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Research Paper

Toward a Better Understanding of Listeriosis Risk among Older Adults in the United States: Characterizing Dietary Patterns and the Sociodemographic and Economic Attributes of Consumers with These Patterns

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ABSTRACT

Older adults are at higher risk of invasive listeriosis compared with the general population. Some foods are more likely than others to be contaminated with or to contain high levels of *Listeria monocytogenes*. The objectives of this study were to (i) determine dietary consumption patterns among older adults in the United States; (ii) evaluate sociodemographic and economic characteristics of older adults associated with each pattern; (iii) determine intake of foods associated with larger relative risk of listeriosis within these patterns; and (iv) rank these patterns based on risk. Data related to older adults (age 60 and older) participating in the cross-sectional National Health and Nutrition Examination Surveys (NHANES) 2009 to 2010, 2011 to 2012, and 2013 to 2014 ($n = 4{,}967$) were included in these analyses. Cluster analysis was used to define dietary patterns based on 24-h dietary recalls from day 1 and day 2. Mean intake of foods associated with higher risk of listeriosis was examined within each pattern, and analysis of variance with Dunnett's method of adjustment was used to evaluate significant differences in mean intake of foods. Patterns were ranked based on relative risk of listeriosis, using outbreak illness attribution data. Five distinct dietary patterns were identified. Patterns ranked at highest relative risk of listeriosis, based on U.S. outbreak illness attribution data, were characterized by relatively higher intakes of fruits, vegetables, and cheeses (~13% respondents) or cereal, milk, and yogurt (~14% respondents). Individuals consuming these dietary patterns differed in sex, race, food security, self-rated diet quality, and self-rated health. Cluster analysis, despite methodological limitations, provides new information on consumption, sociodemographic, and economic characteristics of subgroups within susceptible populations, which may be used to target educational messages.

HIGHLIGHTS

- Cluster analysis of participants' dietary intake generated five dietary patterns.
- Patterns were ranked based on relative risk of listeriosis using attribution data.
- Two patterns with the highest relative risk included more dairy, fruits, and vegetables.
- Patterns differed in sex, race, food security, and reported diet quality and health.
- These results can be used to develop targeted risk-reduction interventions for listeriosis.

Key words: Cluster analysis; Dietary intake; *Listeria monocytogenes*; NHANES

Listeria monocytogenes (23) is a foodborne pathogen that can cause noninvasive listeriosis, which is usually self-limiting, and invasive listeriosis, which can cause meningitis, sepsis, gastroenteritis, neonatal infections, fetal loss, and death *(12, 21, 22, 25)*. Risk of listeriosis is dose-dependent *(8, 19, 37)*. Given exposure via ingestion, the risk of invasive listeriosis has also been shown to be dependent on strain virulence and on characteristics of the host such as age, pregnancy status, gender, and comorbidities *(8, 28, 37)*. The risk of invasive listeriosis is especially high in pregnant women and their fetuses or neonates, immunocompromised individuals, and older adults *(10, 12, 17, 18, 24)*. Adults aged 65 years and older are particularly vulnerable to invasive listeriosis and its effects, including death. In 2009 to 2011, listeriosis incidence among older adults (≥65

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years) was 4.4 times that of the general population and, among older adult cases, the fatality rate was 24% *(9)*. In a study on the food safety perception and behaviors of older adults, 66% of older adults reported eating potentially hazardous food over the previous year, and 72% had never heard of *L. monocytogenes* as a problem in food *(7)*. As of 2017, those aged 65 years and older in the United States represented almost 15% of the population, and they are projected to constitute nearly 22% of the population by the year 2040 *(1)*.

To our knowledge, information is lacking on the characteristics of older adults who are more likely to consume foods associated with higher risk of listeriosis. As with all foods, these specific foods are not likely to be consumed in isolation, but rather as components of a pattern of eating. The published literature on dietary patterns of older U.S. adults is also lacking, and therefore, knowledge of dietary patterns and characteristics of consumers with patterns that may be associated with higher risk of listeriosis in older adults is unknown. The National Health and Nutrition Examination Survey (NHANES) and the resulting publicly available 24-h recall data provide a tool that can be used to examine both the dietary patterns of older adults and the consumption of foods associated with *Listeria* risk.

Dietary patterns can be examined using *a priori* approaches, which involve calculating a score of the overall quality of a diet based upon predetermined dietary standards, against which each participant is evaluated, or *a posteriori* approaches, which use dietary data at hand to identify dietary patterns *(16)*. Both of these approaches can capture the complexity of dietary patterns because the correlation among intakes of specific foods is accounted for, and they allow the main foods consumed to be evaluated by characteristics of the consumers. For this study, we used cluster analysis, an *a posteriori* approach, to identify dietary patterns based on foods reported in the NHANES 24-h recall that were most commonly consumed together by people in this sample. This allows us to determine the intake of foods associated with higher risk of listeriosis within each of the patterns and characteristics of people consuming these dietary patterns.

The objectives of this study were to (i) determine dietary consumption patterns, from 2-day recalls, among older adults in the United States; (ii) determine characteristics of older adults consuming foods associated with these dietary patterns; (iii) estimate the mean intake of foods associated with relatively larger risk of listeriosis within the dietary patterns of older adults; and (iv) rank these patterns based on risk of listeriosis. This study was approved by the National Center for Health Statistics Research Ethics Review Board.

MATERIALS AND METHODS

Population and sample. The study sample included adults aged 60 years and older ($n = 4{,}967$) from the 2009 to 2010, 2011 to 2012, and 2013 to 2014 cycles of NHANES, who participated in the dietary interview portion, known as What We Eat In America (WWEIA). NHANES is a series of cross-sectional surveys of noninstitutionalized, civilian U.S. residents conducted by the National Center for Health Statistics to assess the health and nutrition status of the U.S. population *(6)*. Details of the NHANES study design and data sets are available online *(6, 11)*.

Sociodemographic and economic variables. Data for this analysis included age, sex, race or ethnicity, marital status, education, employment, food security status, use of social services (Supplemental Nutrition Assistance Program, emergency food services, and cash assistance from government agencies), and poverty-income classification. Poverty-income classification in NHANES is based on the ratio of household income to the poverty threshold (PIR), developed by the Department of Health and Human Services. We used a PIR <1.85 to designate poverty, which is the upper level commonly used to determine eligibility for federal assistance programs *(11)*.

Dietary assessment. NHANES combines an in-home interview with physical examinations at mobile examination centers, where participants undergo health examinations and an in-person dietary interview to provide data for WWEIA *(5, 6, 11, 31)*. Dietary data are collected using the U.S. Department of Agriculture (USDA)'s fully computerized Automated Multiple-Pass Method for collecting 24-h dietary recalls *(2)*. The USDA processes the dietary data and categorizes the foods and beverages reported into approximately 15 major WWEIA food categories: dairy, protein foods, mixed dishes, grains, snacks and sweets, fruit, vegetables, nonalcoholic beverages, alcoholic beverages, water, fats and oils, condiments and sauces, sugars, infant formula and baby food, and "other," and 150 food subcategories *(11)*. The focus of the food categorization system is to group similar foods and beverages based on usage and nutrient content. Each WWEIA food within the subcategories is linked to the food codes in the Food and Nutrient Database for Dietary Studies (FNDDS), which provides ingredient proportions and nutrient values for each WWEIA food *(3)*.

For our cluster analysis (described below), we consolidated the 150 WWEIA food subcategories (excluding those under the major categories of water, infant formula, and baby food) into 41 new food groups according to the similarity of the foods (see Table 1). Individuals were then clustered into dietary patterns based on the mean grams of intake from these 41 new food subcategories. The purpose of the cluster analysis was to place individuals into mutually exclusive groups such that persons in a given cluster had similar diets that differed from those of persons in other clusters. Five clusters, designating five distinct dietary patterns, were generated using this method.

In the WWEIA dataset, some foods that are commonly eaten as combination items (e.g., some cheeseburgers) are listed as single-entry foods, and the FNDDS provides the nutrition information for that food as a single item. For the risk ranking component of our study (described below), we estimated the serving intakes of foods and food ingredients associated with higher relative listeriosis risk per serving or with outbreaks by linking the WWEIA food intake data to the Center for Nutrition Policy and Promotion's Food Pattern Equivalents (FPED) data *(6)*. Foods and beverages in FPED are disaggregated into their component ingredients and assigned to 37 food groups, such as total vegetables, total fruit, etc. *(4)*. FPED disaggregates all foods reported in the survey to individual ingredients, using data from a recipe file, and assigns those ingredients to food groups *(4)*. For example, a hamburger with tomatoes and mayonnaise, on a bun, with no cheese is separated into red and orange vegetables (tomatoes), bun (refined or whole grains), meat, oils, and solid fats. Servings of FPED food groups are measured in cups, ounces, cup or ounce equivalents, or teaspoons. The servings of FPED

TABLE 1. *Mean intake of selected What We Eat in America food categories, by dietary pattern cluster, in NHANES participants aged 60 years and older, NHANES 2009 to 2014*[a]

	Mean (g) ± SE				
WWEIA food categories	Vegetables, fruits, and cheeses (*n* = 660)	RTE cereal, milk, and yogurt (*n* = 710)	Grain dishes and sandwiches (*n* = 1,911)	Meat mixed dishes (*n* = 371)	Meats and white potatoes (*n* = 1,315)
Alcoholic beverages	204.0 ± 27.2	134.6 ± 23.4	159.2 ± 17.3	263.8 ± 46.9[b]	243.3 ± 18.7
Beans, peas, and legumes	21.1 ± 3.1	18.2 ± 2.2	23.8 ± 2.1	25.9 ± 4.4	27.5 ± 2.9[b]
Breads and rolls	107.5 ± 4.3	86.7 ± 4.3	64.3 ± 2.7	95.2 ± 5.2	132.7 ± 3.5[b]
Burgers	8.0 ± 2.6	6.6 ± 1.6	8.6 ± 1.3	7.9 ± 3.3	10.8 ± 1.7[b]
Cheese	66.4 ± 3.4[b]	28.6 ± 2.0	12.5 ± 0.7	28.5 ± 4.4	29.2 ± 2.0
Chicken and turkey sandwiches	4.3 ± 1.5	7.7 ± 2.3	6.9 ± 1.3	11.3 ± 3.6[b]	4.7 ± 1.4
Cured meats and poultry	39.8 ± 2.4	32.5 ± 2.5	19.0 ± 1.2	41.8 ± 4.1	74.6 ± 3.2[b]
Coffee and tea	1,445.1 ± 79.2	1,011.3 ± 39.7	785.5 ± 31.7	1,238.2 ± 82.8	1,362.3 ± 46.2[b]
Cooked cereals	90.2 ± 13.2[b]	28.7 ± 4.4	78.9 ± 7.7	85.4 ± 14.5	53.1 ± 4.2
Cooked grains and mixed grain dishes	115.4 ± 10.2	102.3 ± 7.7	190.4 ± 11.5[b]	114.2 ± 11.2	91.0 ± 6.3
Snacks and sweets	180.2 ± 11.4	220.3 ± 8.3	137.5 ± 6.2	201.0 ± 13.0	223.0 ± 7.2[b]
Condiments	32.8 ± 3.0[b]	14.2 ± 1.3	10.0 ± 0.6	16.5 ± 2.6	27.9 ± 2.9
Milk, yogurt, and dairy substitutes	336.1 ± 16.5	675.8 ± 30.4[b]	217.8 ± 9.9	312.7 ± 28.7	238.9 ± 14.5
Diet, sweetened beverages, and flavored water	337.0 ± 24.4	436.2 ± 28.2	420.4 ± 18.1	638.1 ± 63.7	769.9 ± 39.6[b]
Eggs	32.4 ± 3.1	19.1 ± 2.0	24.8 ± 1.6	35.8 ± 3.6	83.3 ± 3.9[b]
Eggs and breakfast sandwiches	4.9 ± 1.4	5.2 ± 1.5	11.8 ± 2.2	14.5 ± 5.5[b]	8.5 ± 2.4
Fats	27.5 ± 1.9	32.5 ± 2.2	15.0 ± 0.9	22.9 ± 2.2	40.3 ± 2.7[b]
Fruits	383.3 ± 15.4[b]	315.3 ± 12.4	169.6 ± 5.9	212.5 ± 18.9	167.5 ± 5.6
100% juice	189.9 ± 53.4[b]	181.1 ± 19.0	124.8 ± 9.4	140.0 ± 17.5	129.7 ± 8.9
Meats	40.1 ± 4.1	39.4 ± 3.4	27.8 ± 2.0	30.1 ± 4.1	100.9 ± 6.6[b]
Meat mixed dishes	27.3 ± 4.0	19.2 ± 3.0	16.9 ± 1.5	453.7 ± 16.1[b]	29.6 ± 2.9
Mixed dishes Asian	26.7 ± 6.0	27.5 ± 4.3[b]	21.3 ± 2.5	22.1 ± 6.1	12.0 ± 2.6
Mixed dishes Mexican	18.7 ± 3.1	24.3 ± 5.0	33.4 ± 3.5[b]	16.8 ± 4.6	22.7 ± 3.1
Mixed dishes pizza	22.6 ± 4.7	36.9 ± 12.1[b]	21.3 ± 3.3	27.7 ± 6.6	28.1 ± 3.5
Mixed dishes soups	131.4 ± 13.0	136.7 ± 10.8[b]	131.3 ± 8.8	112.6 ± 18.8	79.0 ± 7.5
Nuts, and seeds	33.0 ± 3.7[b]	27.0 ± 2.9	13.1 ± 1.1	18.3 ± 2.9	16.2 ± 1.5
Other foods	2.8 ± 0.8[b]	1.1 ± 0.5	1.7 ± 0.4	0.4 ± 0.2	1.9 ± 0.8
Other sandwiches	6.9 ± 2.4	7.6 ± 1.8	10.8 ± 2.0[b]	6.8 ± 3.8	6.4 ± 1.4
Poultry	59.2 ± 4.0[b]	46.0 ± 3.4	52.7 ± 2.6	34.1 ± 5.1	49.7 ± 2.8
Poultry mixed dishes	30.7 ± 4.5	46.3 ± 6.2[b]	30.5 ± 4.2	31.7 ± 11.2	29.5 ± 4.3
Processed soy products	2.8 ± 1.3	4.9 ± 2.2[b]	1.9 ± 0.6	0.8 ± 0.5	0.5 ± 0.2
Quick breads	25.7 ± 2.7	16.4 ± 2.1	26.1 ± 2.2	37.2 ± 5.7[b]	36.8 ± 2.3
RTE cereals	17.1 ± 1.4	94.3 ± 2.4[b]	8.0 ± 0.5	20.8 ± 2.6	13.0 ± 1.0
Salad dressings and vegetable oils	47.0 ± 2.5[b]	9.8 ± 1.0	4.9 ± 0.4	7.1 ± 1.1	8.1 ± 0.9
Sauces and gravies	10.1 ± 1.6	8.2 ± 1.3	12.7 ± 1.6	12.8 ± 2.3	20.4 ± 2.1[b]
Seafood mixed dishes	21.2 ± 4.3[b]	18.8 ± 2.8	13.9 ± 2.1	19.2 ± 4.6	17.6 ± 4.8
Seafood	54.3 ± 5.9[b]	31.6 ± 4.0	37.8 ± 4.0	13.9 ± 3.0	33.2 ± 2.8
Sugars	13.2 ± 1.5	11.9 ± 0.9	12.7 ± 0.8	24.2 ± 3.4[b]	22.6 ± 1.4
Tortillas	3.4 ± 0.6	3.7 ± 0.8	7.9 ± 1.2[b]	5.3 ± 1.6	5.8 ± 1.4
Vegetables excluding potatoes	458.2 ± 15.1[b]	207.1 ± 12.7	141.0 ± 5.0	166.9 ± 13.4	184.7 ± 7.1
White potatoes	48.1 ± 3.9	58.1 ± 5.0	35.0 ± 2.2	61.4 ± 8.8	165.6 ± 8.0[b]

[a] The vegetables, fruits, and cheeses cluster consumed the most from the vegetables, excluding potatoes, fruits, cheese, salad dressings and vegetable oils, and seafood groups. The RTE cereal, milk, and yogurt cluster consumed the most from the milk, yogurt, and dairy substitutes, and RTE cereals groups. The grain dishes and sandwiches cluster consumed the most from the cooked grain and mixed grains dishes, "other" sandwiches, and Mexican mixed dishes groups. The meat mixed dishes cluster consumed the most from the meat mixed dishes and sandwiches (egg-breakfast and chicken-turkey). The meats and white potatoes cluster consumed the most from the meats, white potatoes, breads, and eggs groups.

[b] Mean intake of this food was highest for this cluster.

food groups from WWEIA data were calculated by obtaining the product of the amounts of the foods consumed in grams and the servings per 100 g of each food and ingredient and dividing the results by 100. In these analyses, the FPED food groups assessed included vegetables (total and red and orange [tomatoes]), fruit (citrus, melons and berries, and other fruit), dairy (milk, yogurt, and cheese), and protein foods (meat, cured meat, organ, poultry).

Where necessary, to identify ingredients, the FNDDS Standard Reference Links files (FNDDS SR Links) were linked to the intake data. The FNDDS SR Links files provide "recipes" listing proportions of component ingredients (SR descriptions) in the foods. Examples of instances where the FNDDS SR Links were used include the following:

(i) To distinguish between foods in an "or" situation. For example, a WWEIA food description "meat loaf made with chicken or turkey," where the distinction between chicken or turkey was made using the SR descriptions.

(ii) To identify ingredients in instances in which the FPED serving equivalents for the food group of interest had a value, but the specific ingredients could not be determined from the WWEIA food description. For instance, "spaghetti with tomato sauce and meatballs or spaghetti with meat sauce or spaghetti with meat sauce and meatballs," which has FPED's protein foods "meat" food group serving equivalents, but the meat could be beef, pork, veal, lamb, and game meat. For such foods, the SR descriptions were also used to determine the ingredient in question.

(iii) To distribute FPED serving equivalents among ingredients when the foods are mixtures, such as fast foods pizza made with Italian pork sausage, and chicken. The FPED serving equivalents for such foods were recalculated by either assigning the whole FPED food group value to a food category or dividing serving equivalents among ingredients. In this example, the FPED food category value for protein food "meat" was assigned to pork, and the protein food "poult" value assigned to chicken.

(iv) For foods in which the ingredients could not be determined from the WWEIA food description, and the FNDDS SR Links files did not provide ingredients, assumptions were made regarding the specific ingredients present in the foods. For example, the meat in the SR description "fast foods, cheeseburger; single, large patty; with condiments and mayonnaise" was assumed to be beef.

Rank of dietary patterns based on relative risk. The Interagency Food Safety Analytics Collaboration (IFSAC) 2019 Attribution Report considered attribution among 17 food categories *(20)*. In this report, listeriosis outbreaks for which a single food vehicle could be identified were attributed to foods in only nine of these categories; outbreak data from 1998 to 2017 were included, with largest weight given to outbreaks that occurred from 2013 to 2017. Using this qualitative information, dietary pattern risk-based scores were determined from the sum of mean intakes (in servings) of foods in each of eight of these nine categories. One of the categories (beef) was excluded because it had negligible attribution in the report (0.0%) *(20)*. A second set of dietary pattern risk-based scores were also determined from the sum of the weighted mean intakes of these eight food categories within each pattern. Each individual's intake of a given food category (in servings) was multiplied by the attribution fraction for that category, and then a weighted mean total score was obtained for each cluster.

Statistical analysis. The FASTCLUS procedure *(32),* in SAS (version 9.4, SAS Institute Inc., Cary, NC) *(34),* was used to generate dietary pattern clusters using intakes of foods in grams. The FASTCLUS procedure requires the number of clusters to be specified in advance and generates mutually exclusive clusters by comparing Euclidean distances between each respondent and each cluster centroid in an iterative process using a k-means method. Respondents are placed in clusters with centroids nearest to them, and each respondent belongs to only one cluster *(32, 38)*. The method guarantees that the distances between observations in the same cluster are less than all distances between observations in different clusters *(32)*. However, the k-means method of clustering is sensitive to outliers, placing a larger influence on variables with larger variance, which tend to be selected as the original cluster centers. For this reason, the variables were standardized to have a mean of 0 and a standard deviation of 1, using SAS PROC STANDARD, before performing the cluster analysis.

Characteristics of respondents, intakes of foods associated with relatively higher risk of listeriosis, and summary risk-based scores were examined by dietary pattern cluster. Each dietary pattern was compared with the reference pattern (selected based on the higher consumption of foods considered to be healthful) using multiple comparison tests in analysis of variance (ANOVA), with Dunnett's adjustment for continuous variables and χ^2 test for categorical variables. Pairwise comparisons were also conducted on the weighted and unweighted risk-based scores using multiple comparison tests in ANOVA, with Dunnett's adjustment. SAS survey procedures were used, adjusting for NHANES complex survey design variables (cluster, strata, and appropriate sample weights) *(33),* except for cluster analysis, which does not accept cluster and strata information.

RESULTS

Sample characteristics. This study included 4,967 adults aged 60 years and older. In this sample, 48.3% were men; 79.4% of the men were non-Hispanic White, as were 78.1% of the women. Compared with women, a higher proportion of men were married or partnered (79.4 versus 54.7%, $P < 0.0001$), had some college-level education or were college graduates (61.9 versus 56.1%, $P = 0.001$), and were employed (35.9 versus 26.5%, $P = 0.0004$). Men had higher incomes and were more food secure (results not shown). A higher proportion of the women received Supplemental Nutrition Assistance Program benefits (10.8 versus 7.4%, $P < 0.0001$), received emergency food (6.0 versus 3.9%, $P = 0.03$), and ate meals at senior or community centers (7.4 versus 3.7%, $P < 0.0001$).

Dietary patterns. The five distinct dietary patterns identified based on the 24-h dietary recalls from day 1 and day 2 and each pattern's mean intake across the 41 WWEIA food groups are shown in Table 1. The patterns were assigned names by first determining which food groups each pattern consumed the most of, and then comparing the mean consumption of these foods to the dietary pattern with the next highest mean consumption. Most patterns were named based on the two food groups that had the greatest difference in consumption: ready-to-eat (RTE) cereals, milk, and yogurt; grain dishes and sandwiches; and meats and white potatoes. Because one of the patterns consumed the most of three types of foods that are associated with listeriosis outbreaks (vegetables, fruits, and cheeses), these foods were chosen to name the group even though they

TABLE 2. *Characteristics of NHANES study participants, aged 60 years and over, by dietary pattern cluster, NHANES 2009 to 2014*[a]

	n (column %)[b]				
Characteristics	Vegetables, fruits, and cheeses (*n* = 660)	RTE cereal, milk, and yogurt (*n* = 710)	Grain dishes and sandwiches (*n* = 1,911)	Meat mixed dishes (*n* = 371)	Meats and white potatoes (*n* = 1,315)
Age (yr) mean ± SE	69.0 ± 0.3	71.5 ± 0.4***	69.7 ± 0.2	69.4 ± 0.5	68.8 ± 0.2
Sex (men)	266 (39.4)	357 (46.6)*	779 (34.5)	215 (54.3)**	825 (57.4)***
Race or ethnicity					
Non-Hispanic White	428 (86.8)	499 (88.4)	637 (62.4)**	213 (82.1)***	752 (82.7)***
Mexican	36 (1.6)	54 (2.8)**	285 (6.7)***	35 (2.9)	143 (3.9)***
Other Hispanic	47 (2.3)	32 (1.5)**	272 (6.9)***	29 (2.7)**	82 (2.1)*
Non-Hispanic Black	101 (5.0)	98 (5.0)	506 (14.4)***	72 (8.2)*	287 (8.3)***
Other races	48 (4.2)	27 (2.3)**	211 (9.7)***	22 (4.1)**	51 (3.1)
Marital status (married or partnered)	387 (65.5)	420 (65.5)	1020 (58.8)*	225 (67.3)	809 (68.8)
Education (completed less than 9th grade)	36 (2.5)	65 (4.7)***	448 (14.7)***	44 (6.2)***	141 (6.3)***
Employed	188 (33.1)	135 (21.0)**	473 (27.9)	97 (32.0)	350 (32.8)
Monthly poverty level index > 1.85	434 (77.6)	412 (71.9)*	736 (56.3)***	200 (69.2)**	698 (66.6)***
Received cash assistance from a state or county welfare program	12 (1.8)	11 (1.1)	68 (2.7)	7(1.0)	32 (2.3)
Dietary factors					
Self-rated overall diet (excellent)	119 (20.2)	109 (15.2)	208 (11.8)***	48 (14.1)**	132 (10.0)***
Household food security (fully food secure)	588 (93.8)	627 (92.7)	1,361 (80.5)***	308 (89.5)	1,041 (87.8)**
Emergency food last 12 mo	28 (3.2)	34 (2.7)	205 (8.4)**	25 (3.1)	102 (4.2)
Received SNAP last 12 mo[c]	58 (4.7)	76 (6.7)	389 (14.1)***	53 (9.2)**	175 (8.7)***
Self-rated health (excellent)	81 (17.5)	80 (14.0)	113 (7.6)***	25 (9.3)**	80 (7.2)***

[a] The vegetables, fruits, and cheeses cluster consumed the most from the vegetables excluding potatoes, fruits, cheese, salad dressings and vegetable oils, and seafood groups. The RTE cereal, milk, and yogurt cluster consumed the most from the milk, yogurt, and dairy substitutes, and RTE cereals groups. The grain dishes and sandwiches cluster consumed the most from the cooked grain and mixed grains dishes, "other" sandwiches, and Mexican mixed dishes groups. The meat mixed dishes cluster consumed the most from the meat mixed dishes and sandwiches (egg-breakfast, and chicken-turkey). The meats and white potatoes cluster consumed the most from the meats, white potatoes, breads, and eggs groups.
[b] Significantly different from vegetables, fruits, and cheeses cluster, based on Dunnett's test for continuous variables and χ^2 test for categorical variables. * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.0001$.
[c] SNAP, Supplemental Nutrition Assistance Program.

were not the three with the greatest difference. Another group consumed 15 times the amount of meat mixed dishes compared to the next, so the group was named simply meat mixed dishes.

The vegetables, fruits, and cheeses pattern ($n = 660$) represented about 13% of the total sample and was characterized by relatively higher intakes of fruits, vegetables excluding potatoes, cheese, seafood, and salad dressings and vegetable oils. The grain dishes and sandwiches pattern ($n = 1{,}911$) represented about 39% of the total sample and can be described as having higher intakes of cooked grains and mixed grain dishes, "other" sandwiches, and mixed Mexican dishes. The RTE cereal, milk, and yogurt pattern ($n = 710$) represented about 14% of the total sample and can be described as having higher intakes of milk, yogurt, and dairy substitutes and ready-to-eat cereals. The meat mixed dishes pattern ($n = 371$) represented about 8% of the total sample and had higher intakes of meat mixed dishes and sandwiches (egg-breakfast and chicken-turkey), whereas the meats and white potatoes pattern ($n = 1{,}315$) represented almost 27% of the sample and was characterized by higher intakes of breads, meats (including burgers and cured meats), white potatoes, and eggs.

The grain dishes and sandwiches pattern had the largest proportion of women (65.5%), followed by the vegetables, fruits, and cheeses pattern (60.6%), whereas the meats and white potatoes pattern had the highest proportion of men (57.4%), followed by the meat mixed dishes pattern (54.3%) (Table 2). The RTE cereal, milk, and yogurt pattern had the largest proportion of non-Hispanic White respondents (88.4%) and, along with the vegetables, fruits, and cheeses pattern, had the highest proportion of food-secure respondents (92.7 and 93.8%, respectively) (Table 2). The grain

TABLE 3. *Number and proportion of NHANES participants, aged 60 years and over, consuming foods associated with outbreaks of listeriosis, by dietary patterns cluster, IFSAC Attribution Report for 2019, NHANES 2009 to 2014*[a]

Foods associated with listeriosis outbreaks[b]	n (column %)[c]				
	Vegetables, fruits, and cheeses ($n = 660$)	RTE cereal, milk, and yogurt ($n = 710$)	Grain dishes and sandwiches ($n = 1,911$)	Meat mixed dishes ($n = 371$)	Meats and white potatoes ($n = 1,315$)
Dairy	655 (99.0)	707 (99.5)	1,833 (96.9)	364 (99.0)	1,301 (99.3)
Fruits	575 (87.0)	585 (81.5)*	1,193 (64.2)***	241 (66.8)***	763 (61.2)***
Vegetables	649 (99.0)	631 (89.6)***	1,567 (83.6)***	349 (95.4)**	1,143 (86.7)***
Sprouts	14 (1.9)	9 (1.5)	20 (1.6)	5 (2.4)	12 (1.7)
Turkey	415 (63.0)	450 (63.2)	1,157 (60.6)	178 (48.5)**	778 (57.6)*
Fish	243 (36.7)	202 (25.6)**	485 (25.5)**	71 (17.1)***	270 (20.4)***
Pork	340 (52.7)	369 (51.6)	938 (49.9)	238 (67.1)**	1,025 (78.3)***
Chicken	390 (59.0)	421 (58.5)	1,121 (58.8)	162 (43.6)**	719 (51.5)**

[a] Interagency Food Safety Analytics Collaboration (IFSAC) report for 2019 *(20)*. The vegetables, fruits, and cheeses cluster consumed the most from the vegetables, excluding potatoes, fruits, cheese, salad dressings and vegetable oils, and seafood groups. The RTE cereal, milk, and yogurt cluster consumed the most from the milk, yogurt and dairy substitutes, and RTE cereals groups. The grain dishes and sandwiches cluster consumed the most from the cooked grain and mixed grains dishes, "other" sandwiches, and Mexican mixed dishes groups. The meat mixed dishes cluster consumed the most from the meat mixed dishes and sandwiches (egg-breakfast and chicken-turkey). The meats and white potatoes cluster consumed the most from the meats, white potatoes, breads, and eggs groups.

[b] Fruits include dried and raw fruits; vegetables include row crops (artichokes, asparagus, beets, broccoli, carrots, cauliflower, celery, chives, fennel, horseradish, kohlrabi, leafy greens, leeks, onions, peas, radishes, rutabagas, taro, and turnips); fish excludes shellfish.

[c] Significantly different from vegetables, fruits, and cheeses cluster, based on χ^2 test for categorical variables. * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.0001$.

dishes and sandwiches pattern had the largest proportion in all non-White racial and ethnic groups (14.4% non-Hispanic Black, 6.7% Mexican American, 6.9% other Hispanics, and 9.7% other races), the largest proportion of those with less than 9th-grade education (14.7%), largest proportion below the poverty level index of 1.85 (43.7%), and the lowest proportion of food-secure individuals (80.5%) (Table 2).

The vegetables, fruits, and cheeses pattern had the largest proportion of those rating their diet as excellent (20.2%) and those rating their health as excellent (17.5%) (Table 2). The meats and white potatoes pattern had the lowest proportion of respondents rating their diet and their health as excellent, and this was one of the patterns with lower educational attainment, more poverty, and lower levels of food security (Table 2).

Consumption of foods associated with relatively higher risk of listeriosis. Table 3 shows the number and proportion of people from each cluster who consumed each food associated with listeriosis outbreaks in the IFSAC 2019 Attribution Report *(20)*. The vegetables, fruits, and cheeses pattern had the largest proportion of respondents who consumed vegetable row crops (99.0%), fruit (87.0%), and fish (36.7%), and the second largest proportion of those who consumed dairy products (99.0%) (Table 3). The RTE cereal, milk, and yogurt pattern had the second largest proportion of those who consumed fruit (81.5%) and the largest proportion for dairy products (99.5%). The grain dishes and sandwiches pattern had the lowest proportion of those who consumed vegetable row crops (83.6%), pork (49.9%), and fruit (64.2%), and the meat mixed dishes pattern had the lowest proportion of those who consumed turkey (48.5%) and chicken (43.6%). The meats and white potatoes pattern had the largest proportion of those who consumed pork (78.3%) (Table 3).

Table 4, containing the mean intake of foods attributed to outbreak-associated listeriosis illnesses according to the IFSAC 2019 Attribution Report, shows that the vegetables, fruits, and cheeses pattern consumers ate significantly more fruit, vegetables, and fish, compared with all other patterns, and significantly more dairy when compared with the meats and white potatoes pattern (Table 4). The vegetables, fruits, and cheeses pattern consumers also ate significantly more poultry (chicken and turkey), compared with the meat mixed dishes pattern, and significantly more chicken compared with the meats and white potatoes pattern. On the other hand, the meat mixed dishes pattern and meats and white potatoes pattern consumed significantly more pork compared with all other patterns ($P < 0.05$), whereas the grain dishes and sandwiches pattern consumed the more chicken, compared with the meat mixed dishes pattern and meats and white potatoes pattern ($P < 0.05$) (results not shown).

Risk ranking of dietary patterns. Table 4 lists the fraction of outbreak illnesses attributed to each food (the attribution fraction) as reported in the IFSAC 2019 Attribution Report. Risk-based scores for each dietary pattern based on these attribution data are shown at the bottom of Table 4. When using the unweighted (qualitative) risk-based scoring strategy, the vegetables, fruits, and cheeses pattern had the largest relative risk, followed by the RTE cereal, milk, and yogurt pattern. The meat mixed dishes pattern and the meats and white potatoes pattern had about the same relative risk, both with significantly lower scores than the vegetables, fruits, and cheeses pattern. When using the weighted strategy, where risk scores were

TABLE 4. *Mean intake of foods associated with outbreaks of listeriosis, using percent attribution from the IFSAC Attribution Report for 2019, by cluster of dietary patterns for participants, aged 60 years and over, NHANES 2009 to 2014*[a]

Foods associated with listeriosis outbreaks[b]	% of outbreak illnesses attributed to food group	Mean (servings) ± SE[c]				
		Vegetables, fruits, and cheeses (n = 660)	RTE cereal, milk, and yogurt (n = 710)	Grain dishes and sandwiches (n = 1,911)	Meat mixed dishes (n = 371)	Meats and white potatoes (n = 1,315)
Dairy	48.4	1.63 ± 0.06	2.14 ± 0.08***	2.01 ± 0.07***	1.55 ± 0.07	1.38 ± 0.04***
Fruits	29.3	1.28 ± 0.06	1.02 ± 0.04***	1.15 ± 0.03***	0.70 ± 0.07***	0.52 ± 0.02***
Vegetables	11.8	1.38 ± 0.04	0.67 ± 0.04***	0.52 ± 0.01**	0.85 ± 0.05***	0.59 ± 0.02***
Sprouts	6.4	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.01	0.01 ± 0.00
Turkey	1.9	1.40 ± 1.14	1.26 ± 0.08	1.27 ± 0.05	0.93 ± 0.12***	1.23 ± 0.05
Fish	1.9	0.87 ± 0.10	0.52 ± 0.07***	0.62 ± 0.07**	0.36 ± 0.07***	0.48 ± 0.04***
Pork	0.1	0.61 ± 0.04	0.54 ± 0.04	0.47 ± 0.03*	1.10 ± 0.11***	1.18 ± 0.04***
Chicken	0.1	1.26 ± 0.09	1.15 ± 0.07	1.22 ± 0.05	0.83 ± 0.12***	1.03 ± 0.05**
Total score (unweighted)		8.44 ± 0.21	7.29 ± 0.20***	5.86 ± 0.11***	6.34 ± 0.31***	6.40 ± 0.12***
Total weighted score[d]		137.31 ± 3.63	144.77 ± 3.77	83.30 ± 1.69***	108.35 ± 4.10***	92.43 ± 1.68***

[a] The vegetables, fruits, and cheeses cluster consumed the most from the vegetables excluding potatoes, fruits, cheese, salad dressings and vegetable oils, and seafood groups. The RTE cereal, milk, and yogurt cluster consumed the most from the milk, yogurt and dairy substitutes, and RTE cereals groups. The grain dishes and sandwiches cluster consumed the most from the cooked grain and mixed grains dishes, "other" sandwiches, and Mexican mixed dishes groups. The meat mixed dishes cluster consumed the most from the meat mixed dishes and sandwiches (egg-breakfast and chicken-turkey). The meats and white potatoes cluster consumed the most from the meats, white potatoes, breads, and eggs groups.

[b] Fruits include raw and dried fruits; vegetables include row crops (artichokes, asparagus, beets, broccoli, carrots, cauliflower, celery, chives, fennel, horseradish, kohlrabi, leafy greens, leeks, onions, peas, radishes, rutabagas, and turnips); fish excludes shellfish; chicken includes fast food chicken and canned chicken.

[c] Significantly different from vegetables, fruits, and oils cluster based on Dunnett's test for continuous variables. * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.0001$.

[d] To generate weighted aggregate scores based on the IFSAC 2019 report, the intakes of risky foods were multiplied by the percent of outbreaks that were attributed to that food and then were averaged across dietary patterns (figure 4 of IFSAC Attribution Report for 2019) *(21)*.

weighted based on percentage of outbreak-associated illnesses attributed to each food in the IFSAC 2019 Attribution Report, the total scores for the RTE cereal, milk, and yogurt and the vegetables, fruits, and cheeses patterns were significantly larger than those for all of the other patterns ($P < 0.0001$). The meat mixed dishes pattern had a significantly higher total score than the meats and white potatoes pattern and the grain dishes and sandwiches pattern ($P < 0.0001$, data not shown). The grain dishes and sandwiches pattern had the lowest risk-based score using either scoring strategy.

DISCUSSION

Research and education aimed at older adults, an underreached and vulnerable population, can help ensure that they have the knowledge and skills to optimize their food selections, with the possibility of improving their health *(26)*. To prevent invasive listeriosis among this vulnerable group, it is important that older adults become aware of this food safety issue, particularly those who are most susceptible and those who consume more of the foods associated with a higher risk of listeriosis. Information gathered in this study could be useful in developing and targeting food safety education efforts and in furthering research into food consumption, nutritional status, and risk of listeriosis.

Our results show that some dietary patterns of older adults are associated with greater intake of foods historically associated with higher risk of listeriosis, as determined from an epidemiology-based attribution study. This was evident from both the proportion of older adults in the clusters consuming these foods and the differences in mean intakes of these foods. When the dietary patterns were scored, using two different methods based on mean intake of these foods, the vegetables, fruits, and cheeses and the RTE cereal, milk, and yogurt patterns were identified as being associated with the highest relative risk of listeriosis based both on consumption of foods associated with listeriosis risk and on risk-based scoring.

Approximately 27% of older adults in this study sample were clustered in the vegetables, fruits, and cheeses (∼13%) or RTE cereal, milk, and yogurt (∼14%) patterns, which were determined to have the highest relative risk of listeriosis. The proportion of the population whose diets are aligned with these patterns, therefore, may have a higher relative risk of listeriosis and may be important to target for food safety education or other risk management strategies. Note that these dietary patterns and the foods identified as contributing most to the relatively high listeriosis risk–based scores (fruits, vegetables, and dairy) are also part of a healthy diet. Risk communication and education efforts may be challenged to deliver food safety messages in a way that does not discourage older adults from eating fruits, vegetables, and dairy while providing information on proper storage and preparation methods of these foods.

In our study, those who were clustered within the vegetables, fruits, and cheeses or the RTE cereal, milk, and yogurt patterns had the highest rates of food security and the lowest rates of poverty, and they were most likely to rate their diet quality and health highly. Those with the means and knowledge to make healthy food choices may or may not be educated on how to prevent foodborne illness. Indeed, a 2011 study of older adults from the U.S. Food and Drug Administration's 2006 Food Safety Survey showed that those with more education and higher incomes were less likely to follow recommended food safety practices and had lower awareness of food safety risk *(7)*. Older adults with these characteristics may not be targeted with nutrition education or interventions, due to higher diet quality and less dependence on food assistance programs. However, it may be important to reach them with food safety education. Individuals in the vegetables, fruits, and cheeses pattern were about 61% women, and those in the RTE cereal, milk, and yogurt pattern were also majority women (53.4%). Among the population in general, but especially among those who are older, women are more likely than men to be responsible for food shopping and preparation *(14),* and so food safety education may help protect not only them but also other members of their household.

Additionally, those clustered in the RTE cereal, milk, and yogurt pattern had the highest relative risk of consuming foods associated with listeriosis outbreaks and were also the oldest. Risk of listeriosis is known to increase significantly with age, even after age 60 *(12)*. This may be due to decreased immune function in the older population; however, it would be valuable to understand whether the food choices of older adults increase in relative risk of listeriosis with increasing age. Future research that ranks the risk of dietary patterns in different age groups may provide insight as to the influence of dietary choices on risk of listeriosis and may provide further guidance on how to target messaging to the most at-risk groups.

The third- and fourth-highest ranking dietary patterns in our sample based on the weighted risk-based score were the meat mixed dishes pattern and the meats and white potatoes pattern. The foods that drove the high risk-based score for these patterns (meats), however, were very different from those in the vegetable and oils pattern or the RTE cereal, milk, and yogurt pattern. According to their recalls, individuals in these patterns consumed significantly more pork than did those in the vegetables, fruits, and cheeses pattern or the RTE cereal, milk, and yogurt pattern. Individuals in these patterns were less food secure and were less likely to rate both their diet and their health as excellent, compared with those in the vegetables, fruits, and cheeses or the RTE cereal, milk, and yogurt patterns.

The grain dishes and sandwiches pattern was ranked the lowest relative risk for listeriosis because individuals in this pattern consumed fewer servings of the foods identified by the attribution report as associated with higher risk of listeriosis. This pattern had the highest proportion of all of the non-White race and ethnicity groups and the lowest level of education; individuals in this pattern were the most likely to have received emergency food or Supplemental Nutrition Assistance Program help in the last 12 months and had the lowest food security. In this pattern, there are over twice as many Hispanic (Mexican and other Hispanic) participants compared with the other patterns. This finding is interesting in the context of a previous study that showed that, although, overall, Hispanics were at a higher risk of invasive listeriosis, Hispanics age 60 to 69 years had a lower risk compared with non-Hispanics of the same age *(30)*. Further research on the dietary patterns of older versus younger Hispanics may be important to understand what is contributing to the risk of listeriosis in this population.

Our results suggest that a single profile of an older adult at risk for listeriosis may not exist, and so risk managers and educators may need to access different venues and use targeted messages and strategies to reach the appropriate audiences. Establishing the differences among older adults in consumption patterns of foods that have been associated with higher relative risk of listeriosis, and the characteristics of those consuming these foods, provides critical information that can be used to develop effective risk management strategies. Education on food safety measures, such as handling and storage of foods associated with listeriosis, may help prevent illnesses. Knowledge and understanding of attitudes, practices, and beliefs of each targeted audience may also be needed to develop effective messages that will result in behavior change.

The use of cluster analysis is a novel strategy for examining the relationship between dietary patterns and food safety. However, with this unique methodological approach come some limitations that are important to consider in the interpretation of the results. The statistical program used to do cluster analysis cannot accommodate the full complexity of the NHANES survey design. Thus, we cannot extrapolate from our sample to the United States population. It is still valuable to explore the patterns within this sample, however. Our observations show that dietary data, food safety data, and population data combined can provide new knowledge about who may be at risk. Additionally, our results show patterns and associations that generate questions to be tested in future representative studies.

Although an advantage of this study is that we are using two 24-h recalls, an inherent limitation of dietary data collection is that dietary intake can be variable and change over time. Nevertheless, this is useful information because even a single exposure to *L. monocytogenes* can cause illness that may be life threatening. If and when comprehensive current food frequency questionnaire data for the U.S. population become available, this information could be used to characterize risk based on how common a food is in the participant's diet.

Our study also has limitations with regard to the methods used for identifying and weighting foods that may put consumers at higher risk of listeriosis. The ranking system we created was based on the IFSAC 2019 Attribution Report, which uses outbreak data from 1998 to 2017 and weights most heavily recent data (2013 to 2017), to provide current estimates for foodborne illness attribution. Data for outbreaks in which multiple foods were identified as the vehicle or for which no food vehicle could be identified were not included in the attribution fraction estimates provided in the IFSAC 2019 Attribution Report *(20),* and the results assumed that outbreak data provide attribution information on sporadic listeriosis cases, which comprise the majority of cases of listeriosis *(36)*. It would be valuable to evaluate the risk associated with these consumption patterns using updated risk assessment data, when these data become available; a comprehensive risk assessment of listeriosis from consumption of a wide diversity of foods in the United States has not been conducted since 2003 (although risk assessments focused on specific foods and food safety systems have been completed *(8, 13, 16, 27, 30, 35)*).

This study was innovative in its use of a dietary data set, combined with preexisting food safety data, to explore the risk of listeriosis in the context of dietary patterns, which are more reflective of the foods that the population typically consumes together. This information and methodology can support the development of food safety interventions and identify target groups for messaging specific to their dietary habits.

To our knowledge, this was the first study to use dietary intake data from older adults to explore risk of listeriosis in the United States associated with dietary patterns. Our aim was to categorize individuals' food intake into dietary patterns and to examine intakes of foods historically associated with relatively higher risk of listeriosis within these dietary patterns. We also determined the characteristics of those consuming these higher-risk patterns based on 2 days of intake. Our results showed that multiple patterns may be associated with relatively higher risk, with the risk in each pattern coming from distinctively different foods. Additionally, the contrast in profiles of the groups consuming these patterns suggests that a variety of strategies are likely needed to effectively target food safety education toward these distinctly different groups. It is also important to update the risk assessment data of foods that currently pose the highest risk of listeriosis.

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