Journal of Human Hypertension (2007), 1–8

www.nature.com/jhh

ORIGINAL ARTICLE

Salt and blood pressure in children and adolescents

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To study the relationship between salt intake and blood pressure in children and adolescents, we analysed the data of a large cross-sectional study (the National Diet and Nutrition Survey for young people), which was carried out in Great Britain in 1997 in a nationally representative sample of children aged between 4 and 18 years. A total of 1658 participants had both salt intake and blood pressure recorded. Salt intake was assessed by a 7-day dietary record. The average salt intake, which did not include salt added in cooking or at the table, was 4.7±0.2 g/day at the age of 4 years. With increasing age, there was an increase in salt intake, and by the age of 18 years, salt intake was 6.8±0.2 g/day. There was a significant association of salt intake with systolic blood pressure as well as with pulse pressure after adjusting for age, sex, body mass index and dietary potassium intake. An increase of 1 g/day in salt intake was related to an increase of 0.4 mm Hg in systolic and 0.6 mm Hg in pulse pressure. The magnitude of the association with systolic blood pressure is very similar to that observed in a recent meta-analysis of controlled trials where salt intake was reduced. The consistent finding of our present analysis of a random sample of free-living individuals with that from controlled salt reduction trials provides further support for a reduction in salt intake in children and adolescents.
Journal of Human Hypertension advance online publication, 6 September 2007; doi:10.1038/sj.jhh.1002268

Keywords: salt; blood pressure; cross-sectional study; children and adolescents

Introduction

Increased blood pressure is a major cause of strokes, heart attacks and heart failure.[1] Although increased blood pressure is uncommon in children, blood pressure follows a tracking pattern and individuals who have a higher blood pressure in early life are more likely to develop high blood pressure when they grow older.[2–5] It is therefore important to start interventions on modifiable risk factors early in childhood. There is overwhelming evidence for a causal relation between salt intake (sodium chloride) and blood pressure in adults.[6–10] Increasing evidence suggests that dietary salt intake also plays an important role in regulating blood pressure in children.[11] However, the results from observational epidemiological studies in children are inconsistent, with many showing no significant association between salt intake and blood pressure.[12] This is not surprising given the large day-to-day intraindividual variations of salt intake. Furthermore, in most studies the sample size was small, only a single measurement of salt intake was made, which did not characterize individuals' usual intake, and the methods used to assess salt intake were unreliable. Measuring sodium from 24-h urine collections is the most accurate method in assessing dietary salt intake. In a carefully conducted study, where seven consecutive 24-h urines were collected by all participants, Cooper *et al.*,[13] in 1980, demonstrated a significant linear relationship between urinary sodium and systolic blood pressure in 73 children aged 11–14 years, that is, the higher the salt intake, the higher the systolic blood pressure. The relationship remained significant after controlling for confounding factors.

The National Diet and Nutrition Survey for young people was a large cross-sectional study carried out in Great Britain in 1997 in a nationally representative sample of children and adolescents. We analysed the data to determine whether there was a significant association between salt intake and blood pressure in children and adolescents.

Methods

We obtained the data of the National Diet and Nutrition Survey for young people from the UK Data Archive.[14] The methods used in the Survey are reported in detail elsewhere[15] and only methods relevant to the current analysis are reported in brief here. The survey was carried out in Great Britain in

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Received 12 March 2007; revised 13 July 2007; accepted 14 July 2007

1997 by the Social Survey Division of the Office for National Statistics and Medical Research Council Human Nutrition Research on behalf of the Ministry of Agriculture, Fisheries and Food and the Department of Health. The main aim of the survey was to provide detailed information on the dietary habits and nutritional status of young people in Great Britain. A nationally representative sample of 2672 individuals aged 4–18 years was identified from a postal sift of addresses selected from the Postcode Address File. Only young people living in private households were eligible to be included and only one child per household was selected. An interview, which was the first stage of the full survey protocol, was completed by 2127 young people. A total of 1658 participants (62% of those identified, and 78% of those who completed the interview) had both salt intake and blood pressure recorded and were included in our analysis. The survey protocol was approved by NHS Local Research Ethics Committees in the areas where fieldwork took place, and informed consent was obtained from the young person and/or the person with parental responsibility.[15]

A weighted dietary record of all food and drink consumed over 7 consecutive days was kept by the parent and/or young person depending on age. Dietary salt, potassium and energy intakes were estimated from the 7-day dietary record. After participants had been sitting quietly without eating or drinking anything for about 30 min, blood pressure was measured using the Dinamap 8100 oscillometric monitor. Different cuff sizes were used according to arm circumferences. Three measurements were made at 1 min intervals and the mean of last two readings was used in our analysis. Body weight, standing height and mid-arm circumferences were measured in all age groups, and waist and hip circumferences were measured for those aged 11–18 years.[15]

Results are reported as mean $\pm$s.e.m. Comparisons of blood pressure and other continuous variables according to tertiles of salt intake were made by one-way ANOVA (analysis of variance) for each of the 5-year age groups. Because of the unequal distribution of sex among tertiles of salt intake, the comparisons of blood pressure were also made using General Linear Model with sex and other potential confounding factors as covariates. Additionally, we compared sex-standardized *Z*-scores of blood pressure among tertiles of salt intake for each age group. Independent samples *t*-test was used to compare two groups for continuous variables. Categorical data were analysed by χ^2 test. Multiple linear regression analysis was performed to examine whether there was a significant relationship between salt intake (as a continuous variable) and blood pressure with adjustment for potential confounding factors. All statistical analyses were carried out using Statistical Package for Social Science (SPSS).

Results

Among the 1658 participants included in the analysis, there were 842 boys and 816 girls. The mean age was 11 ± 0.1 years, ranging from 4 to 18 years. The average salt intake, which did not include salt added in cooking or at the table, was 4.7 ± 0.2 g/day at the age of 4 years. With increasing age, there was an increase in salt intake, and by the age of 18 years, salt intake was 6.8 ± 0.2 g/day. The mean blood pressure was $101\pm0.9/55\pm0.8$ mm Hg at the age of 4 years, and increased to $118\pm1.3/59\pm0.8$ mm Hg by the age of 18 years.

Table 1 shows blood pressure and other variables according to tertiles of salt intake by age group. With increasing salt intake, there was an increase in systolic blood pressure, which was statistically significant for the group aged 4–8 and 14–18 years, and borderline significant for the group aged 9–13 years. There was no significant difference in diastolic blood pressure among tertiles of salt intake. However, pulse pressure was significantly increased with increasing salt intake in all age groups. The sex-standardized *Z*-scores of both systolic and pulse pressure were increased with an increase in salt intake for all age groups (Table 1). With increasing salt intake, there were also significant increases in sodium/weight ratio, sodium/energy ratio, sodium/potassium ratio and mid-arm circumference. Body mass index (BMI) and spot urinary sodium/creatinine ratio were significantly increased only in the group aged 4–8 years (Table 1).

Although we grouped participants into 5-year age groups to minimize the confounding effect of age, there was still a small but significant difference in age among tertiles of salt intake for each of the age categories. There was also a significant difference in sex (Table 1). Further analyses were performed by adjusting for age, sex and BMI. The results showed that only for the group aged 14–18 years, there was a significant increase in pulse pressure, whereas other results were no longer significant. The age-, sex- and BMI-adjusted mean systolic pressure (mm Hg) was 101 ± 0.7, 103 ± 0.6 and 103 ± 0.7 ($P=0.350$) according to tertiles of salt intake for those aged 4–8 years, 107 ± 0.6, 107 ± 0.6 and 108 ± 0.6 ($P=0.365$) for those aged 9–13 years and 114 ± 0.8, 117 ± 0.8 and 117 ± 0.8 ($P=0.058$) for those aged 14–18 years. The age-, sex- and BMI-adjusted mean pulse pressure (mm Hg) was 47 ± 0.7, 47 ± 0.7 and 48 ± 0.7 ($P=0.522$) according to tertiles of salt intake for those aged 4–8 years, 51 ± 0.6, 52 ± 0.6 and 53 ± 0.6 ($P=0.172$) for those aged 9–13 years and 57 ± 0.8, 58 ± 0.7 and 60 ± 0.8 ($P=0.036$) for those aged 14–18 years.

Taking all participants together, there was a significant association between salt intake and systolic blood pressure (correlation coefficient $r=0.30$, regression coefficient $b=1.80\pm0.14$ mm Hg/g of salt per day, $P<0.001$), as well as pulse pressure ($r=0.32$, $b=1.78\pm0.13$, $P<0.001$). To examine the

Table 1 Blood pressure and other variables (unadjusted mean ± s.e.m.) according to tertiles of salt intake by age group in the National Diet and Nutrition Survey for young people in Great Britain, 1997

	4–8 years				*9–13 years*				*14–18 years*			
	Tertile of salt intake (g/day)				*Tertile of salt intake (g/day)*				*Tertile of salt intake (g/day)*			
	1 (<4.5)	*2 (4.6–5.5)*	*3 (>5.5)*	P-*values (one-way ANOVA)*	*1 (<5.4)*	*2 (5.5–6.7)*	*3 (>6.7)*	P-*values (one-way ANOVA)*	*1 (<5.7)*	*2 (5.7–7.5)*	*3 (>7.5)*	P-*values (one-way ANOVA)*
Number of participants, boy/girl	75/109	107/78	118/66	<0.001	69/134	102/101	137/66	<0.001	31/134	76/90	127/38	<0.001
Boys (%)	41	58	64		34	50	67		19	46	77	
Age (years)	5.6±0.10	6.1±0.10‡	6.5±0.09‡	<0.001	10.8±0.10	10.7±0.09	11.2±0.09†	<0.001	15.8±0.11	15.7±0.11	16.0±0.11	0.199
Salt intake (g/day)	3.8±0.04	5.0±0.02‡	6.6±0.07‡	<0.001	4.5±0.06	6.0±0.03‡	7.9±0.08‡	<0.001	4.5±0.07	6.5±0.04‡	9.3±0.12‡	<0.001
Sodium intake (g/day)	1.5±0.02	2.0±0.01‡	2.6±0.03‡	<0.001	1.8±0.02	2.4±0.01‡	3.1±0.03‡	<0.001	1.8±0.03	2.6±0.02‡	3.7±0.05‡	<0.001
Sodium/weight ratio (mg/kg)	75±1.2	88±1.3‡	107±2.0‡	<0.001	49±1.1	64±1.0‡	76±1.3‡	<0.001	32±0.7	43±0.7‡	58±1.0‡	<0.001
Sodium/energy ratio (mg/kcal)	1.20±0.01	1.35±0.01‡	1.52±0.02‡	<0.001	1.22±0.02	1.39±0.01‡	1.50±0.02‡	<0.001	1.27±0.02	1.41±0.02‡	1.59±0.02‡	<0.001
Sodium/potassium ratio	0.98±0.02	1.10±0.02‡	1.24±0.02‡	<0.001	1.00±0.02	1.13±0.02‡	1.29±0.02‡	<0.001	0.97±0.02	1.13±0.02‡	1.30±0.02‡	<0.001
BMI (kg/m^2)	15.9±0.11	16.4±0.14†	16.8±0.13‡	<0.001	18.6±0.24	18.7±0.23	19.2±0.22	0.110	21.7±0.29	22.2±0.29	22.4±0.33	0.200
Mid-arm circumference (cm)	18.1±0.1	18.9±0.2‡	19.6±0.2‡	<0.001	22.4±0.3	22.7±0.2	23.4±0.2†	0.008	26.0±0.3	27.0±0.3	27.5±0.3	0.001
Spot urine sodium/creatinine ratio	16.1±0.71	18.1±0.98	19.2±0.68†	0.025	13.2±0.64	13.4±0.45	14.6±0.55	0.154	10.9±0.59	11.3±0.55	10.7±0.45	0.658
Systolic blood pressure (mm Hg)	101±0.6	103±0.7*	103±0.7†	0.010	107±0.7	107±0.6	109±0.6§	0.064	112±0.8	116±0.9‡	119±0.9‡	<0.001
Diastolic blood pressure (mm Hg)	54±0.6	55±0.6	54±0.5	0.305	56±0.6	55±0.5	55±0.6	0.389	57±0.6	59±0.7	57±0.6	0.066
Pulse pressure (mm Hg)	47±0.6	47±0.7	49±0.6†	0.020	51±0.6	52±0.6	54±0.7†	0.012	55±0.7	58±0.8*	63±0.9‡	<0.001
Sex-standardized systolic blood pressure *Z*-score	−0.17±0.07	0.04±0.07*	0.12±0.07†	0.016	−0.05±0.07	−0.08±0.07	0.13±0.07	0.062	−0.19±0.07	0.05±0.08*	0.13±0.08†	0.010
Sex-standardized pulse pressure *Z*-score	−0.12±0.07	−0.04±0.08	0.15±0.07*	0.030	−0.12±0.07	−0.03±0.06	0.15±0.07†	0.018	−0.12±0.08	−0.05±0.08	0.17±0.08†	0.021

Abbreviations: ANOVA, analysis of variance; BMI, body mass index.
*$P<0.05$, †$P<0.01$, ‡$P<0.001$, §$P=0.054$ compared with tertile 1.

independent association of dietary salt intake with blood pressure, we performed multiple linear regression analyses that controlled for the effects of potential confounding variables. As shown in Tables 2 and 3, there was still a significant association between salt intake and systolic, as well as pulse pressure, after adjusting for age, sex, BMI (or mid-arm circumference or waist/hip ratio for those aged 11 years and over) and dietary potassium intake. An increase of 1 g/day in salt intake was related to an increase of 0.4 mm Hg in systolic blood pressure and 0.6 mm Hg in pulse pressure. In the multivariate model, age, sex and BMI were also significantly associated with systolic blood pressure and pulse pressure, whereas there was no significant association of potassium intake with either systolic or pulse pressure. The variables included in the regression models (age, sex, BMI, salt and potassium intake) accounted for 32.2% (R^2) of the variability in systolic pressure and 25.6% of the variability in pulse pressure. With further adjustment for energy intake, the relation of salt intake to pulse pressure was still significant ($b=0.42\pm0.20$, $P=0.034$), whereas the association with systolic blood pressure was no longer significant ($b=0.18\pm0.20$, $P=0.382$). In the multivariate model, energy intake was significantly associated with systolic pressure, but not pulse pressure. Adding energy intake to the multivariate models resulted in little change in R^2 ($R^2=0.324$ for systolic and $R^2=0.258$ for pulse pressure when age, sex, BMI, salt, potassium and energy intake were entered as independent variables). There was no significant association between salt intake and diastolic blood pressure after adjusting for age, sex, BMI and potassium intake (data not shown).

We also performed multiple regression analysis for the three age groups separately. After adjusting for age, sex and BMI, the regression coefficient, $b=0.19\pm0.31$ (mm Hg/g of salt per day) ($P=0.536$) for systolic pressure and $b=0.23\pm0.32$ ($P=0.472$) for pulse pressure in the group aged 4–8 years, $b=0.25\pm0.24$ ($P=0.300$) for systolic pressure and $b=0.52\pm0.23$ ($P=0.023$) for pulse pressure in the group aged 9–13 years, $b=0.46\pm0.24$ ($P=0.055$) for systolic pressure and $b=0.63\pm0.22$ ($P=0.004$) for pulse pressure in the group aged 14–18 years.

Among the 1658 participants included in our analysis, 998 reported to use salt in cooking, 586 did not use salt, 66 used salt alternative (Lo-salt) in cooking (that is, a combination of sodium chloride and potassium chloride), and in 8 participants, it was unclear whether salt was used in cooking or not. With regard to salt added at the table, 340 participants reported to usually add salt at the table and 1318 reported to either occasionally or rarely or never add salt at the table. In the multiple regression analysis, two dummy variables were added to model 1 (Tables 2 and 3), that is, variable 1: salt added in cooking: yes = 1, no = 0 (note: in this analysis, we excluded individuals who used salt

Table 2 Regression models of systolic blood pressure on related variables

	Model 1 ($R^2=0.322$, $P<0.001$)		*Model 2* ($R^2=0.314$, $P<0.001$)		*Model 3* ($R^2=0.172$, $P<0.001$)		*Model 4* ($R^2=0.327$, $P<0.001$)	
	b (*s.e.*)	P-*values*	b (*s.e.*)	P-*values*	b (*s.e.*)	P-*values*	b (*s.e.*)	P-*values*
Salt intake (g/day)	0.40 (0.17)	0.018	0.36 (0.17)	0.035	0.60 (0.23)	0.009	0.39 (0.17)	0.027
Age (years)	0.86 (0.07)	<0.001	0.72 (0.09)	<0.001	1.63 (0.16)	<0.001	0.85 (0.08)	<0.001
Sex	2.06 (0.49)	<0.001	1.96 (0.50)	<0.001	2.94 (0.82)	<0.001	2.19 (0.50)	<0.001
BMI (kg/m^2)	0.80 (0.08)	<0.001	—	—	—	—	0.82 (0.08)	<0.001
Waist/hip ratio ($N=985$)	—	—	—	—	0.52 (4.58)	0.91	—	—
Mid-arm circumference (cm)	—	—	0.77 (0.08)	<0.001	—	—	—	—
Potassium intake (g/day)	0.39 (0.48)	0.41	0.13 (0.48)	0.782	0.45 (0.64)	0.477	0.41 (0.49)	0.402
Salt added in cooking	—	—	—	—	—	—	0.85 (0.49)	0.083
Salt added at the table	—	—	—	—	—	—	−0.05 (0.59)	0.928

Abbreviation: BMI, body mass index.
In model 1 of multiple linear regression, dependent variable was systolic blood pressure and independent variables were age, sex (boy = 1, girl = 0), BMI, salt and potassium intake. Models 2 and 3 were the same as model 1 except that BMI was replaced with mid-arm circumference and waist/hip ratio, respectively. In model 4, two additional variables, that is, salt added in cooking (yes = 1, no = 0) and salt added at the table (usually = 1, occasionally or rarely or never = 0), were added to model 1.

Table 3 Regression models of pulse pressure on related variables

	Model 1 ($R^2=0.256$, $P<0.001$)		*Model 2* ($R^2=0.256$, $P<0.001$)		*Model 3* ($R^2=0.144$, $P<0.001$)		*Model 4* ($R^2=0.262$, $P<0.001$)	
	b (*s.e.*)	P-*values*	b (*s.e.*)	P-*values*	b (*s.e.*)	P-*values*	b (*s.e.*)	P-*values*
Salt intake (g/day)	0.60 (0.17)	<0.001	0.57 (0.17)	0.001	0.80 (0.22)	<0.001	0.59 (0.17)	<0.001
Age (years)	0.63 (0.07)	<0.001	0.48 (0.08)	<0.001	1.00 (0.15)	<0.001	0.62 (0.07)	<0.001
Sex	2.20 (0.48)	<0.001	2.14 (0.48)	<0.001	3.27 (0.78)	<0.001	2.26 (0.49)	<0.001
BMI (kg/m²)	0.61 (0.07)	<0.001	—	—	—	—	0.60 (0.08)	<0.001
Waist/hip ratio (*N*=985)	—	—	—	—	−2.68 (4.34)	0.537	—	—
Mid-arm circumference (cm)	—	—	0.64 (0.08)	<0.001	—	—	—	—
Potassium intake (g/day)	0.67 (0.46)	0.149	0.46 (0.46)	0.318	0.69 (0.60)	0.252	0.74 (0.47)	0.117
Salt added in cooking	—	—	—	—	—	—	1.23 (0.47)	0.010
Salt added at the table	—	—	—	—	—	—	0.06 (0.57)	0.924

Abbreviation: BMI, body mass index.
In model 1 of multiple linear regression, dependent variable was pulse pressure and independent variables were age, sex (boy = 1, girl = 0), body mass index (BMI), salt and potassium intake. Model 2 and 3 were the same as model 1 except that BMI was replaced with mid-arm circumference and waist/hip ratio, respectively. In model 4, two additional variables, that is, salt added in cooking (yes = 1, no = 0) and salt added at the table (usually = 1, occasionally or rarely or never = 0), were added to model 1.

alternative (Lo-salt) in cooking and those in whom the answer to this question was unclear); variable 2: salt added at the table: usually = 1, occasionally or rarely or never = 0. The results showed that neither salt added in cooking nor salt added at the table were significantly associated with systolic blood pressure; however, there was a significant association between salt added in cooking and pulse pressure, that is, individuals who added salt in cooking had a significantly higher pulse pressure compared to those who did not (Tables 2 and 3). The variables included in the regression models (age, sex, BMI, salt and potassium intake, salt used in cooking and salt added at the table) accounted for 32.7% (R^2) of the variability in systolic pressure and 26.2% of the variability in pulse pressure. Adding the two variables (that is, salt used in cooking and added at the table) to the multivariate model had little effect on the quantitative relationship between salt intake and blood pressure (Tables 2 and 3).

Discussion

Our current analysis has two strengths: (1) the data were from a large nationally representative sample of free-living young people in Great Britain; (2) salt intake was estimated from a 7-day dietary record, which could characterize individuals' usual intake more accurately than a dietary record taken over 1–2 days. The analysis showed a significant positive association between salt intake and blood pressure in children and adolescents after adjusting for potential confounding factors. These results provide further support for the accumulating evidence that dietary salt intake plays an important role in determining blood pressure in children and adolescents.

The magnitude of the association between salt intake and systolic blood pressure found in the present analysis of a cross-sectional study in free-living individuals is in good agreement with that observed in controlled trials where salt intake was reduced. A recent meta-analysis of 10 trials in children and adolescents demonstrates that a 42% reduction in salt intake, which is equivalent to a decrease of approximately 3 g/day (that is, from about 8 to 5 g/day) in salt intake, causes a fall in systolic pressure of 1.2 mm Hg ($P<0.001$).[11] In our current analysis, a difference of 1 g/day in salt intake is related to a difference of 0.4 mm Hg in systolic blood pressure (with adjustment for age, sex, BMI and potassium intake), which is very similar to that observed in the salt reduction trials. It could be argued that the fall in blood pressure with a reduction in salt intake is small. However, from a population viewpoint, a small decrease in blood pressure in children and adolescents would have major public health implications in terms of preventing hypertension and therefore cardiovascular disease in the future.

Our subgroup analyses showed that the association between salt intake and blood pressure was not significant in most of the subgroups, particularly for the younger age groups. It is likely that these analyses are underpowered. In adults, it has been shown that for a given change in salt intake, the change in blood pressure is greater in older individuals than in young people.[16] The influence of age on the salt–blood pressure relationship may also exist in children and adolescents. This would make it more difficult to detect a smaller difference in blood pressure between different salt intakes in the younger age groups.

Our analysis has several potential limitations. First, the National Diet and Nutrition Survey for young people is a cross-sectional study. No cause–effect relationship can be drawn from such a study. However, the consistent finding of our present analysis with that from controlled salt reduction trials[11] demonstrates that salt intake is an important determinant of blood pressure in children and adolescents. Second, the salt intake estimated from the National Diet and Nutrition Survey for young people underestimated the actual amount of salt consumed by children as it did not include salt added in cooking or at the table. Although it was recorded whether participants added salt in cooking or at the table, it is impossible to quantify the amount of salt used as 24-h urinary sodium was not measured. However, generally in developed countries, the amount of salt discretionarily added to food is small and the majority of salt intake comes from salt already hidden in food, that is, added to food by the food industry.[17] The question is whether this small amount of discretionary salt would affect the quantitative relationship between salt intake and blood pressure in our analysis? The fact that additional adjustment of salt added in cooking or at the table resulted in little change to the quantitative association between salt intake and blood pressure, would suggest that the confounding effect of salt added in cooking or at the table, if any, would be small. Third, in the National Diet and Nutrition Survey for young people, blood pressure was measured using an automated oscillometric device, that is, Dinamap 8100 oscillometric monitor. Although the Dinamap has been validated in several studies, it has been shown to produce higher systolic and lower diastolic blood pressure levels compared with measurements made using a mercury sphygmomanometer.[18] The blood pressure levels reported in this paper are therefore not comparable to those measured by other devices. However, as the same device was used in all participants, the use of such a device is unlikely to have distorted the relationship between salt intake and blood pressure in this cross-sectional study.

Our finding that salt intake is significantly related to blood pressure is in agreement with the study by Cooper *et al.*[13] who measured sodium excretion from seven consecutive 24-h urine samples in 73 children aged 11–14 years. They found that an increase of 1 g/day in salt intake was associated with an increase of 1 mm Hg in systolic blood pressure, which is greater than that observed in our analysis. This may be due to a number of factors: (1) Cooper *et al.* used the best method to assess dietary salt intake, that is, sodium excretion from seven consecutive 24-h urine collections, and their study was conducted in a better controlled condition than that in the National Diet and Nutrition Survey for young people. (2) A large proportion of participants (54%) were black subjects in Cooper's study, whereas over 90% of participants in our analysis were white subjects (note: ethnic group was not recorded in the National Diet and Nutrition Survey for young people; however, as it was a nationally representative sample, it is conceivable that over 90% of participants were white), and it is well documented that, for a given reduction in salt intake, black subjects have a greater fall in blood pressure than white subjects.[16,19] (3) Other factors, for example difference in participants' age, may also partially contribute to the difference in the magnitude of the relation of salt intake to blood pressure between Cooper's study and our study.

Geleijnse *et al.*[20] examined the effect of habitual salt and potassium intake on the increase in blood pressure with age in 233 Dutch children who were aged 5–17 years at baseline and followed up for at least 7 years. All participants had annual measurements of blood pressure and overnight urinary sodium and potassium. The results showed that the increase in blood pressure in childhood was significantly associated with urinary sodium/potassium ratio after controlling for age, sex, weight, height and other electrolytes.

Stronger evidence for the role of salt in regulating blood pressure in the young comes from the experiments in chimpanzees (98.8% genetic homology with man).[21] Twenty-six chimpanzees with a mean age of 12 years (equivalent to human adolescents) were randomized into two groups: one was given their usual salt intake of approximately 0.5 g/day, which is close to humans' evolutionary intake and, in the other group, salt intake was gradually increased to 5, 10 and 15 g/day, which is similar to the current salt intake in adolescents. During the 20-month study, there was a progressive increase in the difference in blood pressure between the two groups. At the end of the intervention, the high-salt group had a 33/10 mm Hg higher blood pressure than those in the low-salt group. This experiment provides a direct evidence for a causal relationship between salt intake and blood pressure in the young chimpanzees.

Our analysis also shows that salt intake is an independent predictor of pulse pressure in children and adolescents. It has been shown that, in the middle-aged and elderly, pulse pressure is a surrogate marker for central artery stiffness, which is an independent risk factor for cardiovascular disease.[22,23] Furthermore, a reduction in salt intake has been shown to cause a fall in pulse pressure in both young and old people.[24,25] Although brachial artery cuff measurements of pulse pressure in young people are less accurate indicators of central pulse pressure than are those measurements carried out in the elderly (a consequence of the large amplification phenomenon from aorta to the peripheral arteries in the young), differences in pulse pressure among youths may reflect important hemodynamic characteristics, which have consequences later in life.[26]

In our analysis, energy intake has a significant confounding effect on the association between salt intake and blood pressure. It is known that salt intake is significantly correlated with energy intake. For a given concentration of salt in food, the more food an individual eats, the more energy intake the person would have, and the more salt the person would eat as well. Furthermore, a higher salt intake increases soft drink consumption,[27] and thereby increases energy intake as most of the soft drinks targeted at children are high in sugar. The question is which factor (salt or energy) is related to blood pressure. From the literature, salt intake is a well-established risk factor for increased blood pressure, whereas the evidence for a link between energy intake and blood pressure is uncertain.[28] It has been shown that a higher energy intake combined with a lack of exercise causes obesity, which in turn results in an increase in blood pressure.[29] However, it is unclear whether energy intake *per se* is related to blood pressure independent of obesity.

Our analysis also showed that age, sex and BMI were significantly associated with blood pressure. This is in agreement with the findings from previous studies.[30,31] However, in our analysis there was no significant independent association between potassium intake and blood pressure. This is in contrast with the studies in adults where potassium intake was inversely related to blood pressure.[10,32]

In conclusion, our analysis of the data from the National Diet and Nutrition Survey for young people shows that in a free-living population of British children and adolescents, differences in salt intake are associated with differences in blood pressure of public health relevance. The magnitude of the association between salt intake and systolic blood pressure in our analysis is very similar to that observed in a recent meta-analysis of controlled trials where salt intake was changed. These consistent findings provide further support for a reduction in salt intake in childhood. Currently, salt intake in young people is unnecessarily high[33,34] due, in most countries, to hidden salt added to food by the food industry. The high salt intake may predispose them to develop high blood pressure later in life.[2,11] A modest reduction in salt intake is likely to cause a fall in blood pressure in children and adolescents, and a reduction in salt intake combined with other dietary and lifestyle changes, for example, reducing obesity, may prevent the development of hypertension and therefore cardiovascular disease in the future.

What is known about this topic
- Salt intake may play an important role in regulating blood pressure in children.

What this study adds
- In a free-living population of British children and adolescents, differences in salt intake are associated with differences in blood pressure of public health importance.
- The quantitative association between salt intake and systolic blood pressure in individuals on their usual diet is very similar to that found in a meta-analysis of controlled trials where salt intake was changed.
- The consistent findings, from a cross-sectional study and controlled trials, provide strong support for a reduction in salt intake in childhood.

Acknowledgements

We thank the original data creators, depositors, copyright holders, the providers of fund of the Data Collections and the UK Data Archive (University of Essex, Colchester, UK) for the use of data from the National Diet and Nutrition Survey: young people aged 4–18 years. They bear no responsibility for the current analysis or interpretation of the results.

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