

## Dietary Magnesium, Potassium, Sodium, and Children's Lung Function

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To investigate the effects of dietary magnesium, potassium, and sodium on children's lung function, the authors examined cross-sectional dietary data and pulmonary function tests from 2,566 children aged 11–19 years who attended schools in 12 southern California communities during 1998–1999. During school visits, each child completed a health update questionnaire, a validated food frequency questionnaire, and spirometric lung function testing. Low magnesium and potassium intakes were associated with lower lung function. Girls with low magnesium intake had lower forced expiratory flow at 75% of the forced vital capacity ( $FEF_{75}$ ) (–8.3%, 95% confidence interval: –14.8, –1.4) than did girls with higher intake; reductions were larger in girls with asthma (forced expiratory flow between 25% and 75% of the forced vital capacity ( $FEF_{25-75}$ ) (–16.2%, 95% confidence interval: –22.7, –9.1) and  $FEF_{75}$  (–24.9%, 95% confidence interval: –32.8, –16.1)) than in girls without asthma ( $FEF_{25-75}$  (–2.0%, 95% confidence interval: –7.4, 3.8) and  $FEF_{75}$  (–4.1%, 95% confidence interval: –11.3, 3.7)). Boys with low magnesium intake showed deficits in forced vital capacity (–2.8%, 95% confidence interval: –5.4, –0.2) compared with boys with higher intake. The effects of low magnesium intake did not vary substantially in boys with and without asthma. Among girls, low potassium intake was also associated with deficits in forced expiratory volume in 1 second (–2.7%, 95% confidence interval: –5.2, –0.1) and forced vital capacity (–2.4%, 95% confidence interval: –4.7, –0.1). In summary, low magnesium and potassium intakes were associated with lower lung volumes and flows. *Am J Epidemiol* 2002;155:125–31.

child; diet; lung; magnesium; potassium; sodium

As the role of diet in respiratory health receives increasing recognition, a body of evidence is emerging in support of associations between cationic minerals and lung function (1–5). The evidence suggests that magnesium, potassium, and sodium participate in numerous biochemical and physiologic processes that directly influence lung function and indirectly influence respiratory symptoms (3, 4, 6–8). The mechanisms for effects on lung function and symptoms include alteration in smooth muscle function (9), neuromuscular excitability (10), immune function (11), oxidative stress (12), DNA and RNA synthesis, and enzymatic activity (13). Furthermore, these mechanisms contribute to the pathophysiology of asthma, and their effects in cases of inadequate magnesium and potassium intakes may be particularly apparent in children with asthma (3, 4, 14, 15).

The role of magnesium intake in the variation of lung function has been studied in healthy adults and in asthma patients

(3, 16–18). Epidemiologic evidence from a population-based study in adults indicates that low dietary intake of magnesium is associated with impairment of lung function as measured by airway flow rates, airway hyperreactivity, and increased risk of wheezing (3). Studies of asthma patients indicate that dietary magnesium intake and serum magnesium levels are lower than those of healthy controls (19, 20). However, short-term magnesium supplementation trials to assess the effects of supplemental magnesium on lung function and symptoms among patients with asthma have had mixed results (16, 17). Studies also suggest that high sodium intake or low potassium intake may accentuate airway reactivity and reduce flows; however, the interrelations are complex and study results have been inconsistent (2). Serum potassium may be decreased in asthma patients, but the decrease appears to be related to the hypokalemia associated with the use of beta<sub>2</sub> agonist medication (15, 21–23). Although the effects of dietary intake of magnesium, potassium, and sodium on lung function have been reported in adults, the relations between the intake of these minerals and lung function have not been extensively studied in children.

The Children's Health Study offers an opportunity to further investigate the role of dietary mineral intake on children's airway flows (24). We examined cross-sectional data on dietary intake and spirometric measures of lung function from 2,566 participants in the Children's Health Study collected at follow-up visits during the 1998–1999 school year. We used regression splines to assess the effects of low magnesium, potassium, and sodium intakes on lung function.

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Abbreviations:  $FEF_{25-75}$ , forced expiratory flow between 25% and 75% of the forced vital capacity;  $FEF_{75}$ , forced expiratory flow at 75% of the forced vital capacity;  $FEV_1$ , forced expiratory volume in 1 second.

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## MATERIALS AND METHODS

### Study design

The Children's Health Study is a 10-year longitudinal study of long-term air pollution exposure health effects that includes school children who reside in 12 communities within a 200-mile (320-km) radius of Los Angeles, California. Details on the design, site selection, subject recruitment, and assessment of health effects are reported elsewhere (24, 25). At study entry in early 1993, parents or guardians of 3,681 participating children provided written informed consent and completed a self-administered questionnaire on demographics, medical and family health history, and indoor air exposures and household characteristics. In the spring of 1993, pulmonary function testing was conducted, and in each subsequent year of the ongoing study, each child completed a follow-up questionnaire and repeated the pulmonary function testing. In the fall of 1995, a second group of 2,081 fourth grade students (approximately 150 per community) was recruited and completed the same baseline and follow-up questionnaires and pulmonary function testing as the group enrolled in 1993. Beginning in 1998, dietary data were collected using a validated food frequency questionnaire; these were completed by 2,895 children who ranged in age from 11 to 19 years and were enrolled in schools in the participating communities.

### Pulmonary function testing

We focused our investigation on measures of airway flow rates based on the physiologic roles of magnesium, potassium, and sodium and studies of the effects of low magnesium, potassium, and sodium intakes on lung function in adults. We also assessed lung volume to assist in interpreting the data on airway flows. Maximal forced expiratory flow-volume maneuvers were recorded using rolling-seal spirometers (Spiroflow; P. K. Morgan, Ltd., Gillingham, United Kingdom). Spirometric calibrations and room temperatures were measured just before, during, and just after each testing session using flow-volume syringes (Jones Medical Instrument Co., Oak Brook, Illinois), and lung function measures were corrected for changes in calibration or internal temperature. Testing and data management procedures have been reported previously (24). Each subject was asked to perform three satisfactory maneuvers, and no more than seven maneuvers were attempted during any test session. A satisfactory maneuver was defined as the forced vital capacity's agreeing within 5 percent, the FEV<sub>1</sub>'s agreeing within 5 percent, an extrapolated volume for FEV<sub>1</sub> of less than 100 ml or 5 percent of forced vital capacity, an expired volume in the final 2 seconds of less than approximately 50 ml (45 ml × the standard body temperature pressure saturated correction factor), and forced expiratory time's exceeding 3 seconds. Of the 2,895 children who completed a food frequency questionnaire, 2,633 also performed an acceptable pulmonary function testing.

### Dietary information

Dietary intake was assessed using the youth/adolescent questionnaire, a validated food frequency questionnaire

developed by Rockett et al. (26) and Rockett and Colditz (27) for use in older children and adolescents. The questionnaire has 131 food items including snacks and is a modified version of the validated Nurses' Health Study food frequency questionnaire (28). In a validation study, the correlation coefficients between the food frequency questionnaire and three 24-hour dietary recalls were 0.60 for magnesium, 0.56 for potassium, and 0.24 for sodium and were similar to those observed among adults (26, 27).

Nutrient and energy intakes were quantified for each person. Of the 2,633 children who completed both the food frequency questionnaire and lung function tests, 67 children with total energy intake below 500 calories or above 5,000 calories were excluded from analyses, resulting in a final sample size of 2,566 children aged 11–19 years. Because mineral intake depends on gender and total caloric intake, we used sex-specific quintiles for descriptive analyses of magnesium, potassium, and sodium intakes.

Because our a priori hypothesis was that very low magnesium intake is associated with lower lung function in our study population, we chose to compare low intake with higher intake on the basis of two considerations. First, dietary intakes of cationic minerals are known to affect airway physiology. Based on airway physiology, a linear dose-response relation over a large range of magnesium intake would not be expected. Intake of magnesium below some minimal level may increase airway tone and reactivity. Intake above that level would not be associated with as substantial a change in function. Because we live in a period in which most people's dietary intake far exceeds that needed for normal function, we reasoned that only those with very low intake would show effects on lung function. On the basis of the hypothesis that low intake is associated with reduced airway flows, we classified low intake as less than the 20th percentile in analyses of lung function and adjusted all estimates for total caloric intake.

### Sociodemographic, medical history, and exposure data

The Children's Health Study questionnaire provided information on sociodemographic factors, history of respiratory illness and associated risk factors, exposure to environmental tobacco smoke, and maternal smoking history. Ethnicity was defined as non-Hispanic White, Hispanic, African American, Asian, and other ethnicities, based on self-report. Health insurance was defined as any insurance coverage reported for the participant's family.

Baseline questionnaire responses by parents or guardians and self-report of doctor-diagnosed asthma during lung function testing were used to categorize children's asthma status at the time of food frequency questionnaire completion. A child with persistent asthma was defined as any child who had doctor-diagnosed asthma and who was symptomatic in the year before completing the food frequency questionnaire or who took any asthma medication during the 12 months before the date that the questionnaire was completed. A child with wheezing was defined as any child with any lifetime history of wheezing.

Personal smoking was defined as a history of the participant's reporting having ever smoked more than 100 ciga-

rettes, as ascertained by a private interview during spirometry. Exposure to maternal smoking in utero was characterized using the responses from the questionnaire completed by parents or guardians. Each child's environmental tobacco smoke exposure status was based on reports of current smoking status of the mother, father, other adult household members, and regular household visitors.

Participants' height and weight were measured using a standardized protocol, and any respiratory infection within 1 month of testing and exercising within 30 minutes of testing were documented by trained field staff immediately before lung function testing. Body mass index was calculated as the weight (kg)/height (m)<sup>2</sup> and categorized into age- and sex-specific quintiles.

### Statistical analyses

The relations between lung function and physiologic growth factors such as age and height have been found to be highly nonlinear from childhood through adolescence (29, 30). The distributions of magnesium, potassium, and sodium intakes were examined and categorized into sex-specific quintiles. Differences within categories of selected covariates were tested with analysis of variance. We then assessed the effects of magnesium, potassium, and sodium intakes on lung function by using regression splines to capture the nonlinear relation among pulmonary function, age, and height (29–33). Regression splines fit piecewise polynomials that are joined smoothly at the cutpoints, known as knots. This has the advantage of allowing appropriate statistical inference while capturing the nonlinear relations in the data. Initially, a knot was placed at each integer age. The final models were fitted by using knots at ages 13 and 17 years, leading to a more parsimonious model with essentially the same results.

All models were fit separately for males and females because their smoothing shapes for the relation between lung function and age are different. The gender-specific regression model was given as:

$$E\{\log(\text{PFT})\} = \mu + S_1(\text{AGE}) + S_2(\text{AGE}) \times \log(\text{HT}) + \mathbf{X}\beta,$$

where PFT is a pulmonary function test like forced vital capacity or FEV<sub>1</sub>,  $\mu$  is the overall mean, AGE is age at visit, HT is the residual of height at visit after smoothing height on age, and  $\mathbf{X}$  is a vector of covariates (including mineral intake) of interest and a set of adjustment variables (including cohort, community, technician, spirometer, race/ethnicity, barometric pressure, and other possible confounders). This model is an example of the varying-coefficient modeling strategy of Hastie and Tibshirani (34). We used natural cubic splines that impose the additional constraint that the function be linear beyond the boundary knots.

Because we hypothesized that the effects of mineral intake on lung function appeared to be related to low intake, we used categories of low intake (20th percentile) and higher intake (greater than 20th percentile) in the flexible models. Flexible models were fitted that included sex-specific mineral intake and variables for cohort, community, ethnicity, spirometer, spirometer temperature, technician,

and barometric pressure. Note that the models are additive on the log scale, and the results are presented as the percent differences from the reference curve at the mean age. The primary parameters of interest are the main effects for low mineral intake, which characterizes a parallel percent difference in pulmonary function compared with the baseline group of high mineral intake.

All models were adjusted for total energy intake. Based on previous analyses and reported studies, other aspects of diet such as fat, carbohydrate, fruit and vegetable intakes and vitamin intake, parental education (<12 grades, 12 grades, some college, college, and some graduate), household income (<\$7,500, \$7,500–\$14,999, \$15,000–\$29,999, \$30,000–\$49,999, \$50,000–99,999, and  $\geq$ \$100,000), body mass index (weight (kg)/height (m)<sup>2</sup>) cohort- and sex-specific quintiles, insurance status (yes/no), personal smoking (yes/no), environmental tobacco smoke exposure (yes/no), and respiratory illness at lung function test (yes/no) were evaluated as potential confounders and were included in models if the adjusted estimates for intake changed by 10 percent or more compared with the unadjusted estimates. Subjects with missing data for a given covariate were excluded from the analyses that involved that covariate. To assess the modifying effect of asthma on the relation between low magnesium, potassium, and sodium intakes and lung functions, we conducted gender-specific stratified analyses for children with and without asthma. We tested the statistical significance of interaction terms between asthma status and mineral intake. All analyses were conducted by using the S-Plus statistical software package (35).

### RESULTS

Selected characteristics of participants who completed both a food frequency questionnaire and lung function testing are enumerated in table 1. Participants ranged in age from 11 to 19 years and were predominantly non-Hispanic White and from middle-class families with health insurance. Few smoked, but one third were exposed to environmental tobacco smoke. Overall, 23.0 percent reported ever being diagnosed with asthma by a physician, and 14.8 percent had persistent asthma in the year previous to the date of the interview. We note that our prevalences for asthma and persistent asthma are higher than in previous studies in the United States and Australia; however, the prevalence of asthma has increased by 50 percent since 1980, and older studies may not reflect the current prevalence.

Intake of magnesium was higher in boys than in girls; however, both had intakes that were substantially lower than the recommended daily allowance for this age group (410 mg/day for boys, 360 mg/day for girls) (table 2). Less than 14 percent of boys and 12 percent of girls had adequate intakes of magnesium. There was no difference in the mean magnesium intake between children with and without asthma. Potassium intake was also higher in boys than in girls, but intake for both genders was within the recommended range (2,000–3,500 mg/day). Sodium intake was at the upper limit of the recommended range (500–2,400 mg/day).

**TABLE 1. Selected characteristics of participants (n = 2,566), Children's Health Study, Los Angeles, California, 1998–1999**

	No.	%
Sex		
Girls	1,389	54.1
Boys	1,177	45.9
Age (years)		
11–14	1,090	42.5
15–16	617	24.0
17–19	859	33.5
Cohort		
Grade 4 (recruited in 1993)	461	18.0
Grade 7 (recruited in 1993)	1,000	39.0
Grade 4 (recruited in 1995)	1,105	43.1
Race/ethnicity		
Non-Hispanic White	1,481	57.9
Hispanic	678	26.5
Black (African American)	112	4.4
Asian	149	5.8
Others	137	5.4
Parental education		
Some graduate	349	14.1
College	269	10.9
Some college	1,100	44.5
12 grades	466	18.9
<12 grades	286	11.6
Income (\$)		
≥100,000	152	7.0
50,000–99,999	794	36.5
30,000–49,999	597	27.4
15,000–29,999	332	15.2
7,500–14,999	193	8.9
<7,500	110	5.1
Insurance		
Yes	2,136	85.4
Respiratory illness at PFT*		
Yes	429	18.2
Personal smoking		
Yes	657	25.6
Current ETS* exposure		
Yes	847	33.1
In utero exposure		
Yes	377	15.3
Asthma		
Yes	579	23.0
Persistent asthma		
Yes	372	14.8

\* PFT, pulmonary function test; ETS, environmental tobacco smoke.

Low magnesium intake was associated with lower measures for several lung functions (table 3). All the estimates for differences in lung function for low magnesium intake

were negative and were statistically significant for forced vital capacity for boys (–2.8 percent) and forced expiratory flow at 75 percent of the forced vital capacity (FEF<sub>75</sub>) for girls (–8.3 percent). Low potassium intake was associated with lower forced vital capacity in girls, and flows tended to be lower in both boys and girls, although results were statistically significant only for FEV<sub>1</sub> in girls. Estimates for the effects of low sodium intake on flows were in the opposite direction from those for magnesium and potassium. Low sodium intake was generally associated with higher lung function, but estimates were statistically significant only for forced vital capacity among boys. We examined the relation between the sodium/potassium ratio and lung function and found little evidence that the ratio was related to lung function. We found little evidence for confounding by socioeconomic status (income, education), other aspects of diet, or smoking and did not include these covariates in our final models.

Lung function was generally lower in both boys and girls with and without asthma who had low magnesium intake (table 4). Among both boys and girls without asthma, low magnesium intake was associated with lower lung function, especially flows, but the deficits did not achieve statistical significance. Children with asthma had significantly lower flow rates than did children without asthma, independent of magnesium intake. The effects of low magnesium intake on flow rates (forced expiratory flow between 25 percent and 75 percent of the forced vital capacity (FEF<sub>25–75</sub>) and FEF<sub>75</sub>) were significantly larger in girls with asthma than in girls without asthma. Among boys, there was little evidence that the effect of low magnesium intake varied by participants' asthma status. The effects of low potassium and sodium intakes did not vary by asthma status.

## DISCUSSION

Magnesium intake varies over a substantial range in the general population, reflecting differences in both total energy intake and the intake of specific food items (36, 37). Foods vary in magnesium content. Green leafy vegetables, nuts, and whole grains have a high magnesium content, followed by milk, meats, and starches. The magnesium content of refined foods is generally low. Because the consumption of processed and refined foods has increased in the US diet, magnesium intake has decreased and is now more likely to be inadequate, especially among adolescents who have the largest daily magnesium intake requirements (1, 37). This national trend in diet was reflected in the low magnesium intake in our cohort, of whom less than 15 percent reached the recommended daily allowance for magnesium intake, which was lower than that reported by Britton et al. (3) in adults. The primary sources of magnesium in our study were meat, milk, and Mexican food such as tacos.

The low levels of magnesium intake in children may have adverse effects on lung function. In this study, low magnesium intake was associated with decreased lung function, especially for flows among girls with asthma. Boys also showed decreased forced vital capacity with low magnesium intake. Our findings are consistent with effects

**TABLE 2. Mineral intake (mg/day) by participant characteristics, Children's Health Study, Los Angeles, California, 1998–1999**

Mineral	Participant characteristic, age (years)	Boys			Girls		
		Mean (SD)*	20th percentile	<i>p</i> value†	Mean (SD)	20th percentile	<i>p</i> value
Magnesium	11–14	271.5 (120.4)	168.4	0.09	245.3 (114.8)	150.9	0.53
	15–16	256.4 (109.0)	168.8		239.9 (110.4)	146.0	
	17–19	275.7 (117.7)	173.5		248.7 (106.1)	155.0	
Potassium	11–14	2,584.3 (1,169.4)	1,584.8	0.13	2,384.2 (1,149.0)	1,427.1	0.28
	15–16	2,431.8 (1,067.5)	1,566.4		2,275.9 (1,046.0)	1,416.9	
	17–19	2,593.2 (1,124.1)	1,639.5		2,385.1 (1,057.3)	1,454.0	
Sodium	11–14	2,518.5 (1,112.3)	1,576.6	0.04	2,286.6 (1,029.3)	1,443.1	0.34
	15–16	2,382.2 (986.1)	1,483.7		2,190.9 (927.0)	1,416.0	
	17–19	2,586.0 (1,017.0)	1,735.2		2,268.1 (920.4)	1,510.2	

\* SD, standard deviation.

† *p* value of *F* test.

reported among adults (3). To our knowledge, there are no published population-based studies of magnesium intake and lung function in children.

On the basis of our cross-sectional data, we cannot determine whether the effects of low magnesium intake reflect acute reversible effects or chronic irreversible effects. The effects of magnesium on bronchial smooth muscle function might account for decreased lung function. Magnesium is essential for maintenance of electrical potential across cell membranes and therefore modulates bronchial tone and diameter (9, 10). An increase in magnesium concentration relaxes smooth muscle and decreases cholinergic neuromuscular transmission. The acute effects of magnesium on neuromuscular hyperexcitability are mediated by direct and

indirect effects via changes in calcium and potassium levels. Our findings of larger effects on flows in girls with low magnesium intake and asthma are consistent with these mechanisms. A low intake of potassium could affect airway flows among children with asthma by contributing to the lower serum and intracellular levels of potassium that result from increased adrenergic tone in children with either asthma or airway hyperresponsiveness (21, 23). The mechanisms for effects on forced vital capacity may also be related to altered neuromuscular function. Although acute changes in lung function may occur with low magnesium or potassium intake, chronic effects from low magnesium intake are also possible (5, 6, 10). Chronically low magnesium intake in adults is associated with chronic adverse

**TABLE 3. Effect of low daily mineral intake on lung function, Children's Health Study, Los Angeles, California, 1998–1999\***

Mineral	Lung function	Boys		Girls	
		% difference	95% CI†	% difference	95% CI
Magnesium	FVC†	-2.84	-5.4, -0.2	-0.55	-3.1, 2.0
	FEV <sub>1</sub> †	-2.67	-5.4, 0.1	-1.66	-4.4, 1.1
	FEF <sub>25-75</sub> †	-3.63	-9.0, 2.1	-4.84	-9.8, 0.4
	FEF <sub>75</sub> †	-4.69	-12.0, 3.2	-8.33	-14.8, -1.4
Potassium	FVC	0.05	-2.5, 2.7	-2.40	-4.7, -0.1
	FEV <sub>1</sub>	-1.13	-3.8, 1.6	-2.68	-5.2, -0.1
	FEF <sub>25-75</sub>	-3.51	-8.7, 2.0	-3.85	-8.5, 1.1
	FEF <sub>75</sub>	-5.10	-12.2, 2.5	-6.15	-12.3, 0.5
Sodium	FVC	3.03	0.1, 6.0	0.59	-2.2, 3.4
	FEV <sub>1</sub>	2.81	-0.3, 6.0	0.94	-2.1, 4.1
	FEF <sub>25-75</sub>	2.09	-4.0, 8.6	1.99	-3.8, 8.1
	FEF <sub>75</sub>	-0.07	-8.2, 8.8	1.30	-6.4, 9.7

\* Models are adjusted for cohort, community, spirometer, technician, barometric pressure, spirometer temperature, race, and total energy intake.

† CI, confidence interval; FVC, forced vital capacity; FEV<sub>1</sub>, forced expiratory volume in 1 second; FEF<sub>25-75</sub>, forced expiratory flow between 25% and 75% of the forced vital capacity; FEF<sub>75</sub>, forced expiratory flow at 75% of the forced vital capacity.

**TABLE 4. Joint effects of low magnesium intake and asthma\* on lung function in boys and girls, Children's Health Study, Los Angeles, California, 1998–1999†**

Lung function	Magnesium intake	Boys				Girls			
		No asthma (n = 856)		Asthma (n = 306)		No asthma (n = 1,085)		Asthma (n = 273)	
		% difference	95% CI‡	% difference	95% CI	% difference	95% CI	% difference	95% CI
FVC‡	High intake	Reference		1.93	0.2, 3.7	Reference		1.73	-0.2, 3.7
	Low intake	-2.70	-5.5, 0.2	-2.47	-5.9, 1.1	-0.22	-2.9, 2.5	0.15	-3.7, 4.1
FEV <sub>1</sub> ‡	High intake	0.00		-2.59	-4.4, -0.8	0.00		-0.99	-3.0, 1.1
	Low intake	-2.63	-5.6, 0.4	-5.08	-8.6, -1.4	-0.86	-3.8, 2.2	-4.30	-8.3, -0.1
FEF <sub>25-75</sub> ‡,§	High intake	0.00		-11.49	-14.7, -8.2	0.00		-5.83	-9.5, -2.0
	Low intake	-3.84	-9.5, 2.2	-11.70	-18.1, -4.8	-1.97	-7.4, 3.8	-16.17	-22.7, -9.1
FEF <sub>75</sub> ‡	High intake	0.00		-15.12	-19.3, -8.7	0.00		-8.66	-13.5, -3.6
	Low intake	-4.90	-12.7, 2.6	-15.18	-23.6, -6.2	-4.08	-11.3, 3.7	-24.92	-32.8, -16.1

\* Lifetime history of asthma.

† Models are adjusted for cohort, community, spirometer, technician, barometric pressure, spirometer temperature, race, and total energy intake.

‡ CI, confidence interval; FVC, forced vital capacity; FEV<sub>1</sub>, forced expiratory volume in 1 second; FEF<sub>25-75</sub>, forced expiratory flow between 25% and 75% of the forced vital capacity; FEF<sub>75</sub>, forced expiratory flow at 75% of the forced vital capacity.

§ Test for interaction of intake and asthma:  $p < 0.05$  in girls.

health outcomes such as increased cardiovascular morbidity, hypertension, decreased bone mineral density, and insulin resistance, but chronic adverse effects on lung function have not been reported in adults (5, 6, 10). However, the common effects on vascular and airway smooth muscle make chronic effects on lung function biologically plausible. Furthermore, magnesium deficiency affects immune function and responses to oxidative stress that may contribute to the immune dysfunction associated with asthma (11, 12).

We lack data to assess physiologic mechanisms for the differences in effects of mineral intake in boys and girls. Although our findings of larger effects on flow in girls may reflect biologic differences, they may also arise from sex differences in misclassification of intake. Although the validity and reproducibility of the food frequency questionnaires for children and adolescents are generally similar to those of the food frequency questionnaires for adults, the correlations of mineral intakes from the food frequency questionnaire and 24-hour diet recalls were lower in boys than in girls, suggesting that the error in measures of diet may be larger in boys than in girls (27). Because intake is measured with error, the magnitude of the flow deficits in our findings may be smaller than the true deficits associated with low magnesium and potassium intakes.

The interpretation of our findings requires consideration of the limitations in our cross-sectional study design and methods. We used a validated food frequency questionnaire designed to assess usual dietary intake in children and adolescents. The food frequency questionnaire for children and adolescents did not capture intake of minerals from other sources, such as drinking water. The mineral content of water varies with water hardness, and the intakes of magnesium, potassium, and sodium from water consumption are not accounted for in our study. Also, information on supplement use of magnesium was not available specifically for magnesium. However, the intake from supplements was likely to be low according to a study of US children who

took supplements, which found a median intake of 23 mg of magnesium per day (38). We examined vitamin use but found it had little effect on the magnesium-associated deficits. Because intakes of potassium and magnesium are correlated ( $r = 0.98$ ), we were unable to assess the joint effects of magnesium and potassium intakes on lung function. Our data were cross sectional, and respiratory health status may have affected dietary intake. However, deficits as were observed in children without asthma suggest that the effects of mineral intake are unlikely to be completely explained by dietary differences related to asthma. Future longitudinal analyses, as follow-up of the Children's Health Study cohort continues and additional nutrient data are collected, will allow a better assessment of the temporal relations between dietary intake and lung function.

In summary, dietary intake of magnesium was low in our cohort of children aged 11–19 years, reflecting national dietary trends. Low magnesium intake has a number of potential, but as yet undocumented, adverse health effects in children. Our findings indicate that low magnesium intake is associated with small deficits in lung function in children. Lower potassium intake may also affect lung function, but the individual effects of magnesium and potassium could not be separated because high magnesium and potassium levels occur in the same food items. Although the magnitudes of the deficits are small for individual persons, low magnesium intake is prevalent in the general population of children, and the lung function deficits associated with low magnesium may have a substantial impact on respiratory health at the population level. Based on the growing body of evidence that low magnesium intake is associated with adverse outcomes in children, consideration should be given to developing public health interventions to increase magnesium intake. Furthermore, the effects of low magnesium intake in children with asthma may be of clinical significance and warrant recommendations for increased intake of high magnesium content foods.

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