Maternal Prenatal Dietary Potassium, Calcium, Magnesium, and Infant Blood Pressure

Stephen T. McGarvey, Stephen H. Zinner, Walter C. Willett, and Bernard Rosner

We studied the association between the prenatal diets of 212 mothers assessed by a semiquantitative food frequency questionnaire and the blood pressure of their infants. Prenatal potassium, calcium, and magnesium intakes were measured and adjusted for total caloric intake. Infant blood pressure was measured at 2–3 days and at 1, 6, and 12 months of age by using an ultrasonic-auscultatory device and was adjusted for cuff size, observer, and sleep/activity status; age in days in neonates, and weight at 6 and 12 months. Maternal prenatal potassium intake was inversely related to diastolic pressure at 6 months ($r = -0.28$, $p < 0.01$) and at 12 months ($r = -0.30$, $p < 0.05$). After adjustment for neonatal breast versus formula feeding, maternal prenatal calcium intake was inversely related to systolic blood pressure at 1 month ($r = -0.21$, $p < 0.01$), and to diastolic blood pressure at 6 months ($r = -0.27$, $p < 0.01$) and 12 months ($r = -0.24$, $p < 0.05$). Maternal prenatal magnesium intake was inversely related to 6-month systolic blood pressure ($r = -0.20$, $p < 0.05$). In multivariable models with all three cations, maternal prenatal potassium intake was independently and inversely related to diastolic blood pressure at 6 and 12 months. Maternal prenatal calcium intake was independently related to 1-month systolic and 6-month diastolic blood pressure. Age-specific infant blood pressure differences between the upper and lower quartiles of maternal prenatal cation intakes ranged from 3 to 7 mm Hg. These results are consistent with adult studies and suggest that maternal prenatal intakes of potassium, calcium, and perhaps magnesium, influence infant blood pressure throughout the first year of life. *(Hypertension 1991;17:218–224)*
All participants provided written and informed consent on a form approved by the human studies committee of our institutions. The sample is socio-economically representative of Rhode Island except that we attempted to oversample subjects self-reporting as blacks. Although the sample reported here contains approximately 11% black subjects, all ethnic groups are considered together in these analyses.

Infants were studied in the hospital at 2–4 days old and at home at 1, 6, and 12 months of age. Mothers were studied in the hospital postpartum. Prenatal dietary data were available from 212 mothers. Blood pressure data were available from the following cross-sectional samples at each age: 212 newborns, 184 infants at 1 month, 114 at 6 months, and 70 at 12 months of age. The decrease in sample size at each age was primarily because some of the infants had not yet reached the older ages at study termination. There was also some sample attrition because of refusals and change in residence. There were no blood pressure differences at earlier ages between those who later participated and those not old enough or lost to follow-up in the entire sample or between those with and without maternal prenatal diet information. For example, in the entire sample mean systolic blood pressure at 6 months of age was not different between participants and those not seen at the 1-year follow-up (84.7±6.9 mm Hg, n=115 versus 85.7±8.0 mm Hg, N=102; t=0.96, not significant).

Infant blood pressure was measured using the Roche Arteriosonde (Roche Medical Electronics, Cranbury, N.J.), as described in our prior studies. Systolic and Korotkoff IV diastolic blood pressures were recorded three times, were averaged, and were adjusted for sleep/activity status, cuff size, observer, and in the neonates, age in days. Infant blood pressures at 6 and 12 months were adjusted for body weight because of its significant association with blood pressure.

Maternal prenatal diet was assessed postpartum in the hospital by a 116-item, semiquantitative food frequency questionnaire described elsewhere. Reliability and validity of several versions of this questionnaire have been established in several samples of women, including a sample of lower social class pregnant women. In the latter study, the test-retest reliability and validity for calcium as estimated by this questionnaire were among the highest of all nutrients. The time referent for the food frequency questionnaire in this study of pregnant women was the entire pregnancy. A series of questions on vitamin and mineral supplements was used to analyze use of prescribed or over-the-counter prenatal supplements.

Potassium, calcium, and magnesium intakes were adjusted for calories by regression analysis, and the residuals were centered on the mean caloric intake. The food-frequency questionnaire may underestimate sodium intake because it does not contain extensive probes for discretionary salt use, snack, and fast-food items. Consequently we do not use the sodium intake data in any analyses presented here.

However, in detailed analyses of weighed dietary record data from a cohort of nurses, calorie-adjusted sodium intake was minimally correlated with intakes of calcium, potassium, and magnesium and thus is not likely to confound the associations between these nutrients and various outcomes (W.C. Willett, unpublished observations).

Infant diet from birth to 1 month of age was assessed by a series of questions on breast and formula feeding. Based on the responses, the infants were categorized into two groups, breast-fed and formula-fed. Each group included some infants who had consumed both breast milk and infant formula, but assignment was based on the greater number of weeks of a given type of feeding in the neonatal period.

Sociodemographic factors included maternal report of race and mother's and father's education and occupation. Mother's occupation was the last regular job before hospitalization for childbirth. The higher category of either the mother's or the father's education and occupation was used to classify the family in the analyses of pregnancy diet and sociodemographic factors.

Statistical analyses involved the regression of age-specific, adjusted infant blood pressure on the maternal prenatal nutrients singly and then together. In the multivariable regressions, partial correlation coefficients were computed for each nutrient to estimate its independent effect while adjusting for the other nutrients. To further assess the effects on infant blood pressure of maternal prenatal cations, the nutrient distributions were categorized into quartiles, and mean infant blood pressure was computed for each quartile. Family education and occupation, and neonatal diet were included in some models to analyze their potential confounding of the maternal prenatal cation intake and infant blood pressure associations.

Results

Mean maternal prenatal intakes of total calories, potassium, calcium, and magnesium are shown in Table 1. Potassium intake is within the recommended dietary allowance (RDA) range of 2,000–6,000 mg/day. Mean calcium intake exceeds the RDA for pregnant women of 1,200 mg/day; about 85% of this sample of pregnant women consumed amounts of calcium in excess of the RDA. Magnesium intake is between the RDA estimates of 300 mg/day for adult women and that of 450 mg/day for pregnant women.

<p>| Table 1. Mean Maternal Prenatal Nutrient Cation Intakes Estimated by a Food Frequency Questionnaire |
|------------------------------------------|-------------------------------|-------------------------------|-------------------------------|</p>
<table>
<thead>
<tr>
<th>Calories (kcal)</th>
<th>Potassium (mg)</th>
<th>Calcium (mg)</th>
<th>Magnesium (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,601</td>
<td>4,175</td>
<td>1,712</td>
<td>390</td>
</tr>
<tr>
<td>873*</td>
<td>1,415</td>
<td>508</td>
<td>108</td>
</tr>
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</table>

Nutrients are adjusted for calories as described in the text. n=212. *Standard deviation.
Calcium and magnesium intakes during pregnancy were related to sociodemographic factors (Table 2). White women consumed significantly more daily calcium and magnesium than black women. Pregnant women with post-secondary education consumed more potassium, calcium, and magnesium than those with a high school education or less. Prenatal intakes of calcium, potassium, and magnesium also were directly related to occupational level. Those in managerial and administrative occupations consumed significantly more potassium, calcium, and magnesium during pregnancy.

Overall, approximately 92% of the calcium intake was derived from regular food sources. Thus, prenatal and other supplements provided only a small portion of calcium intake. Significant intercorrelations were found among intakes of potassium, calcium, and magnesium: potassium intake was related to that of calcium ($r=0.63$, $p<0.001$) and magnesium ($r=0.63$, $p<0.001$), and intakes of magnesium and calcium also were related ($r=0.62$, $p<0.001$).

Table 3 shows the bivariate correlations between maternal prenatal intakes of potassium, calcium, and magnesium and adjusted infant blood pressure at 2-4 days of age and at 1, 6, and 12 months of age. There were no significant associations between the mothers' pregnancy intake of these cations and newborn blood pressure. However, at 1 month of age maternal prenatal calcium intake was significantly inversely associated with systolic blood pressure. Similarly, maternal prenatal magnesium intake was significantly inversely associated with systolic and diastolic blood pressure at 1 month.

At 6 months of age, maternal prenatal intakes of all three cations were significantly inversely associated with diastolic blood pressure (Table 3). Magnesium intake is also significantly inversely associated with systolic blood pressure. At 12 months of age, maternal prenatal potassium and calcium intakes are significantly inversely related to diastolic blood pressure.

Mean blood pressures by quartile of maternal prenatal cation intake (Table 4) indicate significant differences of from 3 to 7 mm Hg between the upper and lower quartiles of intake, depending on infant age, blood pressure, and the maternal prenatal nutrient. For example, there is a 6.6 mm Hg difference in diastolic blood pressure at 6 months of age be-
Table 4. Mean Infant Blood Pressure by Quartiles of Maternal Prenatal Intake of Nutrients

<table>
<thead>
<tr>
<th>Nutrient quartiles</th>
<th>1 month</th>
<th>6 months</th>
<th>12 months</th>
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<tr>
<td></td>
<td>SBP</td>
<td>DBP</td>
<td>SBP</td>
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<td>SBP</td>
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<td><strong>DBP</strong></td>
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<td>SBP</td>
</tr>
</tbody>
</table>

Potassium quartiles
1) <3,610.8 (51) 71.2 42.2 82.4 42.5 86.4 54.8 88.7 54.0
2) ≥3,610.8 – 4,111.9 (51) 71.0 42.6 77.3 39.2 85.7 53.0 88.0 49.0
3) ≥4,111.9 – 4,687.4 (52) 69.8 42.2 79.0 42.3 85.7 50.9 85.5 48.1
4) ≥4,687.4 (52) 70.3 41.1 78.4 42.0 82.9 49.3* 85.3 48.3*

Calcium quartiles
1) <1,380.5 (49) 71.5 42.1 82.4 41.0 87.0 56.9 89.6 53.1
2) ≥1,380.5 – 1,722.9 (52) 70.8 42.6 81.8 43.1 85.7 51.9 85.8 49.1
3) ≥1,722.9 – 2,048.2 (53) 70.2 41.8 77.9 41.2 83.5 48.6 85.3 47.6
4) ≥2,048.2 (52) 69.9 41.7 75.5* 40.9 84.1 50.3* 86.2 49.7*

Magnesium quartiles
1) <311.8 (52) 72.0 43.7 82.9 43.8 86.2 54.7 88.3 51.7
2) ≥311.8 – <371.5 (52) 68.4 39.1 79.2 41.9 86.2 51.6 87.1 49.1
3) ≥371.5 – <454.8 (51) 72.7 44.1 77.8 40.3 84.5 51.1 85.4 46.7
4) ≥454.8 (51) 69.3 41.2 77.3* 40.1* 83.1* 49.9* 85.6 51.7

Blood pressures are adjusted for observer, sleep/activity status, cuff size, and age in days (hospital visits), and body weight (at 6 and 12 months). Numbers in parentheses are number of infants in group. SBP, systolic blood pressure; DBP, diastolic blood pressure.

*Overall correlation between nutrient and blood pressure was significant at p<0.05.

Between infants in the lowest and highest quartile of maternal prenatal calcium intake.

Table 5 shows the results of multivariable models of the independent cation effects on infant blood pressure at 1, 6, and 12 months of age. Maternal prenatal potassium intake was independently associated with diastolic blood pressure at 6 and 12 months. Maternal prenatal calcium intake was independently related to 1-month systolic and 6-month diastolic blood pressure. Magnesium intake in pregnancy was not significantly related to infant blood pressure independent of potassium and calcium intakes.

Fifty-nine percent (122 of 208) of the infants were fed during the first month of life primarily by maternal breast feeding compared with 41% by commercial infant formulas. Mothers who reported breast feeding their infants during the first postnatal month had higher prenatal intakes of potassium (4,386±807 mg, n=122 versus 3,854±823 mg, n=86; t=4.64, p<0.0001), calcium (1,820±456 mg, n=122 versus 1,580±549 mg, n=86; t=3.43, p<0.001), and magnesium (410±102 mg, n=122 versus 342±98 mg, n=86; t=4.83, p<0.0001) compared with prenatal intakes of mothers using infant formula. There was no difference in maternal prenatal caloric intake between the two types of infant diet at 1 month.

Neonatal diet was significantly related only to adjusted systolic blood pressure at 1 month (F=4.20, p=0.04), with breast fed infants having slightly lower systolic blood pressures. Breast feeding versus formula feeding in the first month did not relate cross-sectionally to diastolic blood pressure at 1 month or prospectively to blood pressures at 6 or 12 months. Thus, neonatal dietary data were included only in models relating maternal prenatal cation intakes to infant blood pressure at 1 month. Maternal prenatal calcium intake was still significantly related to adjusted systolic blood pressure at 1 month (r=0.21, p<0.01) after controlling for neonatal diet. The negative correlations between maternal magnesium intake and blood pressure at 1 month shown in Table 3 were reduced and became nonsignificant with the further control for neonatal diet (r=0.09, NS and r=0.08, NS, for systolic and diastolic blood pressures at 1 month, respectively).

Because of the significant associations between familial sociodemographic characteristics and mater-
TABLE 5. Multivariable Analyses of Maternal Prenatal Nutrients and Infant Blood Pressure at 1, 6, and 12 Months of Age

<table>
<thead>
<tr>
<th>Age-specific Blood Pressure</th>
<th>Partial Correlations of Nutrients and Blood Pressure</th>
<th>1-Month BP (n=177)</th>
<th>6-Month BP (n=122)</th>
<th>12-Month BP (n=70)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic BP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
<td>-0.05</td>
<td>-0.12</td>
<td>-0.16</td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
<td>NS</td>
<td>p=0.20</td>
<td>p=0.01</td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
<td>NS</td>
<td>p=0.08</td>
<td>p=0.01</td>
</tr>
<tr>
<td>Diastolic BP</td>
<td></td>
<td>0.03</td>
<td>-0.23</td>
<td>-0.27</td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
<td>NS</td>
<td>p=0.00</td>
<td>p=0.02</td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
<td>NS</td>
<td>p&lt;0.005</td>
<td>p=0.07</td>
</tr>
</tbody>
</table>

Adjusted blood pressures are regressed simultaneously on potassium, calcium, and magnesium together, and independent effects of each are estimated with partial correlations. BP, blood pressure; NS, not significant.

Discussion

Infant blood pressures at several times in the first year of life were significantly associated with maternal prenatal dietary intake of potassium, calcium, and magnesium. The independent associations of potassium and calcium with blood pressures remained after adjusting for the effects of the other cations. However, because of intercorrelations among the cations and the overall similarity between bivariate and multivariable results, it is difficult to specify the influence of any one cation on most age-specific blood pressures. The difficulty in interpreting the separate effects of potassium, calcium, and magnesium on blood pressure is most likely because of their shared common food sources as has been encountered in other studies. Nevertheless, the results are plausible and consistent with studies in adults that report significant associations between blood pressure and dietary potassium, calcium, and magnesium. To our knowledge, there are no other data supporting an effect of maternal diet on offspring blood pressure, and the results presented here provide the first systematic evidence linking mothers’ dietary intake of cations during pregnancy and their infants’ blood pressures.

One of the mechanisms by which prenatal calcium intake might influence infant blood pressure is the transport of calcium, potassium, and magnesium across the placenta with effects on blood pressure regulation in the developing fetus and infant. There is substantial evidence in humans for active transport of calcium against the gradient from the maternal to the fetal circulation. It may be that variation in maternal calcium intake could influence maternal and fetal serum and tissue calcium levels. Transport of potassium and magnesium across human placental membranes is less well studied, but it is assumed from animal models that transport occurs easily and that maternal levels are related to fetal levels.

Maternal prenatal dietary intakes were measured using a semiquantitative food frequency questionnaire designed for use with registered nurses and studied for its reproducibility and validity. The reproducibility and validity of this questionnaire were recently evaluated in a culturally diverse low-income sample of pregnant Boston women. The questionnaire yielded reliable estimates of prenatal dietary intake for most nutrients and for calcium in particular, which was the best estimated nutrient of those studied. Therefore, it appears that the pregnancy diet measurement in the present study was at least as reliable as dietary assessments in other studies of nonpregnant women, especially in regard to the cations of present interest. Previous extensive validation studies of the questionnaire revealed that responses are consistent within individuals and that subjects do tend to remember what they eat as diets are reasonably consistent over several years.

The association of the sociodemographic characteristics with maternal prenatal cation intakes is similar to other studies in pregnant women and in nonpregnant adults. The increased intake of potassium, calcium, and magnesium in pregnant women with increasing years of education and managerial and professional occupations is possibly due to heightened awareness of nutrition in healthy pregnancies.

Calcium intake in this sample was high relative to the RDA for pregnant women and to other recent studies of pregnant women. Pregnant women from Cambridge, UK, consumed approximately 1,200 mg daily, with women from manual labor families consuming less than those from non–manual labor families. Recent reports of calcium intake in pregnancy among the Supplemental Food Program for Women, Infants, and Children participants and controls are also lower than those in the current study. In a study of low-income pregnant women in Boston, daily calcium intake, assessed by a similar food frequency questionnaire to that used in the present study, averaged almost 1,300 mg. This slightly higher intake could be due to self-selected diets reflecting recent publicity about the health benefits of calcium or to strict adherence to obstetricians’ calcium intake recommendations, among other factors. In the vali-
Nutrient intake was not overestimated compared with diet records. In pregnant women, some overestimation of calcium intake was reported in subjects with very high caloric intake. The data reported in the current study were adjusted for caloric intake. Despite these differences, the association of maternal prenatal cation intake and sociodemographic factors could indicate a potential confounding effect on the infant blood pressure associations. However, in this cohort and others no consistent relation between infant blood pressure and sociodemographic characteristics has been reported.

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Infant diet is another possible confounder of the maternal prenatal diet and infant blood pressure associations. However, maternal prenatal calcium intake was significantly and inversely related to infant systolic blood pressure at 1 month after adjustment for infant diet at 1 month as assessed by breast versus formula feeding. Because of the potential misclassification of later, more complex infant diets based on neonatal breast versus formula feeding and the lack of a bivariate association between neonatal diet and blood pressures at 6 and 12 months, we did not analyze the effect of our limited neonatal diet data on the significant relations between maternal prenatal diet and infant blood pressures at 6 and 12 months. More detailed diet data over the first year of life are needed to resolve this issue.

It is also possible that the mother's pregnancy diet is related both to her postnatal dietary intake and that of her infant. This potential confounder cannot be assessed by our current data set but needs to be evaluated in our follow-up studies.

We observed significant and substantial blood pressure differences among infants up to 1 year of age related to maternal prenatal dietary intake of potassium and calcium, and perhaps also magnesium. The stronger correlations of maternal cation intake and diastolic blood pressure at 6 and 12 months compared with 1 month readings may reflect the greater variability in blood pressure measurements at the earlier visits. These results, combined with the established tracking of blood pressure by 6 months of age suggest a potential effect on early childhood blood pressure of the mother's pregnancy dietary cation intake. The consistency with adult studies and the biological plausibility of the direction of these associations lend further support to the observations. More research is needed to confirm these observations and to elucidate the likely mechanisms for this finding. Further studies should detail the interactions of maternal prenatal diet and infant diet on blood pressure and potential interactions with family history of hypertension. It is possible that dietary factors in pregnancy and early life might exert a protective effect on the ultimate development of elevated blood pressure later in life.

Acknowledgments

We are grateful to Dr. William Oh for his support and to Barbara Davis, RN, Thomas Longest, and Joanne Burrows for their able assistance. S.H.Z., W.C.W., and B.R. express their appreciation for helpful discussions to Edward H. Kass, MD, PhD, a close colleague and mentor, who died while this article was in preparation.

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KEY WORDS • infant blood pressure • diet • potassium • calcium • magnesium
Maternal prenatal dietary potassium, calcium, magnesium, and infant blood pressure.
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Hypertension. 1991;17:218-224
doi: 10.1161/01.HYP.17.2.218

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