nature publishing group

ORIGINAL CONTRIBUTIONS

Hypertension, Dietary Salt Restriction, and Iodine Deficiency Among Adults

Francis A.K. Tayie[1] and Katie Jourdan[2]

BACKGROUND
A common recommendation for the treatment of hypertension is dietary salt intake restriction. However, dietary salt is one of the major sources of iodine. This study evaluated the association between dietary salt restriction and iodine deficiency among adults in the United States.

METHODS
Multiple regression models, which controlled for confounders, were used to evaluate the association between hypertension conditions, salt restriction and iodine deficiency among 996 men and 960 women in the blood pressure and iodine subsamples of the 2001–2004 waves of the National Health and Nutrition Examination Surveys (NHANES).

RESULTS
High proportions of men (24.96%) and women (40.42%) were iodine deficient. Current hypertension or having a history of hypertension among men and women did not associate significantly with iodine deficiency or high iodine status, compared with those without current or history of hypertension. Compared with men not restricting dietary salt, salt restriction did not associate significantly with iodine deficiency among men. Compared with women not restricting dietary salt, women who were restricting dietary salt associated with significantly lower urinary iodine concentration (UIC), $P = 0.01$, and were more likely to be iodine deficient, adjusted odds ratios, 1.79, $P = 0.03$.

CONCLUSIONS
Salt restriction associated with iodine deficiency among women but not men. Alternative sources of iodine should be suggested to persons who are consuming low levels of iodine such as women if they need to restrict dietary salt intake. Among those iodine deficient, health professionals should enquire about salt restriction.

Keywords: *blood pressure; hypertension; iodine deficiency; iodine deficiency disorders; salt restriction; thyroid*

American Journal of Hypertension, advance online publication 17 June 2010; doi:10.1038/ajh.2010.120

One of the common health problems of adults worldwide and in the United States is hypertension. In the United States about 29% of adults have hypertension.[1,2] Hypertension constitutes a significant attributable cause of coronary heart disease, heart failure, stroke, renal disease, and glaucoma.[1,3,4] Due to loss of human life and high cost of the management and treatment of hypertension, and its complications, many recommendations have been forwarded to help prevent it.[5–7] Notable among these recommendations is a reduction in dietary sodium (salt) intake.[5,6,8] This recommendation is warranted because excessive sodium consumption has been associated with hypertension and fluid retention.[5,8–10] In the United States, about 75% of the sodium in the diet comes from salt (NaCl) added by food manufacturers and restaurants.[5,11] Salt consumption lingers around 4,000 mg/day,[5,8] far above the 2,400 mg/day recommended intake.[5]

Restriction of dietary salt consumption as a treatment option for hypertension could mean a significant curtailing of iodine intake and hence risk of iodine deficiency. Iodized salt contains small but substantial amount of the essential mineral iodine. In the human body, iodine is required for the production of thyroid hormones notably, thyroxine (T_4) and triiodothyronine (T_3), which are required for the regulation of various physiological processes including growth, neurological development, body weight, temperature, and rate of oxidation in cells. Regular consumption of iodized salt is an effective prophylaxis against iodine deficiency.[11,12] Iodine deficiency causes deficiency of the thyroid hormones which subsequently results in iodine deficiency disorders (IDD), a major public health problem in many countries.[13] Of great concern among the IDD are developmental failure, mental retardation, neurological damage, dwarfism, hearing loss, and decreased intelligence quotient in children.[13–15] In adults, IDD results in hypothyroidism, infertility, thyroid cancer, goiter, poor cognition, lethargy, and decreased labor productivity.[13–16] In the United States, iodized salt was introduced all over the continent within a short period in 1924 to obviate IDD,[14,17] and voluntary salt iodization was embraced thereafter. Hitherto, IDD were a major health problem. Per the mandate of the United States Food and Drug Administration, domestic iodized salt is fortified with up to 0.01% potassium iodide or

[1]Human Environmental Studies Department, Central Michigan University, Mount Pleasant, Michigan, USA; [2]Department of Health Behavior and Health Education, University of Michigan, Ann Arbor, Michigan, USA. Correspondence: Francis A.K. Tayie (tayie1f@cmich.edu)

Received 29 December 2009; first decision 19 February 2010; accepted 7 May 2010.

copper iodide as iodine sources.[14] Each gram of iodized salt contains about 77 μg of iodine (100 μg potassium iodide) at the production level.[11,12] Taking cognizance of intake levels, food processing effects, and cooking losses, this level of fortification could contribute about 50 μg iodine to the average person's daily iodine need of 150 μg.[11–13]

Measurement of iodine levels in urine is frequently done to assess a person's current iodine nutritional status[13,15] because iodine intake and renal excretion tend to be in a steady state which approximates iodine nutritional status.[15,18] In this study, we evaluated the likelihood of iodine deficiency due to hypertension and salt restriction.

METHODS

Sources of data and study sample. The blood pressure and iodine subsamples from the 2001–2002 and 2003–2004 waves of the United States National Health and Nutrition Examination Survey (NHANES 2001–2004) were used for this study. The NHANES is an ongoing population-based survey, conducted by the National Center for Health Statistics of the Centers for Disease Control and Prevention, to monitor and assess the health status of the noninstitutionalized United States civilian population.[19] The NHANES 2001–2004 uses a stratified, multistage probability cluster sampling method and include interviews, physical examination, and laboratory tests of participants from representative households. In 1999, NHANES was converted from a static survey to a continuous annual survey.[20] Data collected over successive 2-year intervals are periodically released for public use. The NHANES survey data are released together with analytical guides, related notes, and analytical survey weights to ensure unbiased estimation of population averages.[21]

Data from participants in the blood pressure and iodine subsamples of the NHANES 2001–2004 mobile examination center (MEC) were matched into a combined dataset. In the NHANES 2001–2004, subsamples that are representative of the noninstitutionalized United States civilian population provided data on urinary iodine.[22] The final sample for this study comprised participants who had characteristics comparable to the general NHANES population. Inclusion criteria were: ages 20–60 years, nonpregnant, and had complete blood pressure, urinary iodine, and gender information. Participants aged 20–60 years were included to avoid the complex influence of age on blood pressure and glomerular filtration.[23] The NHANES 2001–2004 MEC blood pressure subsamples included only those 20 years and over. The final combined dataset comprised 1,956 participants, 1,043 from NHANES 2001–2002, and 913 from the NHANES 2003–2004. Of the final dataset, 996 were men and 960 were women.

Sociodemographic information: age, gender, income, ethnicity, and education, were obtained from the NHANES demographic questionnaire data files.[19] Physical activity information was obtained from the physical activity and physical fitness data files whereas body weight and body mass index (BMI) data were from the MEC body measures data files.[19] Urinary creatinine and albumin information were obtained from the NHANES 2001–2004 MEC laboratory data files.[19] The Ethics Review Board of the National Center for Health Statistics approved the survey procedures and informed consent was obtained from all participants.[19] The procedures for this study were approved locally by the Institutional Review Board, Office of Research and Sponsored Programs, Central Michigan University.

Identification of hypertension and measurement of blood pressure. Participants were categorized as hypertensive if they had a mean systolic blood pressure of ≥140 mm Hg or diastolic blood pressure of ≥90 mm Hg or affirmed current use of antihypertension medication.[1,24,25] They had history of hypertension if they had ever been told by a health professional that they had hypertension but were not hypertensive at the time of examination.[26] In the NHANES, blood pressure was measured manually by a trained technician using a mercury sphygmomanometer by following a standard protocol.[4,26] Repeated measurements were done and acceptable values were averaged and recorded.[4,26] In this study, the first blood pressure reading was discarded and the second and third blood pressure readings were used, because the first reading was consistently higher than the second and the third, which were closer. The blood pressure measurement protocols were identical for the 2001–2002 and 2003–2004 waves of NHANES.[4,26]

Identification of dietary salt restriction. The NHANES 2001–2004 blood pressure questionnaire contained questions related to dietary salt restriction: "told to reduce sodium for hypertension?," "now reducing sodium/salt?" whereas the dietary interview questionnaire included current use of salt substitute, and salt use in cooking or at the table." Participants who affirmed the "told to reduce sodium for hypertension?," "now reducing sodium/salt?," were using salt substitute, and did not use salt in cooking or at the table," inclusively, satisfied the criteria for dietary salt restriction.[26]

Dietary sodium intake. To enhance the validity and to buttress the salt restriction questions, dietary sodium intake was assessed in relation to hypertension conditions and dietary salt restriction. Data on dietary sodium intake were obtained from the NHANES 2001–2004 MEC dietary interview questionnaire.[19] In the NHANES 2001–2004, dietary sodium intake was assessed by a multiple-pass in-person 24-h dietary recall method.[19] In this study, dietary sodium intake was dichotomized as: moderate, ≤2,400 mg/day and high, >2,400 mg/day, using the Joint National Committee's guidelines for sodium intake.[5,25]

Determining urinary iodine concentration and iodine nutritional status. The NHANES 2001–2004 MEC laboratory data files contained urinary iodine concentration (UIC) data.[27] Iodine nutritional status was determined using urinary iodine cutoffs defined by the World Health Organization and used by Centers for Disease Control and Prevention.[28,29] Three categories were defined as follows: iodine deficient, UIC <100 μg/l; adequate, 100–199 μg/l; and high iodine status, ≥200 μg/l.[27]

During the NHANES, spot urine samples were used for the assessment of iodine nutritional status. Determination of UIC was done by means of an Inductively Coupled Plasma Dynamic Reaction Cell Mass Spectroscopy. The laboratory method used for the determination of UIC is publicly available.[22,26]

Statistical analysis and confounding variable. To account for MEC complex probability sampling design and to apply MEC sampling weights, STATA 10.0 (STATA, College Station, TX) was used to estimate all descriptive and inferential statistics.[20] The SAS 9.1.3 (SAS Institute, Cary, NC) statistical software was used for data organization. In all analyses, the NHANES 2001–2002 and 2003–2004 MEC iodine subsample weights were halved and applied.[21,30] We initially performed gender-stratified descriptive comparisons of proportions that were iodine deficient, had high iodine level or had moderate dietary sodium intake for participants who satisfied the following exposure variables: (i) had history of hypertension but was not hypertensive at the time of examination; (ii) had clinical hypertension at the time of examination; (iii) was restricting dietary salt intake. The referent groups were participants who had no history of hypertension, were normotensive, not restricting dietary salt, respectively. Multiple regression models were used to estimate mean UIC and dietary sodium intake whereas logistic regression models were used to estimate adjusted odds ratios for iodine deficiency, high iodine status, and moderate dietary sodium intake (sodium intake ≤2,400 mg/day) for the exposure variables 1–3 above. The referent group for the moderate sodium intake was those who had high sodium intake (sodium intake >2,400 mg/day). Significant differences among the continuous variables in the background data were tested using the overall *F*-test. Significant differences in the mean UIC and dietary sodium intake within the hypertension and salt restriction categories were tested using a *t*-test. For categorical data, Pearson's χ^2-test of independence with Rao and Scott correction was used to test for significant differences.[31,32] To improve estimator reliability, we controlled for age, body mass index, education, income, physical activity, and ethnicity in all the regression analyses. While a large and a small frame person can have the same BMI, they are not likely to consume the same quantity of food and therefore sodium. Therefore, dietary sodium intakes were adjusted for body weight whereas all other estimations were adjusted for BMI instead. Dietary sodium, urinary albumin, urinary creatinine, and urinary iodine data were log-transformed to achieve normality. Renal differences were corrected using urinary creatinine and urinary albumin concentrations. Controlling for urinary creatinine levels helped to correct for differences in hydration state such as dehydration or polyuria. Renal disease was corrected using urinary albumin and creatinine concentrations. Abnormal urinary albumin and creatinine concentrations are indicative of renal disease.[24,33,34] Due to small sample sizes for some ethnic groups, they were collapsed into three categories: black (non-Hispanic), Mexican-American and other Hispanics, and white (non-Hispanic). The white (non-Hispanic) category included other white ethnicity. Education was collapsed into three levels: less than high school degree, high school degree, and above high school degree. Physical activity was self-reported as less than average, same as average, and greater than the average American. Although physical activity was self-reported, it has been found reliable in many studies.[35,36] The referent groups for the categorical confounding variables were high school degree, average physical activity level, and white (non-Hispanic). All categorical confounding variables were examined as indicator variables. Income was examined as a continuous variable in the form of poverty income ratio, a ratio of the federal poverty threshold provided by the Bureau of Census. Age, body weight, BMI, urinary creatinine, and urinary albumin concentrations were examined as continuous variables. In all analyses, statistical significance was tested at $P < 0.05$.

RESULTS

Sample characteristics

The characteristics of the participants are presented in **Table 1**. Among this sample, 24.7% of the men and 26.0% of women had hypertension. Of these, 15.5% of the men and 15.6% of the women were taking blood pressure medication. Dietary salt restriction was reported by 13.6% of the men and 12.8% of the women. Some of the men (5.9%) and women (4.6%) restricting dietary salt were normotensive at the time of examination. Overall, 25.4 and 32.5% of the men and women, respectively, had moderate dietary sodium intake (sodium ≤2,400 mg/day). On the whole, 26.1% of the men restricting dietary salt intake had moderate sodium intake (sodium ≤2,400 mg/day), compared to 24.9% for men not restricting salt intake. However, 41.3% of the women restricting dietary salt intake had moderate sodium intake (sodium ≤2,400 mg/day), compared to 28.9% of the women not restricting salt intake. The unadjusted mean UIC was (µg/l): men, 149.9 (s.e., 9.2; n = 996) and women, 122.2 (s.e., 8.9; n = 960). Overall, 25.0% of men and 40.4% of women had UIC <100 µg/l and thus were deemed iodine deficient.[27]

Blood pressure, dietary salt restriction, and iodine nutritional status

The initial descriptive comparisons did not show significant associations between hypertension conditions and iodine nutritional status. It is worth mentioning however, that a substantial percentage of women restricting dietary salt were iodine deficient, 47.7%, compared with women not restricting dietary salt, 39.4%, (**Table 2**). The adjusted mean dietary sodium intake and UIC of participants by hypertension categories are shown in **Table 3**. In men and women, current hypertension or having a history of hypertension did not associate with statistically significant differences in dietary sodium intake and UIC, compared with those without history of or who have current hypertension, respectively.

Table 4 shows the adjusted mean dietary sodium intake and UIC of participants by salt restriction status. In both men and women, dietary salt restriction did not associate with statistically significant decreases in the adjusted mean dietary sodium intakes. Among men, dietary salt restriction did not associate

Table 1 | Background characteristics of the study participants by iodine nutritional status and gender

	Men				Women			
Background characteristic	Iodine deficient (n = 255)[a]	Normal iodine level (n = 340)	High iodine status (n = 401)	Men's total (n = 996)	Iodine deficient (n = 369)	Normal iodine level (n = 291)	High iodine status (n = 300)	Women's total (n = 960)
%								
Ethnicity								
White (non-Hispanic)[b]	25.2	32.8	42	74.4	42.6*	27.3	30.2	75.3
Black (non-Hispanic)	30.3	37.2	32.5	10.9	37.7*	38.5*	23.8	12.3
Hispanic[c]	19.8	37.8	42.4	14.7	30.1	34.8	35.1	12.4
Education								
Less than high school	23.9	30.5	45.6*	16.9	32.1	27	40.9*	16
High school degree	27.3	34.8	37.9*	25.1	34.6	38.0*	27.4	23.7
Above high school	24.3	34.5	41.2*	57.9	44.8*	27	28.2	60.3
Physical activity								
Less than average	27.9	33	39.1*	34.5	44.9*	29.1	26	32.7
Average	20.9	33.9*	45.2*	19.6	34.9*	24.6	40.5*	28
Above average	23.8	34.9*	41.3*	45.9	40.9*	33.5	25.7	39.3
				Mean (s.e.)[d]				
Age (years)	41.4 (0.9)	39.2 (0.7)	38.7 (0.7)	39.5 (0.7)	39. 7 (0.9)	39.4 (0.9)	40.4 (0.8)	39.6 (0.9)
BMI (kg/m^2)	26.9 (0.5)	27.0 (0.4)	26.6 (0.5)	26.8 (0.3)	26.6 (0.5)	27.3 (0.7)	27.0 (0.6)	26.9 (0.3)
Body weight (kg)	83.7 (1.4)	86.4 (1.5)	83.5 (1.6)	84.6 (1.0)	74.6 (1.5)	76.5 (1.6)	76.6 (1.9)	75.8 (1.1)
Income (PIR)[e]	3.3 (0.1)	3.3 (0.1)	3.0 (0.1)	3.3 (0.1)	3.2 (0.1)	2.8 (0.1)	2.9 (0.1)	2.9 (0.1)
Urinary albumin (mg/dl)	9.8 (1.1)	8.5 (1.0)	9.2 (1.2)	9.1 (1.0)	10.1 (1.1)	8.8 (1.1)	8.8 (1.1)	9.3 (1.1)
Urinary creatinine (mg/dl)	116.4 (7.0)	117.30 (5.3)	116.3 (5.7)	116.7 (5.7)	119.8 (4.8)	104.0 (6.7)	109.4 (5.4)	111.6 (6.5)
Dietary sodium (mg/day)	3,240.3 (144.2)	3,344.6 (135.6)	3,471 (134.9)	3,348.8 (96.4)	2,908.3 (131.4)	2,989.3 (143.4)	3,108.3 (111.3)	2,998.3 (80.0)

Table contents are based on data from participants in the NHANES 2001–2004 blood pressure and iodine samples, ages 20–60 years with complete data on urinary iodine, blood pressure, and gender. NHANES design corrections and MEC subsample weights were applied.
BMI, body mass index; MEC, mobile examination center; NHANES, National Health and Nutrition Examination Survey.
[a]Number of subjects. [b]White (non-Hispanic) includes other white ethnicity. [c]Includes Mexican Americans and other Hispanics. [d]s.e. corrected using Taylor linearized method to account for complex survey design. [e]PIR is poverty income ratio; income was expressed as a ratio of the federal poverty threshold provided by the Bureau of Census.
*Significantly higher within the same row. Pearson's χ^2-test of independence with Rao and Scott correction was used to test for significant differences within the categorical variables, whereas the overall F-test was used to test for significant differences in age, body mass index, income, dietary sodium, urinary creatinine, and urinary albumin concentrations across levels of iodine status. Within rows, percentages may not add up to 100 because of rounding. In all analysis, significant differences were tested at $P < 0.05$.

with a statistically significant decrease in the adjusted mean UIC compared with men not restricting dietary salt intake. However, among women, dietary salt restriction associated with a statistically significant decrease in the adjusted mean UIC compared with women not restricting dietary salt intake (**Table 4**).

Results of the logistic regression analysis, which controlled for confounders, indicated that, in both men and women, current hypertension or having a history of hypertension was not significantly associated with likelihood of iodine deficiency, high iodine status, or moderate sodium intake, compared with those without current or history of hypertension (**Table 3**). Among men, salt restriction did not associate significantly with likelihood of iodine deficiency, high iodine status, or moderate sodium intake compared with men not restricting dietary salt intake (**Table 4**). However, women who were restricting dietary salt were more likely to have moderate sodium intake, $P = 0.02$, have lower adjusted mean UIC, $P = 0.01$, and be iodine deficient, $P = 0.03$, compared with women not restricting dietary salt intake (**Table 4**).

DISCUSSION

Significant findings

Current hypertension *per se* or having a history of hypertension did not associate significantly with iodine nutritional status in both men and women. However, dietary salt restriction among women associated significantly with moderate salt intake and iodine deficiency. This study provides evidence

Table 2 | Iodine nutritional status of men and women by hypertension conditions and dietary salt restriction

	Men*								Women*							
	Iodine deficient		Normal iodine level		High iodine status		Men's total		Iodine deficient		Normal iodine level		High iodine status		Women's total	
	n[a]	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
History of hypertension[b]																
Yes	54	24.7	56	31.1	77	44.2	187	22	85	45.1	59	25.3	57	29.5	201	21.8
No	151	23.4	229	35.1	266	41.5	646	78	240	39.8	192	29.1	206	31.1	638	78.2
Current hypertension																
Yes	78	29.5	86	31.1	99	39.4	263	24.7	108	41.2	82	31	79	27.8	269	26.9
No	177	23.5	254	34.9	302	41.6	733	75.3	261	40.15	209	29.1	221	30.8	691	73.1
Dietary salt restriction[c]																
Yes	41	25.8	39	30.8	55	43.4	135	13.6	66	47.7	41	22.2	42	30.2	149	12.8
No	214	25	301	34.5	346	40.5	861	86.4	303	39.4	250	30.7	258	30	811	87.2

Table contents are based on data from participants in the NHANES 2001–2004 blood pressure and iodine subsamples, ages 20–60 years with complete data on urinary iodine, blood pressure, and gender. NHANES design corrections and MEC urinary iodine subsample weights were applied.
MEC, mobile examination center; NHANES, National Health and Nutrition Examination Survey.
[a]Number of subjects. [b]Ever told has hypertension but did not have hypertension at the time of examination. [c]Some of the participants restricting dietary salt were not hypertensive at the time of examination.
*Pearson's χ^2-test of independence with Rao and Scott correction was used to test for significant differences between proportions that were with and without hypertension or salt restriction. The outcome variable was iodine nutritional status. The referent groups were those without history of hypertension, without current hypertension, or without salt restriction. Within rows, percentages may not add up to 100 because of rounding. No significant differences were observed within each hypertension or salt restriction category, $P > 0.05$.

that, among this sample, dietary salt restriction associates with iodine deficiency in women.

Interpretations and relationship to published literature

Although the mean UIC for men and women were both above the cutoff for iodine deficiency, the prevalence of iodine deficiency among the participants was high, especially among the women. The high prevalence of iodine deficiency among adults has serious health repercussions because the outcome of iodine deficiency is IDD.[13–16] Literature on studies that link dietary salt restriction to iodine nutritional status is scarce. One study in Poland reported a decrease in UIC among persons consuming limited amount of iodized salt as well as among hypertension patients.[37] In the present study, we provide evidence that the association between salt restriction and iodine deficiency may be true for women but may not be for men in this population. We observed that women tended to have lower UIC than men (**Table 3**), implying that salt restriction among women could have greater overall effect on the already lower iodine levels. It is possible that the different associations observed for men and women may be due to differences in absolute levels of iodine. It is thus likely that dietary salt restriction may associate with iodine deficiency in persons with limited iodine intake irrespective of gender. A recent study has ingeminated the possible difficulties in maintaining essential mineral balance, including iodine, while cutting salt to achieve sodium balance in hypertensives.[38] This is partly because salt is a source of essential minerals such as iodine, iron, zinc, and manganese.[13,14] Thus cutting salt to achieve sodium balance may mean an indirect curtailing of the intake of such minerals.

In men, dietary salt restriction did not associate with moderate dietary sodium intake (sodium intake ≤2,400 mg/day). In women, however, dietary salt restriction associated with moderate dietary sodium intake. Even though salt restriction did not show a statistically significant decrease in dietary sodium intake in men, it was limiting enough in women to influence iodine nutritional status. It is likely that those restricting salt may have more control on salt used at home, most of which is iodized,[11,39] than the mostly uniodized "hidden" salt used in processed foods and restaurants.[40] Between 50 and 70% of the US population choose iodize salt for domestic use.[11,39] On the average, iodized salt contributes about 50 µg iodine/day[11] which is substantial considering the fact that good dietary sources of iodine are few. Despite the presence of iodine absorption inhibitors, goitrogens and other antithyroid factors in some plant foods, persons with limited salt and thus iodine intake may obtain some iodine from root and leafy vegetables grown on iodine-rich soils, and sea foods like sea fish and kelp (seaweed) from uncontaminated sources. Dairy products from animals nurtured on iodine-rich feed supplements could also be good sources of iodine.

Strengths and limitations

This is the first study that looks at the association between dietary salt restriction and iodine deficiency in the United States in an era in which the prevalence of overweight and obesity has increased with an attendant increase in the prevalence of hypertension. In this study, participants were sampled from all over the United States and were representative of the US civilian population. Other strengths are that many possible confounding variables were controlled in this analysis, and that the analysis was gender stratified.

The limitations of the study include the fact that some cell sizes were small during the analysis. Thus, generalization of

Table 3 | Current or history of hypertension among men and women, corresponding dietary sodium intake, urinary iodine concentration, and likelihood of iodine deficiency or high iodine status

Hypertension status*	Dietary sodium intake (mg/day)		Moderate dietary sodium intake (≤2,400 mg/day)		Urinary iodine concentration (µg/l)	Iodine deficient (<100 µg/l)		High iodine status (>200 µg/l)	
	n	Mean (s.e.)[a]	OR[b] (95% CI)	*P* value	Mean (s.e.)	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Men									
Hypertension history[c]									
Yes	187	3,218.2 (132.3)	0.69 (0.41–1.17)		154.5 (8.7)	1.37 (0.53–3.82)	0.46	1.45 (0.88–2.60)	0.16
No	809	3,202.4 (95.3)	1.00 (ref.)	0.35	154.1 (8.3)	1.00 (ref.)		1.00 (ref.)	
Current hypertension									
Yes	263	2,984.3 (125.1)	1.23 (0.78–2.10)	0.1	148.5 (8.1)	1.25 (0.76–2.04)	0.37	1.12 (0.70–1.82)	0.64
No	733	3,211.8 (104.2)	1.00 (ref.)		154.6 (7.9)	1.00 (ref.)		1.00 (ref.)	
Women									
Hypertension history[c]									
Yes	201	2,909.4 (135.1)	1.14 (0.72–1.80)	0.27	131.8 (7.3)	0.94 (0.32–2.82)	0.92	0.60 (0.19–1.89)	0.37
No	759	2,919.2 (97.4)	1.00 (ref.)		138.1 (7.6)	1.00 (ref.)		1.00 (ref.)	
Current hypertension									
Yes	269	2,862.6 (134.2)	1.34 (0.81–2.14)	0.15	129.6 (7.8)	1.28 (0.87–2.43)	0.29	0.81 (0.52–1.26)	0.35
No	691	2,926.8 (112.4)	1.00 (ref.)		135.0 (7.7)	1.00 (ref.)		1.00 (ref.)	

Table contents are based on data from participants in the NHANES 2001–2004 blood pressure and iodine subsamples, ages 20–60 years with complete data on urinary iodine concentration, blood pressure, and gender. NHANES design corrections and MEC subsample weights were applied.
95% CI, 95% confidence interval; MEC, mobile examination center; NHANES, National Health and Nutrition Examination Survey; OR, odds ratio.
[a]s.e. corrected using Taylor linearized method to account for complex survey design. [b]OR is adjusted for age, body mass index, education, ethnicity, income, level of physical activity, urinary albumin, and urinary creatinine concentrations, with the exception of dietary sodium intake which was adjusted for body weight. [c]Ever told had hypertension by a health professional but did not have hypertension at the time of examination.
*Even though there were slight decreases, the differences in dietary sodium intake and urinary iodine concentration by hypertension status were not statistically significant, and no significant associations with iodine deficiency, high iodine status, or dietary sodium intake were observed, $P > 0.05$. The referent groups were those without history or current hypertension. Mean values were adjusted for body mass index, except for dietary sodium intake which was adjusted for body weight.

Table 4 | Dietary sodium intake, urinary iodine concentration, and likelihood of iodine deficiency or high iodine status by dietary salt restriction

Salt restriction[a]		Dietary sodium intake (mg/day)	Moderate dietary sodium intake (≤2,400 mg/day)		Urinary iodine concentration (µg/l)	Iodine deficient (<100 µg/l)		High iodine status (>200 µg/l)	
	n	Mean (s.e.)	OR[b] (95% CI)	*P* value	Mean (s.e.)	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Men									
Yes	135	2,986.0 (144.3)	1.08 (0.68–2.02)	0.48	149.7 (8.6)	1.14 (0.67–1.90)	0.88	1.23 (0.73–2.81)	0.28
No	861	3,201.6 (96.3)	1.00 (ref.)		154.7 (8.8)	1.00 (ref.)		1.00 (ref.)	
Women									
Yes	149	2,778.2 (142.6)	1.60* (1.09–2.40)	0.02	119.5 (7.2)**	1.79* (1.12–3.93)	0.03	1.18 (0.63–2.22)	0.6
No	811	2,919.3 (98.4)	1.00 (ref.)		140.6 (8.4)	1.00 (ref.)		1.00 (ref.)	

Values are based on data from participants in the NHANES 2001–2004 blood pressure and iodine subsamples, ages 20–60 years with complete data on urinary iodine, blood pressure, and gender. NHANES design corrections and MEC subsample weights were applied.
95% CI, 95% confidence interval; MEC, mobile examination center; NHANES, National Health and Nutrition Examination Survey; OR, odds ratio.
[a]Some of the participants restricting dietary salt were not hypertensive at the time of examination. [b]OR is adjusted for age, body mass index, education, ethnicity, income, level of physical activity, urinary albumin, and urinary creatinine concentrations. The referent group was those not restricting dietary salt intake. Mean values and OR were adjusted with body weight instead of body mass index in the case of the dietary sodium intake analysis.
*Significantly higher than those not restricting dietary salt intake, $P < 0.05$. **Significantly lower than those not restricting dietary salt intake, $P = 0.01$.

the results to the entire US population should be made with caution. Only a few of the normotensive participants were restricting dietary salt intake. Therefore, the association between salt restriction and iodine nutritional status could not be partitioned for only hypertensives. Identification of dietary salt restriction was based on self-reported data which is impacted by reporting bias in some cases. However, self-reported data have been found applicable and reliable in many studies.[2,20,35–37] It is worth noting that, even though the analysis was based on UIC, a 24-h dietary recall was used for the estimation of dietary sodium intake. However, a salt consumption survey may give a better assessment of usual dietary sodium intake. As in many other epidemiological studies, not all possible confounders, such as use of diuretics, were controlled in this study. The likelihood of women retaining more iodine and thus excreting less iodine in urine has not been ascertained. Thus the association between dietary salt restriction and iodine deficiency among women can be due to other factors other than salt restriction. Despite these limitations, this study provides substantial evidence that salt restriction associates with low urinary iodine levels and thus iodine deficiency, especially among individuals who are low on iodine such as women.

The observation that salt restriction among women associated with iodine deficiency has an enormous significance because the offspring of iodine deficient women are at risk of IDD, including developmental arrest, neurological damage, deaf and mutism, decreased mental capacity, and infantile cretinism.[13–15] The outcome of this study implies that the mass voluntary domestic salt iodization that was necessary for the prevention of goiter and other IDD in the United States in the 1920's is still relevant today.[13,14,17]

In summary, dietary salt restriction associated with iodine deficiency among women but not among men. Alternative sources of iodine should be suggested to those who need to cut dietary salt for hypertension and for other health reasons. Among those iodine deficient, health professionals should enquire about dietary salt restriction and other dietary behaviors that impact iodine nutrition.

Disclosure: The authors declared no conflict of interest.

1. Moser M, Franklin SS. Hypertension management: results of a new national survey for the hypertension education foundation: Harris interactive. *J Clin Hypertens (Greenwich)* 2007; 9:316–323.
2. Qureshi AI, Surib MFK, Kirmani JF, Divani AA. Prevalence and trends of prehypertension and hypertension in United States: National Health and Nutrition Examination Surveys 1976 to 2000. *Med Sci Monit* 2005; 11: CR403–CR409.
3. Fang EN, Law SK, Walt JG, Chiang TH, Williams EN. The prevalence of glaucomatous risk factors in patients from a managed care setting: a pilot evaluation. *Am J Manag Care* 2008; 14:S28–S36.
4. Ong KL, Cheung BM, Man YB, Lau CP, Lam KS. Prevalence, awareness, treatment, and control of hypertension among United States adults 1999-2004. *Hypertension* 2007; 49:69–75.
5. Havas S, Roccella EJ, Lenfant C. Reducing the public health burden from elevated blood pressure levels in the United States by lowering intake of dietary sodium. *Am J Public Health* 2004; 94:19–22.
6. Whelton PK, He J, Appel LJ, Cutler JA, Havas S, Kotchen TA, Roccella EJ, Stout R, Vallbona C, Winston MC, Karimbakas J. Primary prevention of hypertension: clinical and public health advisory from The National High Blood Pressure Education Program. *JAMA* 2002; 288:1882–1888.
7. National High Blood Pressure Education Program Working Group report on primary prevention of hypertension. *Arch Intern Med* 1993; 153:186–208.
8. Hajjar I, Kotchen T. Regional variations of blood pressure in the United States are associated with regional variations in dietary intakes: the NHANES-III data. *J Nutr* 2003; 133:211–214.
9. Dahl LK. Possible role of salt intake in the development of essential hypertension. 1960. *Int J Epidemiol* 2005; 34:967–72; discussion 972.
10. Perry IJ, Beevers DG. Salt intake and stroke: a possible direct effect. *J Hum Hypertens* 1992; 6:23–25.
11. Dunn JT. Guarding our nation's thyroid health. *J Clin Endocrinol Metab* 2002; 87:486–488.
12. International Council for the Control of Iodine Deficiency Disorders (ICCIDD). Towards a Global Elimination of Brain Damage Due to Iodine Deficiency. <http://www.iccidd. org/pages/protecting-children/fortifying-salt/how-salt-is-iodized/iodate-or-iodide--more-detail.php>. Accessed 25 July 2009.
13. Mannar MG, Dunn JT. *Salt Iodization for the Elimination of Iodine Deficiency.* ICCIDD/MI/UNICEF/WHO, The Netherlands, 1995.
14. Dasgupta PK, Liu Y, Dyke JV. Iodine nutrition: iodine content of iodized salt in the United States. *Environ Sci Technol* 2008; 42:1315–1323.
15. Hollowell JG, Staehling NW, Hannon WH, Flanders DW, Gunter EW, Maberly GF, Braverman LE, Pino S, Miller DT, Garbe PL, DeLozier DM, Jackson RJ. Iodine nutrition in the United States. Trends and public health implications: iodine excretion data from National Health and Nutrition Examination Surveys I and III (1971-1974 and 1988-1994). *J Clin Endocrinol Metab* 1998; 83:3401–3408.
16. Dunn JT, Delange F. Damaged reproduction: the most important consequence of iodine deficiency. *J Clin Endocrinol Metab* 2001; 86:2360–2363.
17. Feyrer J, Politi D, Weil DN. The Economic Effects of Micronutrient Deficiency: Evidence From Salt Iodization in the United States. <http://www.econ.brown. edu/students/Dimitra_Politi/job_market/Dimitra_Politi_Working_Paper.pdf> (2008). Accessed 22 July 2009.
18. Hetzel B, Maberly G. *Iodine*. In Mertz C (ed). *Trace Elements in Human and Animal Nutrition*. Academic Press: New York, 1986, pp. 139–208.
19. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. <http://www.cdc.gov/nchs/nhanes/nhanes2003-2004/quex03 _04.htm> (2004). Accessed 7 July 2009.
20. Hertz RP, Unger AN, Cornell JA, Saunders E. Racial disparities in hypertension prevalence, awareness, and management. *Arch Intern Med* 2005; 165: 2098–2104.
21. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics. National Health and Nutrition Examination Survey analytical guide 2004. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. <http://www.cdc.gov/nchs/data/nhanes/nhanes_03_04/ nhanes_ analytic_guidelines_dec_2005.pdf> (2005). Accessed 4 August 2009.
22. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). Urinary iodine sub-sample notes. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. <http://www. cdc.gov/nchs/data/nhanes/nhanes_subsample_ notes.pdf> (2002). Accessed 4 August 2009.
23. Blum M, Averbuch M, Wolman Y, Aviram A. Protein intake and kidney function in humans: its effect on 'normal aging'. *Arch Intern Med* 1989; 149:211–212.
24. Coresh J, Wei GL, McQuillan G, Brancati FL, Levey AS, Jones C, Klag MJ. Prevalence of high blood pressure and elevated serum creatinine level in the United States: findings from the third National Health and Nutrition Examination Survey (1988-1994). *Arch Intern Med* 2001; 161:1207–1216.
25. Joint National Committee. The sixth report of the Joint National Committee on prevention, evaluation, and treatment of high blood pressure. *Arch Intern Med* 1997; 157:2413–2446.
26. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics. Physician examination manual. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. <http://www.cdc.gov/nchs/data/nhanes/nhanes_03_04/PE.pdf> (2003). Accessed 1 August 2009.
27. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). Urinary iodine measurement documentation. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention. <http: //www.cdc.gov/nchs/data/nhanes/nhanes_03_04/l06uio_c. pdf> (2004). Accessed 3 August 2009.
28. World Health Organization. Assessment of Iodine Deficiency Disorders and Monitoring Their Elimination: A Guide for Program Managers. 3rd ed. Geneva (Switzerland): World Health Organization (WHO/NHD/01.1). <http://www. whqlibdoc. who.int/ publications/2007/9789241595827_eng.pdf> (2007). Accessed 14 March 2008.
29. Centers for Disease Control and Prevention (CDC). National Report on Biochemical Indicators of Diet and Nutrition in the U.S. Population 1999–2002. Department of Health and Human Services. NCEH Pub. No. 08-2982c. <http://www.cdc.gov/ nutritionreport/download.html> (2008). Accessed 1 August 2009.
30. Alaimo K, Olson CM, Frongillo EA Jr. Low family income and food insufficiency in relation to overweight in US children: is there a paradox? *Arch Pediatr Adolesc Med* 2001; 155:1161–1167.
31. Flores G, Olson L, Tomany-Korman SC. Racial and ethnic disparities in early childhood health and health care. *Pediatrics* 2005; 115:e183–e193.
32. Rao JNK, Scott AJ. The analysis of categorical data from complex sample surveys: chi-squared goodness-of-fit and independence in two-way tables. *J Am Stat Assoc* 1981; 76:221–230.

33. Barclay L. Glomerular Filtration Rate, Urinary albumin may help predict end-stage renal disease. *J Am Soc Nephrol*, published online 8 April 2009.
34. Hallan SI, Ritz E, Lydersen S, Romundstad S, Kurt Kvenild K, Orth SR. Combining GFR and albuminuria to classify CKD improves prediction of ESRD. *J Am Soc Nephrol* 2009; 20:1069–1077.
35. Jones SJ, Frongillo EA. Food insecurity and subsequent weight gain in women. *Public Health Nutr* 2007; 10:145–151.
36. van Dam RM, Willett WC, Manson JE, Hu FB. The relationship between overweight in adolescence and premature death in women. *Ann Intern Med* 2006; 145:91–97.
37. Grzesiuk W, Dabrowska J, Osikowska-Loksztejn M, Kondracka A, Kolasinska K, Bar-Andziak E. [Effectiveness of iodine prophylaxis in hypertensive patients on salt restricted diet]. *Pol Arch Med Wewn* 2005; 113: 147–154.
38. Jessani S, Hatcher J, Chaturvedi N, Jafar TH. Effect of low vs. high dietary sodium on blood pressure levels in a normotensive Indo-Asian population. *Am J Hypertens* 2008; 21:1238–1244.
39. Institute of Medicine (IOM), Food and Nutrition Board. *Dietary Reference Intakes: Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. National Academy Press: Washington, DC, 2001.
40. The Public Health Committee of the American Thyroid Association. Iodine supplementation for pregnancy and lactation – United States and Canada: recommendations of the American Thyroid Association. *Thyroid* 2006; 16:949–951.