



Sources of Sodium in US Adults From 3 Geographic Regions

Editorial, see p 1784

BACKGROUND: Most US adults consume excess sodium. Knowledge about the dietary sources of sodium intake is critical to the development of effective reduction strategies.

METHODS: A total of 450 adults were recruited from 3 geographic locations: Birmingham, AL (n=150); Palo Alto, CA (n=150); and the Minneapolis–St. Paul, MN (n=150), metropolitan areas. Equal numbers of women and men from each of 4 race/ethnic groups (blacks, Asians, Hispanics, and non-Hispanic whites) were targeted for recruitment. Four record-assisted 24-hour dietary recalls were collected from each participant with special procedures, which included the collection of duplicate samples of salt added to food at the table and in home food preparation.

RESULTS: Sodium added to food outside the home was the leading source of sodium, accounting for more than two thirds (70.9%) of total sodium intake in the sample. Although the proportion of sodium from this source was smaller in some subgroups, it was the leading contributor for all subgroups. Contribution ranged from 66.3% for those with a high school level of education or less to 75.0% for those 18 to 29 years of age. Sodium inherent to food was the next highest contributor (14.2%), followed by salt added in home food preparation (5.6%) and salt added to food at the table (4.9%). Home tap water consumed as a beverage and dietary supplement and nonprescription antacids contributed minimally to sodium intake (<0.5% each).

CONCLUSIONS: Sodium added to food outside the home accounted for ~70% of dietary sodium intake. This finding is consistent with the 2010 Institute of Medicine recommendation for reduction of sodium in commercially processed foods as the primary strategy to reduce sodium intake in the United States.

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Clinical Perspective

What Is New?

- This study identifies the major sources of sodium in the diets of adults from 3 geographic regions in the United States.
- The study shows that sodium added to food outside the home accounts for more than two thirds of total sodium intake, whereas sodium added to food at the table and in home food preparation is a minor contributor to total sodium intake.
- Study findings align with a 2010 Institute of Medicine recommendation for reduction of sodium in commercially processed foods as the primary strategy to reduce sodium intake in the United States.

What Are the Clinical Implications?

- Commercially processed and restaurant foods should be the primary focus when educating patients on strategies for lowering sodium in the diet.
- For packaged food products, the Nutrition Facts panel may be useful in identifying lower-sodium products.
- When individuals eat outside the home, sodium content information for menu items should be requested and used as a guide in making food choices.
- Limiting salt added to food at the table and in home food preparation should also be encouraged, but patients should be advised that changes in these behaviors alone may not be sufficient for achieving the recommended intake level.

Sodium reduction has been a component of the Dietary Guidelines for Americans since 1980.¹ However, despite long-standing recommendations to limit sodium, most American adults and children consume too much. The prevalence of excess US dietary sodium intake in 2009 to 2012 ranged, by age group, from 85.0% to 93.7%.² On the basis of the presumption that most sodium consumed came from sodium added to commercially packaged and prepared foods, in 2010, the Institute of Medicine recommended gradual stepwise reductions of the sodium content of these foods as the primary strategy to reduce intake.³

Although numerous studies have examined the contributions to sodium intake of specific foods, food categories, and supplements/antacids,⁴⁻⁷ the amount of discretionary salt added by the consumer (eg, at the table) is difficult to estimate. Thus, most studies are unable to estimate sodium intake from all sources and the relative contribution of each source. In 1991, Mattes and Donnelly⁸ reported that sodium added to food in commercial processing was the primary source of sodium in the diet (77.0% of total intake), followed by sodium inherent in food (11.6%), sodium from salt added to food

at the table (6.2%), sodium from salt added to food in home cooking (5.1%), and water ingested as a beverage (0.1%).

Given the changes in national food production and consumption patterns in the 25 years since the Mattes and Donnelly⁸ article was published, an update is warranted. Furthermore, the sample size in that study was small (n=62 adults), and participants were homogeneous (predominately female and white from 1 US geographic region). Thus, we conducted a study to provide contemporary data on the major sources contributing to total sodium intake in a larger, more diverse sample of adults, with a primary focus on the proportion of total intake from sodium added to food outside the home (eg, added during commercial processing and preparation).

METHODS

Population and Recruitment

Between December 2013 and December 2014, a convenience sample of 450 adults was recruited from 3 geographic locations: Birmingham, AL (n=150); Palo Alto, CA (n=150); and the Minneapolis–St. Paul, MN (n=150), metropolitan areas. We recruited into the study equal numbers of women and men from each of 4 race/ethnic groups (blacks, Asians, Hispanics, and non-Hispanic whites).

Recruitment and data collection activities were conducted by the University of Alabama at Birmingham, Stanford University, and the University of Minnesota–Twin Cities. Recruitment strategies included invitations extended to university employees at each of the universities; study fliers posted around campus and at various community health fairs; university and community newspaper advertisements; and e-mail messages sent to study participants in past studies who had consented to being notified of future studies.

During a screening telephone interview, potential participants were determined eligible if they were between 18 (Palo Alto and Minneapolis–St. Paul) or 19 (Birmingham) and 75 years old, were generally healthy, and had a telephone. Exclusion criteria included being pregnant or breastfeeding or having chronic kidney disease or diabetes insipidus. Participants at all sites were offered a \$10 token of appreciation for each completed 24-hour diet recall interview (total of 4 interviews or \$40). All participants provided written informed consent. The institutional review board at each participating institution and the Centers for Disease Control and Prevention reviewed and approved the study procedures.

Overview of Data Collection and Measurements

The dietary assessment procedures were designed to allow quantification of the amount and proportion of sodium from the following sources: (1) salt added to food at the table; (2) salt added to food in home food preparation; (3) sodium from home tap water consumed as a beverage; (4) sodium that is inherent to food; (5) sodium that is added to food in processing outside the home; and (6) sodium from dietary supplements and nonprescription antacids.

Participants attended 1 clinic visit and completed 4 record-assisted telephone 24-hour dietary recall interviews over an 11-day period. Duplicate samples of salt added to food at the table and in home food preparation were collected by the participant on each of the 4 days for which dietary recalls were collected.

Before the clinic visit, participants were asked if their home drinking water was from a private well. In addition, they were asked if their tap water was softened or if it was filtered by a home filtration system. If they responded affirmatively to 1 or 2 of these questions, they were instructed to bring a sample of their home tap water to their clinic visit using a study provided collection kit.

At the clinic visit, tap water samples were collected from participants as appropriate, and a questionnaire was administered to obtain information about demographics, smoking, and general health. Height was measured with a wall-mounted stadiometer, and weight was measured with a digital scale. Four telephone 24-hour dietary recall interviews were scheduled with the participants within the next 11 days. Three of the recalls were scheduled to capture eating for a weekday, and 1 recall was scheduled to capture eating on a weekend day. Participants were given a food record form to complete the day before each scheduled recall. Participants were instructed to record on the form the foods eaten and, for foods to which salt was added in home preparation, the total yield (total amount prepared). Participants were given salt collection kits to use in collecting duplicate samples of salt added to their food at the table and in home food preparation. They were instructed to collect the duplicate samples the day before each scheduled telephone recall, thus aligning collection with the 24-hour dietary recall period.

Collection of Duplicate Samples of Salt

For collection of salt added to food at the table, participants were instructed to shake the same amount of salt added to food at the table throughout the day into a plastic resealable collection bag provided by the study for this purpose. The same instructions were provided to collect duplicate amounts of salt added to food in home food preparation, with a separate bag used for each food item prepared with salt. In addition, participants were asked to record the name of the food item and to share the instructions and collection bags with anyone else in their household who may have prepared food at home the day of collection.

Preaddressed postage-paid envelopes were provided for mailing the duplicate salt samples to the study center. At each study center, the contents of each bag were weighed on a digital scale, and the weight was entered into a spreadsheet.

Dietary Recall Collection

All 24-hour dietary recalls were administered by staff at the University of Minnesota Nutrition Coordinating Center who were trained and certified in the administration of dietary recalls following study procedures. Nutrition Data System for Research software (developed by the Nutrition Coordinating Center, University of Minnesota, Minneapolis) was used for the administration and analysis of the recalls.⁹ Use of dietary supplements and nonprescription antacids over the 24-hour

recall period was assessed with the Nutrition Data System for Research Dietary Supplement Assessment Module.¹⁰

A variety of study-specific procedures were used during recall collection and processing to ensure that the sources of sodium of interest in this study could be ascertained. For example, participants were asked whether certain types of foods (baked goods, mixed dishes, salads, cooked vegetables, etc) had been prepared at home. If the food had been prepared at home, they were asked whether salt had been added in preparation. If it had, they were asked additional questions such as the yield of the recipe (how much was made).

Procedures for Calculating Sodium Intake by Source

Postrecall data processing procedures included calculating sodium from home tap water consumed as a beverage using participant-specific sodium content values for water. If the participant's home tap water was from a public water supply and he or she did not have a water softener or water filtration system in the home, the sodium content of water in his or her community as published in municipal water quality reports was used. For the remaining participants, the water sample turned in at the clinic visit was chemically analyzed (Traut Water Analysis Laboratory, Wiate Park, MN) to determine its sodium content.

Sodium from salt added to food at the table and in home food preparation was calculated from data from the duplicate salt samples. The duplicate sample data were added to the dietary recall records following a detailed set of data calculation and entry rules.

To estimate the amount of sodium in foods that was inherent and added outside the home, we adhered to the definitions developed by Mattes and Donnelly.⁸ These researchers defined inherent as sodium that is naturally present in food, and they defined sodium added to food outside the home as sodium contributed by the addition of sodium compounds in processing food outside the home. Examples of these compounds include sodium chloride, sodium benzoate, sodium phosphate, and sodium bicarbonate (baking soda). For every food, the proportion of sodium in the food considered to be added to food outside the home was estimated with a set of rules and procedures ([online-only Data Supplement](#)).

The validity of sodium intake estimates from the 24-hour dietary recalls was evaluated in a subset of study participants ($n=150$). Four 24-hour urine collections were obtained from the subset over the same time period that the 24-hour dietary recalls were collected. A full description of methods and findings of the validation component of the study is being reported in another article. To summarize key findings, mean 24-hour urinary sodium level in the subset was 3198 compared with 3325 mg/d from the 24-hour dietary recalls ($P=0.30$).

Data Analysis

For analyses carried out to describe sodium intake by source, means and mean proportions¹¹ were calculated. For each study participant, mean daily sodium intake overall and from each source was calculated by averaging the sodium intake estimates from the four 24-hour dietary recalls collected from the participant. One participant had only 3 recalls, and the average

was calculated from 3 instead of 4 recalls for this person. The mean estimates were used in analyses to characterize sodium intake. Because food intake is known to vary from weekday to weekend days, data were weighted so that results reflect the appropriate balance of weekday and weekend days in a week.

To characterize sources of sodium among population subgroups, analyses were carried out stratified by sex, age, level of education, race, and geographic region. Multivariate regression analyses were conducted to determine whether differences between groups were statistically significant ($P < 0.05$). If the overall F test for a demographic variable was significant, pairwise comparisons were conducted. Analyses were carried out with SAS version 9.3 (SAS Institute Inc, Cary, NC).

RESULTS

In accord with recruitment targets, 450 participants were recruited; one-half of participants were female, and one-third were from each of the 3 study sites (Table 1). The numbers of participants were approximately equal by age group, and about one-third of participants were

non-Hispanic white with approximately equal numbers of Asian, black, and Hispanic participants. Demographics by race are provided in Table 1. Recruitment targets for each ethnic group varied by site; consequently, distribution of race by site is unequal.

Mean total daily sodium intake in the sample was 3501 mg/d. Total sodium intake was similar across the age groups examined in multivariate-adjusted analyses (Table 2). There were differences in total sodium intake by sex (24% higher in men), race (higher in blacks and Asians compared with Hispanics), education level (17% higher in those with high school or lower level of education compared with college graduates), site (higher in Alabama compared with California and Minnesota), and body weight (17% higher in those who were obese compared with normal-weight participants).

The proportion of total sodium intake by source is presented in the Figure. For the total sample, sodium added to food outside the home (in commercial food processing, restaurant food preparation, etc) was the

Table 1. Demographic and Health Characteristics of Study Participants Overall and by Race

	Total Sample, n (%)	Asian, n (%)	Black, n (%)	Hispanic, n (%)	Non-Hispanic White, n (%)
Sex (n=450)					
Female	227 (50.4)	51 (51.0)	51 (51.0)	49 (50.0)	76 (50.0)
Male	223 (49.6)	49 (49.0)	49 (49.0)	49 (50.0)	76 (50.0)
Age, y (n=450)					
18–29	120 (26.7)	34 (34.0)	25 (25.0)	24 (24.5)	37 (24.3)
30–44	103 (22.9)	21 (21.0)	23 (23.0)	26 (26.5)	33 (21.7)
45–59	134 (29.8)	29 (29.0)	30 (30.0)	30 (30.6)	45 (29.6)
60–74	93 (20.7)	16 (16.0)	22 (22.0)	18 (18.4)	37 (24.3)
Highest level of education (n=448)					
High school graduate or less	61 (13.6)	2 (2.0)	22 (22.0)	28 (28.6)	9 (6.0)
Some college or technical school	97 (21.7)	9 (9.1)	41 (41.0)	20 (20.4)	27 (17.9)
College and above	290 (64.7)	88 (88.9)	37 (37.0)	50 (51.0)	115 (76.2)
Site (n=450)					
Alabama	150 (33.3)	0 (0)	75 (75.0)	0 (0)	75 (49.3)
California	150 (33.3)	75 (75.0)	0 (0)	48 (49.0)	27 (18.0)
Minnesota	150 (33.3)	25 (25.0)	25 (25.0)	50 (51.0)	50 (32.9)
History of hypertension (n=446)					
Yes	108 (24.2)	16 (16)	32 (33.0)	21 (21.4)	39 (25.8)
Body weight status* (n=450)					
Normal or underweight	153 (34.0)	58 (58.0)	18 (18.0)	26 (26.5)	51 (33.6)
Overweight	156 (34.7)	32 (32.0)	33 (33.0)	34 (34.7)	57 (37.5)
Obese	141 (31.3)	10 (10.0)	49 (49.0)	38 (38.8)	44 (29.0)
Home tap water (n=430)					
Softened	22 (5.1)	7 (7.7)	2 (2.0)	9 (10.0)	4 (2.7)

*Based on the following body mass index cut points: >30 kg/m², obese; 25 to 29.9 kg/m², overweight; and <25 kg/m², normal or underweight.

Table 2. Total Sodium Intake and Intake by Source by Demographic and Health Characteristics Adjusted for Sex, Age, Race, and Site (n=450)

	Sodium Intake, by Source, Mean (SE), mg/d							Energy, Mean (SE), kcal/d
	Total	Added at Table	Added in Home Food Preparation	Home Tap Water	Inherent to Food	Added Outside the Home	Dietary Supplements and Nonprescription Antacids	
Sex								
Female	3123 (91)	213 (32)	206 (30)	8 (1)	406 (13)	2169 (76)	7 (2)	1762 (40)
Male	3886 (92)	240 (32)	218 (30)	8 (1)	490 (14)	2748 (77)	2 (2)	2191 (41)
<i>P</i> value	<0.001	0.54	0.77	0.75	<0.001	<0.001	0.13	<0.001
Age, y								
18–29	3551 (127)	123 (44)	138 (41)*	7 (2)	490 (18)*	2660 (103)	5 (3)	2080 (55)*
30–44	3545 (136)	248 (47)	156 (44)*†	8 (2)	468 (20)*†	2496 (112)	3 (3)	1990 (59)*†
45–59	3510 (120)	251 (42)	264 (39)†‡	7 (1)	433 (17)†‡	2436 (98)	0.02 (3)	1998 (52)*†
60–74	3383 (144)	283 (50)	290 (46)‡	10 (2)	399 (21)‡	2242 (118)	8 (4)	1840 (62)†
<i>P</i> value	0.81	0.06	0.02	0.34	0.006	0.06	0.34	0.04
Race								
Asian	3551 (163)*	151 (56)*	206 (52)	10 (2)	440 (24)*	2559 (133)*	0.03 (4)	1936 (70)*†
Black	3798 (163)*	404 (57)*	240 (63)	8 (2)	448 (24)*	2561 (134)*	10 (4)	2023 (71)*†
Hispanic	3138 (153)†	186 (53)†	277 (49)	6 (2)	398 (22)*	2143 (125)†	0.3 (4)	1843 (66)*
Non-Hispanic white	3503 (118)*†	164 (41)†	126 (38)	9 (1)	506 (17)†	2571 (96)*	6 (3)	2105 (51)†
<i>P</i> value	0.03	0.002	0.06	0.28	0.001	0.03	0.40	0.03
Highest level of education								
High school graduate or less	3854 (192)*	509 (67)*	167 (64)	5 (2)	418 (28)	2536 (158)	11 (5)	1874 (84)
Some college or technical school	3809 (147)*	266 (50)†	195 (48)	7 (2)	442 (22)	2709 (121)	4 (4)	2088 (64)
College and above	3302 (88)†	139 (29)‡	211 (27)	9 (1)	457 (13)	2358 (72)	3 (2)	1964 (38)
<i>P</i> value	0.003	<0.001	0.83	0.26	0.47	0.05	0.34	0.09
Site								
Alabama	3899 (146)*	455 (51)*	295 (47)	1 (2)*	385 (21)*	2634 (120)	2 (4)*	1907 (63)
California	3247 (116)†	125 (40)†	195 (37)	9 (1)†	468 (17)†	2316 (94)	9 (3)†	1955 (50)
Minnesota	3346 (133)†	100 (46)†	147 (43)	14 (2)‡	490 (19)†	2425 (109)	6 (3)†	2068 (58)
<i>P</i> value	0.003	<0.001	0.12	<0.001	0.003	0.11	0.05	0.21
History of hypertension								
Yes	3715 (139)	326 (48)	157 (45)	10 (2)	445 (20)	2631 (112)	0.1 (4)	1994 (60)
No	3402 (79)	190 (27)	234 (26)	8 (1)	446 (11)	2374 (63)	6 (2)	1964 (34)
<i>P</i> value	0.06	0.02	0.15	0.32	0.95	0.05	0.20	0.67
Body weight status								
Normal or underweight	3254 (120)*	183 (42)	172 (39)	9 (1)	434 (18)	2340 (99)	0.3 (3)	1905 (62)
Overweight	3439 (112)*	253 (39)	188 (36)	8 (1)	453 (16)	2410 (92)	7 (3)	2002 (49)
Obese	3805 (121)†	243 (42)	278 (39)	7 (1)	457 (18)	2628 (99)	5 (3)	2022 (53)
<i>P</i> value	0.007	0.44	0.13	0.75	0.62	0.12	0.27	0.26

*†‡Values with different superscripts are statistically significantly different ($P<0.05$).

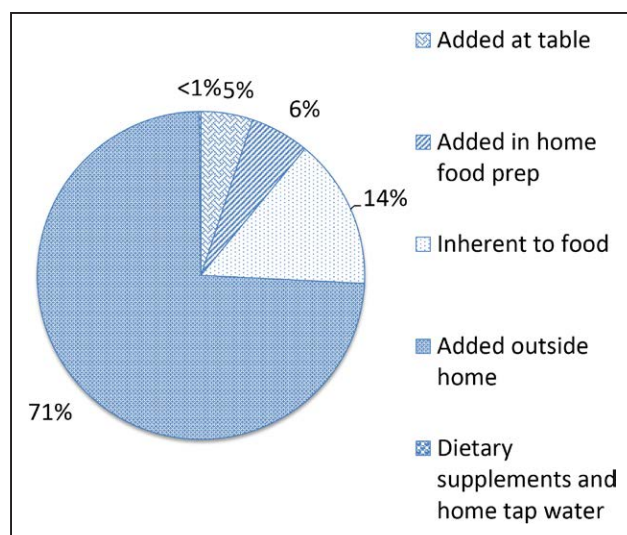


Figure. Proportion of total sodium intake from various sources (n=450).

leading source of sodium, accounting for 70.9% of total sodium intake. Sodium inherent to food was the next highest contributor (14.2%), followed by salt added in home food preparation (5.6%) and salt added to food at the table (4.9%). Home tap water consumed as a beverage and dietary supplements and nonprescription antacids each contributed <0.5% to total sodium intake.

Numerous differences in sources between demographic groups were found in multivariate-adjusted analyses (Table 3). However, for all groups, sodium added to food outside the home was the leading contributor to sodium intake (66.3%–75.0%); and sodium inherent to food, salt added in home food preparation, and salt added to food at the table were the next largest contributors. In all groups, sodium from home tap water and sodium from dietary supplements were minor contributors (<0.5% for most groups).

Sodium added to food outside the home was a higher proportion of total sodium intake among those 18 to 24 years of age (75.0%) compared with those in the older age groups (67.4%–70.5%). Conversely, salt added to food in home food preparation and salt added at the table were larger contributors to total sodium intake among older compared with younger participants.

Numerous differences in sodium sources by race were found. Asians and non-Hispanic whites obtained less sodium from salt added to food at the table (3.3% and 4.0%, respectively), whereas blacks obtained a greater share of sodium from this source (8.0%) compared with these groups. Non-Hispanic whites obtained less sodium from salt added to food in home preparation (3.5%) compared with Hispanics (8.6%).

Multiple differences in sources of sodium by education level were evident. Those with the lowest level of education obtained a higher proportion of sodium from salt added to food at the table compared with those with

a higher level of education. In contrast, sodium inherent in food and sodium from home tap water made up smaller proportions of total sodium in those with a high school degrees or less education compared with those with a higher level of education.

A number of differences in sources of sodium by site were evident. Most notable is that participants in Alabama obtained a greater proportion of sodium from salt added to food at the table (9.5%) compared with participants in California (3.4%) and Minnesota (2.3%). Analyses were carried out to evaluate whether sources of sodium differed on weekdays and weekend days, and proportions were found to be similar for weekdays and weekend days.

DISCUSSION

Sodium added to food outside the home was the leading source of sodium in this diverse sample, accounting for more than two-thirds (70.9%) of total sodium intake. Although this source of sodium was a smaller proportion of sodium intake in some subgroups, it was the leading contributor for all groups (range, 66.3%–75.0%). These findings are consistent with those of the Mattes and Donnelly⁸ study. In that study, which consisted of a sample of predominately female and white adults from 1 US geographic region (n=62), 77% of total sodium intake was attributable to sodium added to food outside the home. Like Mattes and Donnelly,⁸ we found sodium inherent to food, sodium from salt added to food at the table, sodium from salt added in home food preparation, and sodium from water consumed as a beverage to be notably smaller contributors than sodium added to food outside the home.

We found statistically significant differences in sources of sodium intake among demographic subgroups. In some cases, the differences observed were modest and may be of limited public health significance. In other cases, the differences were sizable and potentially worthy of consideration in the design of sodium reduction interventions. Most notable is that although sodium added to food outside the home accounted for the majority of intake, sodium from salt added to food at the table accounted for 9.5% of total sodium intake for those from the Alabama site (455 mg/d). If sodium from salt added to food at the table were reduced by 400 mg/d among study participants residing in Alabama, notable reductions in blood pressure and the incidence of coronary heart disease, myocardial infarction, and stroke might be expected according to projections of dietary sodium reductions reported by Bibbins-Domingo et al.¹² Whether salt added at the table is a significant source of sodium intake among adults in Alabama, or potentially in other geographic areas, warrants further investigation.

Table 3. Proportion of Total Sodium Intake From Various Sources by Demographic and Health Characteristics Adjusted for Sex, Age, Race, and Site (n=450)

	Total Sodium Intake, by Source, Mean (SE), %					Dietary Supplements and Nonprescription Antacids
	Added at Table	Added in Home Food Preparation	Home Tap Water	Inherent to Food	Added Outside the Home	
Sex						
Female	5.6 (0.7)	5.9 (0.7)	0.3 (0.1)	14.1 (0.4)	70.5 (1.2)	0.3 (0.1)
Male	4.5 (0.7)	6.1 (0.7)	0.2 (0.4)	13.9 (0.4)	70.6 (1.2)	0.04 (0.1)
<i>P</i> value	0.23	0.81	0.16	0.69	0.91	0.09
Age, y						
18–29	2.8 (0.9)*	3.7 (1.0)*	0.2 (0.6)	14.8 (0.6)	75.0 (1.6)*	0.2 (0.1)
30–44	6.0 (1.0)†	4.8 (1.1)*	0.3 (0.7)	14.5 (0.6)	69.2 (1.7)†	0.10 (0.1)
45–59	5.3 (0.9)†	7.0 (0.9)†	0.2 (0.6)	13.4 (0.6)	70.5 (1.5)†	0.003 (0.1)
60–74	6.1 (1.0)†	8.5 (1.1)†	0.4 (0.7)	13.4 (0.7)	67.4 (2.0)†	0.3 (0.2)
<i>P</i> value	0.01	0.006	0.26	0.20	0.01	0.42
Race						
Asian	3.3 (1.2)*	6.6 (1.3)*†	0.3 (0.8)	13.5 (0.7)*	71.9 (2.1)	0.03 (0.2)
Black	8.0 (1.2)†	5.2 (1.3)*†	0.3 (0.8)	12.9 (0.7)*	69.3 (2.1)	0.4 (0.2)
Hispanic	5.0 (1.1)*†	8.6 (1.2)*	0.2 (0.8)	13.9 (0.7)*†	68.4 (1.9)	0.02 (0.2)
Non-Hispanic white	4.0 (0.8)*	3.5 (0.9)†	0.4 (0.6)	15.6 (0.6)†‡	72.4 (1.5)	0.3 (0.1)
<i>P</i> value	<0.001	0.02	0.36	0.008	0.24	0.09
Highest level of education						
High school graduate or less	10.6 (1.3)*	5.0 (1.5)	0.1 (0.1)*	12.2 (0.9)*	66.3 (2.4)	0.4 (0.2)
Some college or technical school	5.0 (1.0)†	6.1 (1.2)	0.2 (0.2)*	12.7 (0.7)*	70.7 (1.9)	0.2 (0.2)
College and above	3.7 (0.6)†	6.2 (0.7)	0.4 (0.4)†	14.9 (0.4)†	71.7 (1.1)	0.1 (0.1)
<i>P</i> value	<0.001	0.77	0.008	0.002	0.16	0.30
Site						
Alabama	9.5 (1.0)*	7.8 (1.1)	0.02 (0.7)*	11.4 (0.7)*	68.6 (1.8)	0.1 (0.2)*
California	3.4 (0.8)†	5.9 (0.9)	0.3 (0.6)†	14.9 (0.5)†	70.7 (1.5)	0.4 (0.1)†
Minnesota	2.3 (0.9)†	4.2 (1.0)	0.5 (0.7)‡	15.8 (0.6)†	72.4 (1.7)	0.2 (0.1)*†
<i>P</i> value	<0.001	0.13	<0.001	<0.001	0.42	0.04
History of hypertension						
Yes	6.5 (1.0)	4.1 (1.1)	0.3 (0.3)	12.9 (0.6)	73.7 (1.8)	0.0007 (0.1)
No	4.5 (0.6)	6.7 (0.6)	0.3 (0.4)	14.4 (0.4)	69.3 (1.0)	0.2 (0.1)
<i>P</i> value	0.09	0.05	0.88	0.04	0.03	0.23
Body weight						
Normal or underweight	4.2 (0.9)	5.7 (0.9)	0.4 (0.3)*	14.0 (0.6)*	71.1 (1.5)	0.0007 (0.1)
Overweight	6.0 (0.8)	5.2 (0.9)	0.3 (0.5)†	14.1 (0.5)*†	70.7 (1.4)	0.3 (0.1)
Obese	5.0 (0.9)	7.1 (1.0)	0.2 (0.3)†	12.9 (0.6)†	69.8 (1.5)	0.2 (0.1)
<i>P</i> value	0.27	0.32	0.04	0.03	0.82	0.29

*†‡Values with different superscripts are statistically significantly different ($P<0.05$).

Consistent with other studies involving samples of US adults,^{2,13–15} mean sodium intake in our sample (3501 mg/d) was well above the recommended intake

level of 2300 mg/d.¹⁶ We found sodium intake to be higher among men compared with women, which is consistent with other findings.^{2,14,15} However, some specific

findings of demographic differences in sodium intake were inconsistent with other findings. We found sodium intake to be higher among those with less education, which is inconsistent with other studies in which no difference¹⁴ or lower intake¹⁵ in those with less education was found. Sodium intake was notably higher among those from the Alabama site (3899 mg/d), whereas previous research has found sodium intake to be lower among those in southeastern compared with nonsoutheastern states.^{17,18} Blacks had a higher sodium intake in our sample, whereas other studies have found sodium intake of blacks to be lower than that of other groups.^{2,15,17,18}

Study strengths include a larger sample size (n=450) than the previous study that identified sources of sodium in the diet of a sample of adults in the United States.⁸ In addition, the sample in our study had better representation with respect to race and geographic areas.

Study limitations include the use of a convenience rather than a probability-based sample, potentially limiting the generalizability of the results. The prevalences of hypertension (24%) and overweight/obesity (66%) in the study sample were similar to those in the US adult population (29.1% and 68.5% for hypertension and overweight/obesity, respectively^{19,20}). However, the educational attainment distribution of the sample differed from the general population (the study sample included more college graduates). The process of completing multiple 24-hour dietary recalls and collecting duplicate samples of salt used at the table and in home food preparation could have led to changes in eating behavior and salt use (Hawthorne effect), although we have no way of assessing whether this may have occurred.

Our data suggest that sodium added to food outside the home accounts for the majority of sodium consumed by US adults. These findings support the primary Institute of Medicine–recommended strategy to reduce sodium intake in the United States through setting targets to reduce the sodium content of commercially processed and prepared foods.³ According to a recent report, 36 countries have set voluntary sodium targets for specific foods.²¹ In the United Kingdom, this approach resulted in an ~15% (560 mg/d sodium, or 1.4 g/d salt) reduction in the average population sodium intake from 2003 to 2011 and was associated with significant decreases in blood pressure and cardiovascular disease deaths over the same time periods.²² Public education efforts should continue, with foods consumed outside the home (eg, restaurant and commercially processed foods) the primary focus of this education. Limiting salt added to food at the table and in home food preparation should also be recommended but framed as a secondary strategy that may be helpful when paired with efforts to limit sodium from restaurant and commercially processed foods.

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DISCLOSURES

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention, the National Institutes of Health, or the US Department of Health and Human Services.

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FOOTNOTES

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Continuing medical education (CME) credit is available for this article. Go to <http://cme.ahajournals.org> to take the quiz. *Circulation* is available at <http://circ.ahajournals.org>.

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Sources of Sodium in US Adults From 3 Geographic Regions

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SUPPLEMENTAL MATERIAL

Supplemental Methods: Rules and procedures for estimating the proportion of sodium in food added during processing outside the home.

For every food the proportion of sodium in the food considered 'added to food outside the home' was estimated using the following rules and procedures:

- 1) A proportion of 0 (no sodium in the food considered added outside the home) was assigned for basic/single ingredient foods that are generally processed in a manner that does not involve the addition of sodium compounds or ingredients that contain sodium compounds. Examples of foods for which this rule was applied include most fruits, fresh vegetables, cooking oils, natural sweeteners, and yogurts.
- 2) A proportion of 1 (all sodium in the food considered added outside the home) was assigned to foods composed entirely or nearly entirely of sodium compounds. Examples of items for which this rule was applied include sea salt, regular salt, lite salt, seasoning sauce, garlic salt, onion salt, celery salt, baking soda, and baking powder. Note that sodium from salt added to food at the table or in home food preparation was the exception to this rule (all of the sodium was attributed to salt added to food at the table or in home preparation in these cases).
- 3) A proportion of 1 was assigned was assigned to foods that contain sodium compounds but very little if any inherent sodium. Examples of foods for which this rule was applied include salad dressings and savory sauces such as soy and tabasco sauces.
- 4) For most multi-ingredient foods (e.g. Oreo cookie, Honey Nut Cheerios, Funyons) the proportion of sodium in the food added outside the home was calculated based on the recipe/formulation for the food in the NDSR food and nutrient database. For example, from

the ingredients in the Oreo cookie formulation (sugar, unbleached enriched flour, canola oil, cocoa, high fructose corn syrup, cornstarch, baking soda, salt, etc.) the proportion could be calculated using the proportions for the ingredients determined using rules 1 and 2.

5) For multi-ingredient foods that lack formulations in the NDSR database, the proportion was generally determined by estimating the amount of sodium added outside the home via comparison with the sodium content of a version of the food or product that does not have a sodium containing compound added in processing. The procedures for food categories that include foods that require use of this rule are as follows:

Meats : For most dried (e.g. beef jerky), pickled, and other processed forms of meats the proportion added outside the home was estimated from recipes/formulation (Rule 4). The exception is cured pork (ham). For cured pork the proportion was determined by subtracting the sodium in the fresh (unprocessed) form of the meat from that in the processed form to estimate the amount, and in turn the proportion, added to the food outside the home:

$$\frac{(\text{sodium in 100 grams of ham} - \text{sodium in 100 grams of unprocessed pork})}{\text{total sodium in 100 grams of ham}} = \text{proportion of sodium in ham that is added outside the home.}$$

Cheeses: For 'low sodium' cheeses none of the sodium in the cheese was considered added outside the home because sodium containing compounds are not generally added during processing in the preparation of these cheeses (potassium chloride used as substitute). All of the sodium in cheese substitutes was considered added outside the home following Rule 3. For regular cheeses the inherent sodium was calculated from the amount of milk needed to equal the fat in the cheese. The amount of sodium in the milk was considered the inherent amount. The inherent amount was then subtracted from the total sodium for the cheese to determine the amount, and in turn the proportion, that was added outside the home.

Beverages: For some beverages (e.g. coffee, tea, wine, beer, etc.) none of the sodium in the beverage was considered added outside the home because sodium containing ingredients are not typically added in processing (Rule 1 applied). For other beverages sodium is added in processing, mostly through the use of sodium citrate or sodium bicarbonate as ingredients (sodium bicarbonate is often used in making carbonated water). For these beverages, which include some sports drinks, energy drinks, drink mixes, fruit drinks, soft drinks, and club soda, the proportion of sodium that is added outside the home was estimated by calculating the difference in the sodium content of the beverage with sodium added in processing and tap water.

Dr. Carolyn Lam:

Welcome to Circulation on the Run, your weekly podcast summary and backstage pass to the journal and its editors. I'm Dr. Carolyn Lam, Associate Editor from the National Heart Center, and Duke National University of Singapore. In just a moment, we will be discussing the sources of sodium in the US diet, results that may surprise you, and that carry profound public health importance. But first, here's your summary of this week's issue.

The first original paper advances the field of cardiac tissue engineering by establishing a defined serum-free protocol to generate functional human myocardium from pluripotent stem cells. In this paper by first author, Dr. Tiburcy, corresponding author Dr. Zimmermann and colleagues from the University Medical Center Goettingen in Germany, the authors systematically investigated cell composition, matrix and media conditions to generate engineered human myocardium from embryonic and induced pluripotent stem cells and fibreglass, under serum-free conditions. The engineered human myocardium demonstrated important structural and functional properties of post-natal myocardium, including rod-shaped cardiomyocytes with M-bands, systolic twitch forces, a positive force-frequency response, inotropic responses to beta adrenergic stimulation, evidence of advanced molecular maturation by transcriptome profiling and the engineered human myocardium even responded to chronic cholinomimetic toxicity with contractile dysfunction, cardiomyocyte hypertrophy, cardiomyocyte death, and anti-pro BNP release, which are all classical hallmarks of heart failure.

Finally, the authors demonstrated scalability of engineered human myocardium according to anticipated clinical demands for cardiac repair. In summary, this paper provides proof of concept for a universally applicable technology for maturation and scalable production of engineered human myocardium, something that is termed a stride forward in an accompanying editorial by Doctors Yang and Murray, from University of Washington in Seattle.

The next paper describes a new frontier for interventional cardiology, the percutaneous therapy for tricuspid regurgitation. Here, Dr. Nickenig and colleagues, from University Hospital Bonn in Germany, recruited 64 consecutive patients deemed unsuitable for surgery who underwent mitroclip treatment for chronic, severe tricuspid regurgitation for compassionate use. Twenty-two patients were also concurrently treated with a mitroclip system for mitral regurgitation as a combined procedure. The degree of tricuspid regurgitation was severe or massive in 88% of patients before the procedure. The mitroclip device was successfully implanted in the tricuspid valve in 97% of cases.

After the procedure, tricuspid regurgitation was reduced by at least one grade in 91% of patients. 13% of patients with tricuspid regurgitation remained severe after the procedure. There were significant reductions in effective regurgitant orifice area, vena contracta width, and regurgitant volume. There were no intra-procedural deaths, cardiac tamponade, emergency surgeries, stroke, myocardial infarction or major vascular complications.

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There were three in-hospital deaths. New York Heart Association class was significantly improved and six minute walk distance increased significantly. In summary, this study demonstrates that trans-catheter treatment of tricuspid regurgitation with the mitroclip system seems to be safe and feasible in this cohort of pre-selected patients.

The next paper describes the pooled safety analysis of evolocumab, a fully human monoclonal antibody to PCSK-9. Dr. Toth of Johns Hopkins University School of Medicine and the PROFICIO investigators perform this pooled analysis from the PROFICIO program, which included over 6,000 patients from 12 Phase 2 and 3 trials, and the corresponding open-label extension trials, and they showed that treatment with evolocumab, up to one year, was not associated with discernible differences in adverse events, serious adverse events, or key laboratory assessments, compared to control or standard of care.

In addition, adverse events rates did not increase among patients attaining very low levels of LDL cholesterol, of less than 25 milligrams per deciliter, compared to patients attaining LDL cholesterol levels above 40 milligrams per deciliter. In summary, the present analysis confirms a favorable benefit risk profile for evolocumab treatment for up to one year.

Does aggressive blood pressure lowering prevent recurrent atrial fibrillation after catheter ablation? Well, this question is addressed in a randomized, open-label clinical trial known as the Substrate Modification With Aggressive Blood Pressure Control or SMAC-AF Trial. In this trial, Dr. Parkash of Halifax, Canada and colleagues, randomly assigned 184 patients with atrial fibrillation and a blood pressure of greater than 130 over 80 to aggressive blood pressure lowering, with a target of less than 120 over 80, or to standard blood pressure treatment, to a target of less 140 over 90, prior to their scheduled atrial fibrillation catheter ablation.

The primary outcome was symptomatic recurrence of atrial fibrillation, atrial tachycardia, or atrial flutter lasting greater than 30 seconds, determined 3 months beyond catheter ablation. The authors found no additional benefit to the addition of aggressive blood pressure lowering over a median of 3.5 months, over standard blood pressure therapy, in patients undergoing catheter ablation for atrial fibrillation to prevent recurring atrial arrhythmia.

In subgroup analysis, a signal of benefit was observed in groups whose blood pressure were lower at the point of entry into the study, and in those patients who were older. The duration of blood pressure lowering in the study did not result in reduction of recurrent atrial fibrillation after catheter ablation, however there was a higher rate of hypotension requiring medication adjustment in the aggressive blood pressure group.

Thus, this trial showed that neither aggressive blood pressure lowering compared to standard blood pressure lowering, nor the duration of aggressive

blood pressure treatment reduced atrial arrhythmia occurrence after catheter ablation for atrial fibrillation, but resulted in more hypotension.

Well, that wraps it up for our summaries! Now, for our feature discussion ...

Our topic today is so universal and so important. It's about sodium intake and the sources of sodium, at least in the US, and I have with me two lovely ladies, the corresponding author of our paper, Dr. Lisa Harnack, from School of Public Health, University of Minnesota, and a regular on the show, shall I say, Dr. Wendy Post, Associate Editor from Johns Hopkins. Welcome, ladies!

Dr. Wendy Post: Thanks you, Carolyn! It's a pleasure to be here.

Dr. Lisa Harnack: Thanks, thanks.

Dr. Carolyn Lam: Lisa, let's dig right into your paper. Let's start by discussing that there was a prior paper that looked at sources of sodium in the US population. So please tell us, what inspired you to do your paper, and were you surprised by your findings?

Dr. Lisa Harnack: Right, well the previous study was over 25 years old, and it involved just 69 people from one geographic area, and, you know, it was informative, but it didn't tell us about America today, and how much sodium we're getting from different sources, and it didn't tell us much about a variety of ethnic groups ... we're a diverse country. So the CDC actually funded this study, and really they saw the need for it and laid out that this study needed to be done, as it was done, in three geographic areas, representing different ethnic groups.

Dr. Carolyn Lam: Tell us what you did.

Dr. Lisa Harnack: So, we recruited 450 people from 3 different areas, from Minneapolis/St. Paul metropolitan area ... Stanford was a partner in this study and they recruited people from that area of California, and then, finally, Birmingham, Alabama was a partner was a partner, and we got participants from there.

So the racial groups we had represented were white Americans, African Americans, Asian Americans and Hispanics.

Dr. Carolyn Lam: Yeah, I was really struck ... you had almost equal representation of women as well, didn't you?

Dr. Lisa Harnack: Right, so we made sure we had half of the participants were women, so we could really see how things stood with a variety of groups.

Dr. Carolyn Lam: That's excellent. What I was really impressed, as I'm sure, Wendy, you were, too, was the detail of the methodology. Could you tell us a little bit about that?

Dr. Wendy Post: Right, so we wanted to know all the sources of sodium. Part studies have tended to not ask about salt added to food at the table, and in home food preparation, because it's really hard to actually know ... you know, if you ask somebody, "Oh, did you add salt at the table? How much did you add?" They don't know. They just say, "Oh, well, I shook some salt on." So, we had people collect duplicate samples of the salt they added to food at the table and home food preparation. We gave them little baggies ... collection bags ... you know, after they added salt at the table, shake some into the baggy. So, we knew exactly how much because people do add salt in the home, so they have some control over how much sodium is in their diet. But the question is in how much under people's control in their home versus what's coming from the food supply.

Dr. Carolyn Lam: Right. And what I loved about the results is ... I think that it would challenge a lot of what people expect. Because when we talk about sodium restriction, everyone thinks, "Oh, it's the additional salt we add." And your study actually had surprising results. So, could you tell us?

Dr. Wendy Post: Yes, so it really was clear that the salt that people add at the table is just 5% of their total sodium intake, on average, across people in our study, and the salt added in home food preparation, like maybe the salt you add to your pasta when you're boiling it or to your eggs ... that was just 6%. So, 11% of the sodium in our study participants' diets was sort of that under-your-control in-the-home, and the rest was from other sources. So, the other things we looked at was, "Will water contribute some sodium?" So, we wanted to see how much comes from your home tap water. There's sodium that's just naturally occurring in food, like milk just naturally contains some sodium. So we wanted to look and see how much came from just naturally occurring in the food, and then the other question was how much is added by food manufacturers as part of making the food product, and that included the salt that might be added in making potato chips, as well as in restaurants ... the salt that might be added in making French fries or a pasta dish at a restaurant.

Dr. Carolyn Lam: And the biggest culprit?

Dr. Lisa Harnack: Yes, the biggest culprit was that latter source ... food added in processing.

Dr. Carolyn Lam: I thought that was amazing. Wendy, what do you think the public health message is? I mean, 70% almost of the salt's coming from processed foods from outside. What do we do? Stop eating it? What do we do?

Dr. Wendy Post: Right, so, on the editorial board for Circulation, we really liked this paper because of its very high impact for a public health message. So, as was stated, the sodium that we're getting in our diet is largely coming from processed foods and from foods we eat in a restaurant. So there are a number of ways that that can be modified and one is for our patients to read food labels and to make smart choices when they are shopping for processed foods in the supermarket.

But the other is for food manufacturers to decrease the amount of sodium in the products that they are making and there are voluntary suggestions by the FDA that food manufacturers reduce the sodium content of the food, and especially bread is incredibly high in sodium, and I suspect that most of our patients don't know that. So, if we were able to reduce the amount of sodium in the food supply by just a small fraction, it could have a large public health impact because we all eat.

So, it would affect everybody, and then I think the other really important public health message is about eating in restaurants and, of course, some people eat out more than others, and some people eat out in fast food restaurants, which, of course, are very high in sodium, but even in some of the nice restaurants that we go to, even expensive restaurants, the food is very heavily salted and I, for one, when I go out to eat, and sometimes don't like the taste of the food because it has so much salt in it, when I'm used to eating a low sodium diet.

So, there are a number of changes that occur on that level. One is for our patients to understand what foods tend to have a lot of sodium at a restaurant, but also for restaurants to notify their clientele of what foods are potentially lower in sodium and calories and generally provide the nutrient value so that we can make smart choices when we eat out.

Dr. Carolyn Lam: Yeah, indeed, congratulations, Lisa - what an important paper. Quick question, so that was the overall main message, but did you find any differences by different racial groups, by sex, by different socioeconomic status?

Dr. Lisa Harnack: We did find some differences. We found one difference was it looked like African Americans tend to add more salt at the table than some of the other groups, and, actually, Asians add less in our study. But still for all groups, that sodium added to food in processing was still the main source by a long shot, so, although there were some small differences by groups, it was clear that for all groups, the issue was the sodium added in processing.

Dr. Carolyn Lam: And for both Lisa and for Wendy, do you think these results are generalizable even beyond the US?

Dr. Wendy Post: I'd imagine that there would be quite a lot of variability, based on the habits of the various populations. So, here we're talking about eating outside the home, or food that's processed outside of the home, so there may be countries where most people are producing their own food and not necessarily buying processed foods or eating in restaurants, and then this would definitely be less applicable. And, of course, there are differences in foods that we eat based on our different ethnic groups.

Dr. Lisa Harnack: No, I would agree with what's just said. It really could be variable, but it does seem that a lot of countries are concerned about processed foods. Some countries implemented mandatory limits on the sodium in the foods in their

food supply, so that would indicate to me that they know there's ... for some countries, there's serious concern about this source of sodium.

Dr. Carolyn Lam: Yeah, and I think this is really a wake-up message for us to examine where these sources of sodium ... I mean, even that simple message that it could be coming from bread, from drinking water, I think that would be surprising to a lot of us, even those of us practicing in medicine. Wendy, finally, you thought this was important enough to invite an editorial. I'd really like your thoughts there.

Dr. Wendy Post: You'll be able to read the editorial when it comes out in print, but the editorial also congratulates the authors on a really important paper, and the important public health messages, and, especially, compliments the authors on having a diverse group of participants, including ethnic minorities and men and women, and different geographic locations, so overall, it's a very important paper that I'm sure will have an important impact on the public health of our country and others.

Dr. Carolyn Lam: Listeners, you heard it right here. Remember, you're listening to Circulation on the Run. Please share this episode, and tune again next week!