregnancy have higher risk of vascular dysfunction, hypertension, and more advanced cardiovascular disease after delivery versus women with only uncomplicated pregnancies (Lane-Cordova et al. 2019). Taken together, the results of these studies suggest that women with a history of preeclampsia might benefit from DASH-type diets after delivery to avoid hypertension and more advanced cardiovascular disease later in life.

A major limitation of our study is that we estimated actual dietary sodium and potassium intake using self-reported dietary data. Self-report tends to underestimate actual sodium consumption by 4–34% and overestimate potassium intake by 16% (Espeland et al. 2001; Freedman et al. 2015; Leiba et al. 2005). However, self-reported sodium intake and urinary excretion are modestly to moderately correlated, and the correlation between reported and actual sodium-to-potassium ratio is stronger (Freedman et al. 2015). Patterns of under- or overestimation of sodium and potassium are similar among different ethnic groups (Espeland et al. 2001). The NHANES protocol included two days of recall using an in-person interview, and multiple days of sampling are associated with more accurate dietary data (Freedman et al. 2015). Our cohort's mean sodium and potassium intake were comparable to those reported using gold-standard urinary excretion techniques in other US adults in NHANES (Cogswell et al. 2018). Thus, we believe that the use of dietary recall to quantify sodium and potassium intake is justified as a reasonable method of investigating the association of dietary sodium and potassium intake with blood pressure. Also, our samples for subgroup analyses by ethnicity were small, particularly for black women. Race/ethnicity-specific associations of dietary intake and blood pressure should be conducted in larger samples.

Conclusions

Blood pressure was not different in pregnant women between quartiles of sodium or potassium intake or the sodium-to-potassium ratio. Blood pressure was not associated with self-reported sodium or potassium intake or the sodium-to-potassium ratio in a nationally representative sample of normotensive pregnant women, though associations of sodium and potassium with blood pressure in larger samples of race/ethnic subgroups warrant further investigation. Our findings suggest dietary sodium and potassium intake are dissociated from blood pressure during normotensive pregnancy.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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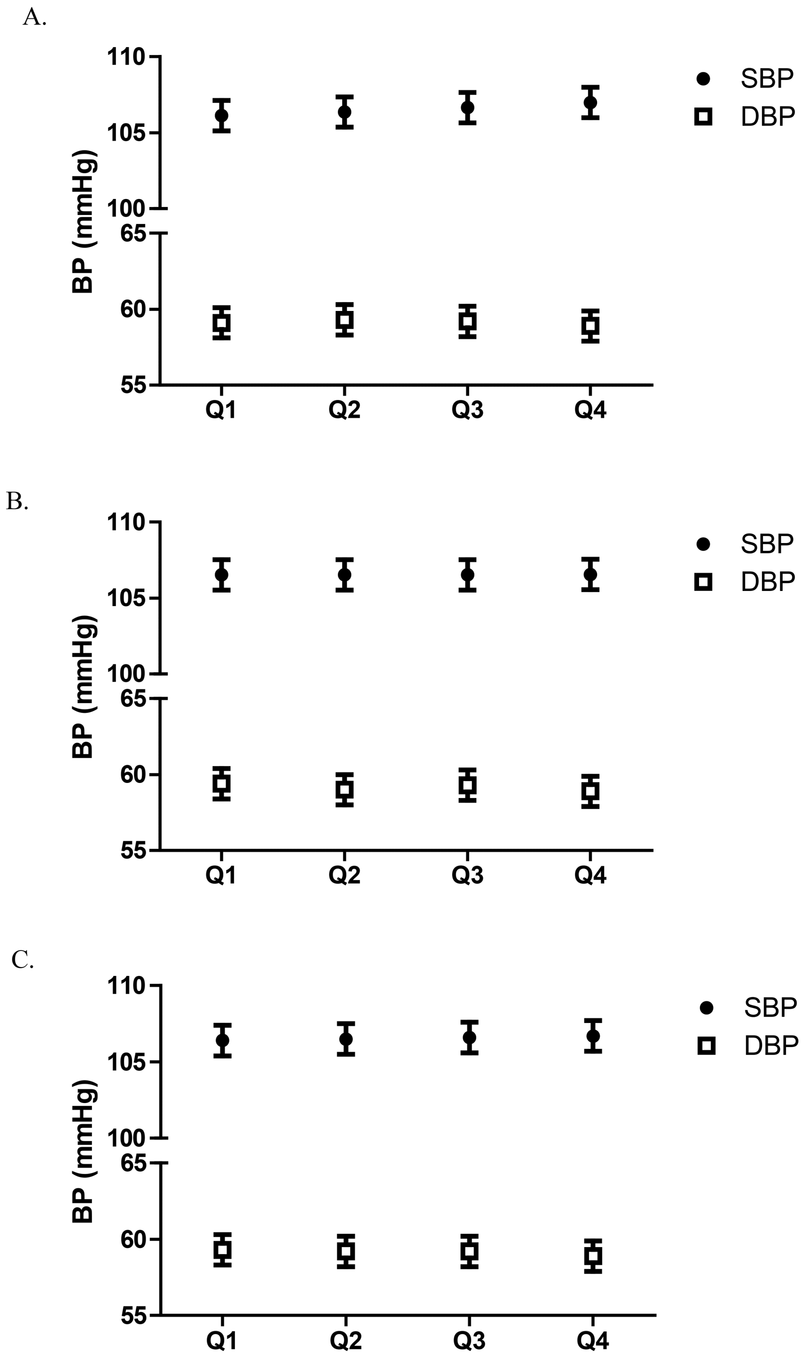

Figure 1.

Age and race/ethnicity-adjusted mean BP by quartile of sodium (A), potassium (B), and sodium-to-potassium ratio (C).

There was no difference in age and race/ethnicity-adjusted mean SBP and DBP between quartiles of sodium or potassium intake or the sodium-to-potassium ratio, p>0.20 for all. Data are mean ± SD.

Table 1.

Characteristics of participants by quartile of self-reported sodium intake.

	Q1 *n=225; (≤2581.9 mg/day)*	**Q2** *n=225; (≥2581.9, <3363.54 mg/day)*	**Q3** *n=223; (≥3363.54, < 4337.42 mg/day)*	**Q4** *n=311; (>4337.42 mg/day)*	***p-value***
Sodium Intake (mg/day)	2021 ± 29	2974 ± 15	3850 ± 18	5570 ± 96	<0.001
Potassium Intake (mg/day)	2325 ± 72	2801 ± 63	3122 ± 68	3911 ± 101	<0.001
Sodium-to-Potassium Ratio	1.11 ± 0.04	1.20 ± 0.03	1.39 ± 0.03	1.58 ± 0.04	<0.001
Total Intake (kcal/day)	1639 ± 33	2099 ± 31	2459 ± 36	3088 ± 59	<0.001
Age (yrs)	27.8 ± 0.3	28.4 ± 0.3	27.8 ± 0.3	27.1 ± 0.3	0.03
Month of Pregnancy	5.4 ± 0.2	5.8 ± 0.1	5.7 ± 0.2	5.5 ± 0.1	0.30
Race/Ethnicity (n, %)					<0.001
Mexican	92, 41	77, 24	46, 31	78, 25	
Other Hispanic	16, 7	12, 5	13, 6	17, 5	
Non-Hispanic White	88, 39	101, 45	110, 49	148, 48	
Non-Hispanic Black	19, 8	19, 8	34, 15	45, 14	
Other or Not Reported	10, 4	16, 7	20, 9	23, 7	
Annual Income (n, %)					0.06
$0–14,999	30, 14	19, 8	25, 11	56, 18	
$15,00-$34,999	62, 28	55, 24	53, 24	66, 21	
$35,000-$64,999	56, 25	63, 28	65, 29	83, 27	
≥$65,000	71, 32	87, 39	78, 35	103, 33	
Data Missing	6, 3	1, <1	2, 1	3, 1	
Education (n, %)					0.01
< High School	71, 32	67, 30	46, 21	77, 25	
High School Diploma or GED	46, 21	41, 18	39, 17	66, 21	
Some College	62, 28	55, 24	74, 33	90, 29	
College Degree	46, 21	61, 28	64, 29	78, 25	

	Q1 ***n=225; (≤2581.9 mg/day)***	**Q2** ***n=225; (≥2581.9, <3363.54 mg/day)***	**Q3** ***n=223; (≥3363.54, < 4337.42 mg/day)***	**Q4** ***n=311; (>4337.42 mg/day)***	***p-value***
Marital Status (n, %)					0.29
Married	158, 72	163, 74	151, 70	185, 63	
Widowed	0, 0	0, 0	0, 0	0, 0	
Separated/divorced	6, 3	7, 3	10, 4	9, 2	
Never Married	25, 11	26, 12	32, 15	61, 21	
Living with Partner	30, 14	25, 11	22, 10	39, 14	
Data Missing	0, 0	0, 0	0, 0	1, <1	
Current Smoking (n, %)					0.50
Every Day	10, 4	12, 7	15, 7	34, 11	
Some Days	5, 2	2, <1	7, 3	12, 4	
None	210, 94	211, 93	201, 90	265, 85	
Smoked >100 Cigarettes in Lifetime (n, %)	55, 24	60, 27	70, 31	125, 40	<0.001
BMI (kg/m^2)	28.5 ± 0.4	29.3 ± 0.4	29.2 ± 0.4	28.7 ± 0.4	0.21
SBP (mmHg)	107 ± 1	106 ± 1	108 ± 1	108 ± 1	0.60
DBP (mmHg)	59 ± 1	59 ± 1	60 ± 1	58 ± 1	0.83

BMI: body mass index; SBP: systolic blood pressure; DBP: diastolic blood pressure. Data are mean ± standard error unless otherwise noted.

Table 2.

No association of self-reported sodium or potassium intake or sodium-to-potassium ratio with SBP or DBP in normotensive pregnant women.

	SBP		**DBP**	
	B	**95% CI**	***b***	**95% CI**
Sodium *unadjusted*	0.24	−0.12, 0.61	−0.11	−0.52 0.31
Sodium *adjusted*	0.16	−0.20, 0.52	−0.04	−0.47, 0.39
Potassium *unadjusted*	0.02	−0.41, 0.45	0.05	−0.43, 0.54
Potassium *adjusted*	0.18	−0.24, 0.60	0.05	−0.46, 0.55
Sodium-to-Potassium Ratio *unadjusted*	0.15	−0.83, 1.13	−0.43	−1.54, 0.67
Sodium-to-Potassium Ratio *adjusted*	−0.54	−1.55, 0.47	−0.04	−1.23, 1.16

Units=1000 mg/day of sodium or potassium. Adjustment variables included: age, race/ethnicity, education, marital status, BMI, smoking, and month of pregnancy.