RESEARCH REPORT

HUMAN NUTRITION

Title: Influence of fresh and lean pork consumption on diet quality and functional limitations among American older adults, 1999-2016 – **NPB #18-002**

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Industry Summary:
The two objectives of the project are to (1) assess the influence of fresh and lean pork consumption on diet quality among U.S. adults 18 years and older and (2) functional limitations in U.S. older adults 65 years and above, using data from the National Health and Nutrition Examination Survey (NHANES) 2005–2016 waves.

Approximately 19.4%, 16.5%, and 16.1% of U.S. adults 18 years and older consumed pork, fresh pork, and fresh lean pork, respectively. Prevalence of pork, fresh pork, and fresh lean pork consumption differed by sex, race/ethnicity, and education level. Increased fresh and lean pork rather than total pork intake was related to marginally improved nutritional intakes (i.e., protein, magnesium, potassium, selenium, zinc, phosphorus, and vitamins B_1, B_2, B_3, and B_6) with lesser increases in daily total energy, saturated fat, and sodium intakes. Pork, fresh pork, and fresh lean pork consumption was not found to be associated with the Healthy Eating Index (HEI)-2015 score.

Approximately 21%, 18%, and 16% of older adults 65 years and older consumed pork, fresh pork, and fresh lean pork, respectively. An increase in pork consumption by one ounce-equivalent/day was associated with a reduced odds of activities of daily living (ADLs) by 12%, instrumental activities of daily living (IADLs) by 10%, and any functional limitation by 7%. An increase in fresh pork consumption by one ounce-equivalent/day was associated with a reduced odds of ADLs by 13%, IADLs by 10%, general physical activities (GPAs) by 8%, and any functional limitation by 8%. Similar effects were found for fresh lean pork consumption on ADLs, IADLs, GPAs, and any functional limitation.

In conclusion, U.S. adult pork consumers may increase their share of fresh and fresh lean pork over total pork consumption in an effort to increase their daily intakes of beneficial nutrients while minimizing intakes of energy, saturated fat, and sodium. In addition, there is some preliminary evidence linking fresh/lean pork consumption to a reduced risk of functional limitations among U.S. older adults.

Key Findings:

- Prevalence of pork, fresh pork, and fresh lean pork consumption among U.S. adults 18 years and older differed by sex, race/ethnicity, and education level.
- Increased fresh and lean pork rather than total pork intake was related to marginally improved nutritional intakes with lesser increases in daily total energy, saturated fat, and sodium intakes.
- An increase in pork consumption by one ounce-equivalent/day among U.S. older adults 65 years and older was associated with a reduced odds of activities of daily living (ADLs) by 12%, instrumental activities of daily living (IADLs) by 10%, and any functional limitation by 7%.
- An increase in fresh pork consumption among U.S. older adults 65 years and older by one ounce-equivalent/day was associated with a reduced odds of ADLs by 13%, IADLs by 10%, general physical activities (GPAs) by 8%, and any functional limitation by 8%.

Keywords: pork; diet; nutrient intake; functional limitation; older adult

Scientific Abstract:

Introduction: Pork consumption, in particular fresh/lean pork consumption, provides protein and other essential micronutrients that older adults need daily and may hold the potential to prevent functional limitations resulting from sub-optimal nutrition.

Objectives: The two objectives of the project are to (1) assess the influence of fresh and lean pork consumption on diet quality among U.S. adults 18 years and older and (2) functional limitations in U.S. older adults 65 years and above, using data from the National Health and Nutrition Examination Survey (NHANES) 2005–2016 waves.

Materials & Methods: Nationally-representative sample from the National Health and Nutrition Examination Survey (NHANES) 2005–2016 waves were analyzed. First-difference estimator addressed confounding bias from time-invariant unobservables (e.g., eating habits, taste preferences) by using within-individual variations in pork consumption between 2 nonconsecutive 24-hour dietary recalls. Nineteen validated questions assessed five functional limitation domains: activities of daily living (ADLs), instrumental activities of daily living (IADLs), leisure and social activities (LSAs), lower extremity mobility (LEM), and general physical activities (GPAs). Logistic regressions were performed to examine pork, fresh pork, and fresh lean pork intake in relation to functional limitations among NHANES older adults.

Results: Approximately 19.4%, 16.5%, and 16.1% of U.S. adults 18 years and older consumed pork, fresh pork, and fresh lean pork, respectively. Prevalence of pork, fresh pork, and fresh lean pork consumption differed by sex, race/ethnicity, and education level. Increased fresh and lean pork rather than total pork intake was related to marginally improved nutritional intakes (i.e., protein, magnesium, potassium, selenium, zinc, phosphorus, and vitamins B_1, B_2, B_3, and B_6) with lesser increases in daily total energy, saturated fat, and sodium intakes. Pork, fresh pork, and fresh lean pork consumption was not found to be associated with the Healthy Eating Index (HEI)-2015 score. Approximately 21%, 18%, and 16% of older adults 65 years and above consumed pork, fresh pork, and fresh lean pork, respectively. An increase in pork consumption by one ounce-equivalent/day was associated with a reduced odds of ADLs by 12%, IADLs by 10%, and any functional limitation by 7%. An increase in fresh pork consumption by one ounce-equivalent/day was associated with a reduced odds of ADLs by 13%, IADLs by 10%, GPAs by 8%, and any functional limitation by 8%. Similar effects were found for fresh lean pork consumption on ADLs, IADLs, GPAs, and any functional limitation.

Discussion: U.S. adult pork consumers may increase their share of fresh and fresh lean pork over total pork consumption in an effort to increase their daily intakes of beneficial nutrients while minimizing intakes of energy, saturated fat, and sodium. This study found some preliminary evidence linking fresh/lean pork consumption to a reduced risk of functional limitations. Future studies with longitudinal/experimental designs are warranted to examine the influence of fresh/lean pork consumption on functional limitations.

Fresh and Lean Pork Consumption in Relation to Nutrient Intakes and Diet Quality among U.S. Adults, 2005–2016

Abstract

Background: This study assessed the influence of pork consumption on nutrient intakes and diet quality among U.S. adults.

Methods: Nationally-representative sample (N=27,117) from the National Health and Nutrition Examination Survey (NHANES) 2005–2016 waves were analyzed. First-difference estimator addressed confounding bias from time-invariant unobservables (e.g., eating habits, taste preferences) by using within-individual variations in pork consumption between 2 nonconsecutive 24-hour dietary recalls.

Results: Approximately 19.4%, 16.5%, and 16.1% of U.S. adults consumed pork, fresh pork, and fresh lean pork, respectively. Prevalence of pork, fresh pork, and fresh lean pork consumption differed by gender, race/ethnicity, and education level. An increase in pork, fresh pork, and fresh lean pork consumption by 1 ounce-equivalent per day was found to be associated with an increase in the Healthy Eating Index (HEI)-2010 score by 0.15, 0.20, and 0.22, respectively. An increase in pork, fresh pork, and fresh lean pork consumption by 1 ounce-equivalent per day was found to be associated with an increase in intakes of total energy by 26.1, 23.2, and 22.6 kcal, protein by 4.0, 4.0, and 4.0 g, saturated fat by 0.5, 0.4, and 0.4 g, sodium by 64.4, 54.8, and 53.5 mg, magnesium by 3.7, 3.6, and 3.6 mg, potassium by 84.6, 82.6, and 82.6 mg, selenium by 6.8, 6.8, and 6.7 µg, zinc by 0.3, 0.3, and 0.3 mg, phosphorus by 30.6, 30.1, and

29.7 mg, vitamin B_1 by 0.17, 0.18, and 0.18 mg, vitamin B_2 by 0.04, 0.04, and 0.04 mg, vitamin B_3 by 0.78, 0.78, and 0.79 mg, and vitamin B_6 by 0.10, 0.10, and 0.10 mg, respectively.

Conclusion: Pork, fresh pork, and fresh lean pork consumption was positively associated with diet quality measured by HEI-2010. Increased pork, fresh pork, and fresh lean pork consumption was also associated with greater daily intakes of total energy, protein, saturated fat, sodium, magnesium, potassium, selenium, zinc, phosphorus, and multiple B vitamins. Increased fresh and lean pork rather than total pork intake was related to marginally better nutritional intakes as a function of pork consumption with lesser increases in energy, saturated fat, and sodium intake.

Keywords: Pork; Diet quality; Nutrient intake

Background

Pork is often included in the U.S. diet. Within the U.S., pork ranks third in annual meat consumption following beef and chicken.[1] Between 2014–2016, U.S. adults averaged 50 pounds of pork consumption a year, accounting for over a quarter of overall meat intake.[1] When incorporated into a balanced diet, animal protein such as pork can provide essential nutrients including but not limited to protein, iron, zinc, and multiple B vitamins.[2] The U.S. Department of Health and Human Services has raised recent concerns that more than 40% of U.S. residents are not meeting the recommended dietary guidelines for protein intake.[3] Previous studies documented fresh and fresh lean pork consumption to be associated with increased daily intakes of protein, phosphorus, potassium, selenium, zinc, and vitamins B_2, B_3, B_6, and B_{12}.[4] Considering the associated dietary intakes, including pork in a balanced diet may improve overall diet quality for U.S. adults, particularly for those who choose fresh and lean pork.

Arguments against pork consumption largely focus on issues related to environmental sustainability, including animal welfare, and/or health implications of processed meat intake. The carbon footprint of meat production warrants recommendations for reduced pork intake[5], but others argue that the contribution of red meat to diet quality deserves more appreciation in consideration of protein and micronutrients less commonly obtained from plant-based alternatives.[6] A primary concern is the saturated fat content and the preparation method, such as processed meats, which may include or increase unhealthy substances.[7] Others argue that the guidelines regarding reduced consumption of red meats do not adequately differentiate between processed and unprocessed red meat and therefore may be too restrictive.[8] Fresh and fresh lean pork consumers were found to have comparable daily fat and saturated fat intake compared to non-consumers, suggesting that unprocessed fresh and fresh lean pork can be part of a healthy diet.[9]

This study advances previous findings and assesses the impact of including pork in U.S. adult diets. Specifically, it addresses nutrient intake and diet quality in relation to pork consumption for adults aged 18 years and older and contributes to previous literature in three main ways. This analysis considers pork, fresh pork, and fresh lean pork as distinct categories, examining the relationship of each with diet quality and daily nutrient intakes. Second, it produces population-level analyses and estimates via examination of a large-scale nutrition survey involving a 12-year interval (2005–2016). Finally, this study offers a first-difference modeling approach, which addresses and removes potential confounding bias from any discrepancies in time-invariant individual characteristics. The study hypothesized that pork consumption, namely fresh and fresh lean pork consumption, would be positively associated with increased daily intakes of protein, iron, magnesium, potassium, selenium, zinc, phosphorus, and vitamins B_1, B_2, B_3, B_6, and B_{12}. These 12 nutrients are notably rich in pork products.[2,4,6,9] Conversely, pork consumption was also hypothesized to be associated with higher daily intakes of total energy, saturated fat, and sodium, but the increase would be lower for fresh and fresh lean pork consumption.

Methods

Survey setting and participants

The National Health and Nutrition Examination Survey (NHANES) is a program of studies conducted by the National Center for Health Statistics (NCHS) to assess the health and nutritional status of children and adults. The program began in the early 1960s and periodically conducted separate surveys focusing on different population groups or health topics. Since 1999, the NHANES has been conducted continuously in 2-year cycles and has a changing focus on a variety of health and nutrition measurements. A multistage probability sampling design is used to select participants representative of the civilian, non-institutionalized U.S. population. Certain population subgroups are oversampled to increase the reliability and precision of health status indicator estimates for these groups. Detailed information regarding the NHANES sampling design, questionnaires, clinical measures, and individual-level data can be found elsewhere.[10]

Dietary interview

Except for the NHANES 1999–2000 wave where all participants were asked to complete a single 24-hour dietary recall, all subsequent waves incorporated 2 dietary recalls, with the first collected in-person and the second by telephone 3 to 10 days later. In both interviews, each food or beverage item and corresponding quantity consumed by a participant from midnight to midnight on the day before the interview was recorded. The in-person dietary recall (day 1) was conducted by trained dietary interviewers in the Mobile Examination Center (MEC) with a standard set of measuring guides. These tools aimed to help the participant accurately report the volume and dimensions of the food/beverage items consumed. Upon completion of the in-person interview, participants were provided measuring cups, spoons, a ruler and a food model booklet, which contained 2-dimensional drawings of the various measuring guides available in the MEC, to use for reporting dietary intake during the telephone interview (day 2). Following the dietary interview, the caloric and nutrient contents of each reported food and/or beverage item were systematically coded with the U.S. Department of Agriculture (USDA) Food and Nutrient Database for Dietary Studies (FNDDS). Access restrictions apply to the day 2 dietary recall data collected in the NHANES 2001–2002 wave, whereas dietary data for both recall days are released to the public for all subsequent waves.

Pork consumption

Each food item consumed is assigned an 8-digit FNDDS code in the NHANES. Pork products occupy the codes 22000100–22820000. However, FNDDS codes do not differentiate fresh or fresh lean pork. We thus linked FNDDS codes to the USDA National Nutrient Database for Standard Reference (SR), which assigns a 5-digit Nutrient Databank (NDB) number to each food item. The NDB numbers are linked to the FNDDS codes in the FNDDS link files. Pork is a unique food group classified in the SR, and each pork product is associated with a detailed text description. Fresh pork refers to pork products that do not contain any artificial flavor or flavoring, coloring ingredient, chemical preservative, or any other artificial or synthetic ingredient; and the products and their ingredients are not more than minimally processed (e.g., ground). We identified fresh pork products using the keywords “fresh” or “raw”, and lean pork products using “lean” in the description. Fresh lean pork products are pork products that are both fresh and lean. The SR defines fresh lean pork as fresh pork containing less than 10 g of fat, 4.5 g of saturated fat, and 95 mg of cholesterol per 100 g of product. To estimate the ounce-equivalents of pork consumption, we further merged the NHANES data with the corresponding Food Patterns Equivalents Database (FPED). A new version of the FPED is developed for each NHANES wave. FPED converts the foods and beverages in the FNDDS to the USDA food patterns (FPs) components, and the FPs are measured as ounce-equivalents for protein foods. Due to the modifications of the FPs classifications in FPED over the years, we adopted the most recent version of FPs classifications that has been consistent since the NHANES 2005–2006 wave.

A pork consumer is defined as an adult NHANES participant who consumed any pork products on either dietary recall day. Analogously, a fresh or fresh lean pork consumer is defined as an adult participant who consumed any fresh or fresh lean pork products on either dietary recall day, respectively. In contrast, a pork non-consumer is defined as an adult participant who consumed no pork products on both dietary recall days.

Diet quality

The Healthy Eating Index (HEI)-2010 was developed by the USDA as a measure of dietary quality in accordance with the Dietary Guidelines for Americans (DGA), 2010.[3,11] It consists of 12 components: total fruit, whole fruit, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, fatty acids, refined grains, sodium, and empty calories (calories from solid fats, alcohol, and added sugars). With a maximum score of 100, a higher HEI-2010 score reflects closer adherence to the DGA. We calculated each NHANES participant's HEI-2010 score on either dietary recall day using the FPED and following the procedures established by the USDA and the National Cancer Institute.[11]

Nutrient Intakes

In the dietary recall data, energy derived from each consumed food/beverage item was recorded based on the quantity of food/beverage reported and the corresponding energy contents. We calculated daily caloric intake (kcal) and daily intakes of protein (g), saturated fat (g), sodium (mg), iron (mg), magnesium (mg), potassium (mg), selenium (μg), zinc (mg), phosphorus (mg), vitamin B_1 (mg), vitamin B_2 (mg), vitamin B_3 (mg), vitamin B_6 (mg), and vitamin B_{12} (μg) from pork products alone as well as from all foods/beverages on either dietary recall day among pork consumers, fresh pork consumers, fresh lean pork consumers, and pork non-consumers.

Individual characteristics

The following individual characteristics were reported for U.S. adults aged 18 years and older: sex, age (stratified into 2 age groups: 18–64 years of age and 65 years of age and older), race/ethnicity (non-Hispanic white, non-Hispanic African American, non-Hispanic other race or multi-race, and Hispanic), education (high school and below, and college and above), marital status (married, divorced/separated/widowed, and never married), household income (income to poverty ratio [IPR] $< 130\%$, $130\% \leq$ IPR $< 300\%$, and IPR $\geq 300\%$), smoking status (non-smoker, and former or current smoker), self-rated health (good or excellent health, and fair or poor health), chronic conditions (diabetes, arthritis, coronary artery disease, stroke, and cancer), survey wave, and obesity status. Participants' body height and weight were measured by stadiometer and digital scale in the MEC. Body mass index (BMI) is defined by weight in kilograms divided by height in meters squared (kg/m^2). Adult obesity was defined as BMI ≥ 30 kg/m^2 based on the international classification of adult BMI values.[12]

Sample size

This study used individual-level data from the NHANES 2005–2006, 2007–2008, 2009–2010, 2011–2012, 2013–2014, and 2015–2016 waves. Among a total of 28,704 U.S. adults aged 18 years and older who participated in the 24-hour dietary recalls, 1,587 that were pregnant, lactating, and/or on a special diet to lose weight at the time of interview were excluded, resulting in a final sample of 27,117 participants.

Statistical analyses

Using descriptive statistics, we summarized individual characteristics of pork consumers, fresh pork consumers, fresh lean pork consumers, and pork non-consumers. Additionally, their daily caloric intake, daily intakes of protein, saturated fat, sodium, choline, iron, selenium, zinc, phosphorus, vitamin B_2, vitamin B_3, vitamin B_6, and vitamin B_{12} from pork products alone as well as from all foods/beverages were estimated.

Logistic regressions were performed to estimate the adjusted odds ratios of pork, fresh pork, or fresh lean pork consumption with respect to individual characteristics among NHANES adult participants. The dependent variables were dichotomous variables for any pork, fresh pork, or fresh lean pork consumption on either dietary recall day.

First-difference estimator was performed on pork, fresh pork, and fresh lean pork consumers using data from their day 1 and day 2 dietary interviews that provided 2 observations per person. The outcome (e.g., daily total caloric intake and zinc intake) of participant *i* on day *t* ($t = 1, 2$) is denoted by y_{it}. We let vector $\boldsymbol{X}_i$ represent the set of variables that vary by participant, but remain constant within-participant between the 2 dietary interviews (e.g., sex and race/ethnicity). Given the short recall time interval of 3–10 days, $\boldsymbol{X}_i$ includes individual characteristics that vary only in the longer term, such as age, education attainment, income level, body weight, etc. Continuous variable $pork_{it}$ denotes daily pork (or fresh and fresh lean pork) consumption in the unit of ounce-equivalents by participant i on day *t*. Indicator variable we_{it} denotes whether day *t* was a weekend (Friday, Saturday or Sunday).

A pooled cross-sectional setup (a conventional regression that treats repeated measures within each study subject as independent observations) specifies the outcome y_{it} as a function of an unobservable term that varies by participant α_i, observable variables that vary by participant $\boldsymbol{X}_i$, observable variables that vary within-participant between the 2 dietary interviews $pork_{it}$ and we_{it}, and an independently-distributed unobservable disturbance term ε_{it}.

[1] $y_{it} = \boldsymbol{\mu X}_i + \beta_1 pork_{it} + \beta_2 we_{it} + \alpha_i + \varepsilon_{it}$

Due to the presence of the unobservable term α_i (e.g., eating habits, taste preferences), estimating equation [1] by controlling for the observables $\boldsymbol{X}_i$ only is prone to omitted variable bias. The first-difference estimator eliminates the bias by taking the difference between the 2 days of data within each participant, so that α_i and $\boldsymbol{\mu X}_i$ that are common within-participant are removed.

[2] $y_{i1} - y_{i2} = \beta_1(pork_{i1} - pork_{i2}) + \beta_2(we_{i1} - we_{i2}) + (\varepsilon_{i1} - \varepsilon_{i2})$

Equation [2] was estimated for each outcome variable (i.e., HEI-2010 score, daily total caloric intake, and daily intakes of protein, saturated fat, sodium, choline, iron, selenium, zinc, phosphorus, vitamin B_2, vitamin B_3, vitamin B_6, and vitamin B_{12}) and each type of pork consumption (i.e., pork, fresh pork, and fresh lean pork). There are 14 outcome variables and 3 types of pork consumption so that a total of 42 regressions were estimated.

The NHANES 2005–2016 multi-wave complex survey design was accounted for in both descriptive statistics and regression analyses. All statistical procedures were performed in Stata 15.1 SE version (StataCorp, College Station, TX). A p-value < 0.05 was considered as being statistically significant.

Results

Table 1 reports individual characteristics of 2005–2016 NHANES adult pork consumers and non-consumers. Pork, fresh pork, and fresh lean pork consumers occupied 19.4%, 16.5%, and 16.1% of the study sample, respectively. They averaged daily consumption of 1.5 ounce-equivalents of pork, 1.7 ounce-equivalents of fresh pork, and 1.7 ounce-equivalents of fresh lean pork. Daily total energy intake averaged 227.1, 155.5, and 155.4 kcal from pork, fresh pork, and fresh lean pork products, respectively. Pork consumers daily acquired 18.5 g of protein, 4.0 g of saturated fat, 560.6 mg of sodium, 1.3 mg of iron, 24.4 mg of magnesium, 324.8 mg of potassium, 27.8 µg of selenium, 2.2 mg of zinc, 196.6 mg of phosphorus, 0.43 mg of vitamin B_1, 0.24 mg of vitamin B_2, 4.46 mg of vitamin B_3, 0.33 mg of Vitamin B_6, and 0.64 µg of vitamin B_{12} from pork products. Daily intake of sodium from fresh pork (344.0 mg) and fresh lean pork products (343.7 mg) was noticeably lower than those acquired from pork products (560.6 mg). Other nutrient intakes from fresh pork and fresh lean pork products were also modestly lower than those acquired from pork products.

Diet quality and daily saturated fat intake were similar between pork consumers and non-consumers, whereas pork consumers' daily intakes of total energy, protein, sodium, and most other nutrients (except for iron and vitamin B_{12}) were higher than non-consumers. Pork, fresh pork, and fresh lean pork consumers averaged an HEI-2010 score of 49.4, 49.7, and 49.7, respectively, compared to 50.4 among pork non-consumers. Pork consumers and non-consumers averaged 27.3 and 26.0 mg of daily saturated fat intake, respectively. In contrast, pork consumers averaged 2200.2 kcal of daily total energy, 89.5 g of protein, and 3747.5 mg of sodium, compared to 2078.8 kcal of daily total energy, 81.0 g of protein, and 3439.1 mg of sodium among pork non-consumers.

Table 2 reports the adjusted odds ratios of pork, fresh pork, and fresh lean pork consumption estimated from the logistic regressions. Females were less likely to consume pork, fresh pork, and fresh lean pork products than males. African Americans and other race/multi-race were more likely to consume pork, fresh pork, and fresh lean pork than whites, and Hispanic were more likely to consume pork than whites. People with college education and above were less likely consume pork, fresh pork, and fresh lean pork than those with high school or lower education. Compared to their married counterparts, those never married were less likely to consume pork, fresh pork, and fresh lean pork. People with diabetes were more likely to consume fresh pork and fresh lean pork than their non-diabetic counterparts. Age, income, obesity status, smoking, self-rated health, and other chronic diseases (except diabetes) were unassociated with pork consumption.

Table 3 reports the estimated effects of pork, fresh pork, and fresh lean pork consumption on daily energy/nutrient intake and diet quality using the first-difference estimator. An increase in pork, fresh pork, and fresh lean pork consumption by 1 ounce-equivalent per day was found to be associated with an increase in HEI-2010 score by 0.15 (95% confidence interval [CI] = 0.01, 0.31), 0.20 (95% CI = 0.05, 0.36), and 0.22 (95% CI = 0.06, 0.37), respectively. An increase in pork, fresh pork, and fresh lean pork consumption by 1 ounce-equivalent per day was found to be associated with an increase in intakes of total energy by 26.1, 23.2, and 22.6 kcal, protein by 4.0, 4.0, and 4.0 g, saturated fat by 0.5, 0.4, and 0.4 g, sodium by 64.4, 54.8, and 53.5 mg, magnesium by 3.7, 3.6, and 3.6 mg, potassium by 84.6, 82.6, and 82.6 mg, selenium by 6.8, 6.8, and 6.7 µg, zinc by 0.3, 0.3, and 0.3 mg, phosphorus by 30.6, 30.1, and 29.7 mg, vitamin B_1 by

0.17, 0.18, and 0.18 mg, vitamin B_2 by 0.04, 0.04, and 0.04 mg, vitamin B_3 by 0.78, 0.78, and 0.79 mg, and vitamin B_6 by 0.10, 0.10, and 0.10 mg, respectively. In contrast, no association linking pork, fresh pork, and fresh lean pork consumption with daily intakes of iron and vitamin B_{12} was identified.

Discussion

Regular inclusion of pork in the diet by U.S. adults can contribute nutrients essential to diet quality. Until now, there has been little examination of the relationship between different categories of pork consumption and diet quality or specific nutrient intakes. This study offers consideration of pork consumption in relation to the diet quality and nutrient intakes of U.S. adults based on data from a nationally representative nutrition survey conducted over 12 years. Approximately 19%, 17%, and 16% of U.S. adults consumed pork, fresh pork, and fresh lean pork, respectively. Prevalence of pork, fresh pork, and fresh lean pork consumption differed by sex, race/ethnicity, and education level. An increase in pork, fresh pork, and fresh lean pork consumption by 1 ounce-equivalent per day was associated with an increase in HEI-2010 score by 0.15, 0.20, and 0.22, respectively. Pork, fresh pork, and fresh lean pork consumption was also associated with increased daily intakes of total energy, protein, saturated fat, sodium, magnesium, potassium, selenium, zinc, phosphorus, and multiple B vitamins.

This study was consistent with results from past studies on the positive effect of pork consumption on some essential macronutrient and micronutrient intakes, such as protein, phosphorus, potassium, selenium, and zinc.[2,4,6,9] Additionally, the current study distinguished the contribution between pork and fresh/lean pork intake on diet quality and nutrient intakes. While overall pork consumption was associated with the largest increase in specific nutrient intakes, increased nutrient intakes attributable to fresh pork and fresh lean pork consumption were fairly comparable. Conversely, fresh pork and fresh lean pork intakes were associated with less increase in daily intakes of total energy, saturated fat, and sodium than overall pork consumption. Specifically, an increase in pork consumption by 1 ounce-equivalent per day was associated with an increase in total energy by 26.1 kcal, saturated fat by 0.5 g, and sodium by 64.4 mg. An increase in fresh lean pork consumption by 1 ounce-equivalent per day was associated with an increase in total energy by 22.6 kcal, saturated fat by 0.4 g, and sodium by 53.5 mg. Moreover, fresh pork and fresh lean pork consumption tended to be associated with a larger increase in diet quality compared to overall pork intake. Because increased fresh and fresh lean pork, rather than overall pork, intake was related to marginally better micronutrient intakes as a function of pork consumption with lesser increases in energy, saturated fat, and sodium intake, U.S. adults who consume pork may benefit nutritionally from fresh/lean pork intake more so than overall pork intake.

Our findings suggest pork consumption differs by individual characteristics. Similar differential patterns in red meat consumption, including pork, are well-documented.[13–15] The heterogeneous patterns of pork consumption by sex and race/ethnicity could be explained in part by cultural and dietary tradition variations as well as some biological differences.[13] Lower educational levels were previously found to be associated with red and/or processed meat consumption as compared to consumption of fish and poulty.[13] However, it is possible that such an association could be partially explained by individuals with higher education levels having a better understanding of meat consumption choices in relation to weight control and chronic disease prevention, perhaps choosing to consume less red meat to moderate energy balance and influence personal health. General meat consumption has been associated with adiposity in U.S. adults.[15,16] Pork consumption in this analysis of the NHANES adult sample could possibly be related to or increase risk of diabetes. However, we are not able to make any causal correlations from this cross-sectional evaluation because of potential confounding bias and reverse causality.

This study has several limitations worth addressing. First, the NHANES is a probability sample that includes noninstitutionalized U.S. adults, which means it does not include information on dietary intakes of patients in mental facilities, incarcerated populations, institutionalized older adults, or active duty military personnel. It is possible that the NHANES could have measurement errors related to the self-reported nature of the dietary intakes as well as the issue of social desirability bias.[17] We used the first-difference estimator to remove confounding bias from unobservable factors which remain constant within-participant over the 2 dietary interviews. However, this analysis could not account for other factors such as differences in daily physical activity, emotions, or appetite. The first-difference estimator tends to be less precise and have larger standard error, making it underpowered compared to pooled cross-sectional estimators. This is because the effect estimation only included a subsample of individuals who alternated their pork consumption choices between the 2 dietary recall days. On the other hand, those who did not consume pork at all were not included. Finally, this analysis only addressed immediate and short-term nutritional impacts of pork consumption. Analysis related to the impact of changes in diet quality and nutrient intakes related to long-term pork consumption and long-term health and disease is beyond the scope of our study. Indeed, future studies on the long-term impacts of pork consumption are warranted.

In conclusion, this study assessed the impact of pork consumption on energy/nutrient intakes and diet quality among U.S. adults using data from a nationally representative nutrition survey. Pork, fresh pork, and fresh lean pork consumption was positively associated with diet quality measured by HEI-2010. Additionally, pork, fresh pork, and fresh lean pork consumption was associated with increased daily intakes of total energy, protein, saturated fat, sodium, magnesium, potassium, selenium, zinc, phosphorus, and multiple B vitamins. U.S. adults may benefit from increasing fresh and fresh lean pork intakes to marginally improve diet quality and consume beneficial nutrients, while minimizing intakes of energy, saturated fat, and sodium from overall pork consumption. This study has limitations regarding measurement error and observational study design. Future studies are needed to examine the long-term impact of fresh and fresh lean pork consumption on diet quality, nutrient intakes, and health promotion.

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Table 1 Individual characteristics of 2005–2016 NHANES adult pork, fresh pork, and fresh lean pork consumers and pork non-consumers

Individual characteristics	**Pork consumers** Mean ± SD	**Fresh pork consumers** Mean ± SD	**Fresh lean pork consumers** Mean ± SD	**Pork non-consumers** Mean ± SD
Sample size	5,618	4,831	4,420	21,499
Daily total energy/nutrient intake				
Diet quality (HEI-2010)	49.35 ± 11.80	49.70 ± 11.75	49.71 ± 11.73	50.37 ± 12.93
Energy (kcal)	2200.23 ± 835.39	2182.39 ± 840.22	2182.99 ± 839.65	2078.81 ± 789.97***
Protein (g)	89.48 ± 35.81	89.27 ± 35.83	89.31 ± 35.79	80.95 ± 33.74***
Saturated fat (g)	27.26 ± 13.92	26.88 ± 13.81	26.89 ± 13.80	26.01 ± 13.26
Sodium (mg)	3747.51 ± 1526.51	3712.47 ± 1534.70	3713.85 ± 1533.73	3439.11 ± 1429.44***
Iron (mg)	15.29 ± 7.57	15.04 ± 7.26	15.05 ± 7.25	15.33 ± 7.73
Magnesium (mg)	305.27 ± 122.37	304.28 ± 121.36	304.40 ± 121.14	300.89 ± 131.30
Potassium (mg)	2812.75 ± 1050.01	2820.45 ± 1046.18	2821.77 ± 1043.46	2667.93 ± 1066.32***
Selenium (µg)	126.57 ± 56.02	126.65 ± 56.84	126.74 ± 56.80	110.90 ± 49.76***
Zinc (mg)	12.38 ± 6.41	12.33 ± 6.46	12.33 ± 6.45	11.61 ± 6.79*
Phosphorus (mg)	1420.30 ± 562.94	1413.23 ± 564.79	1413.83 ± 564.08	1363.75 ± 559.40***
Vitamin B_1 (mg)	1.88 ± 0.85	1.90 ± 0.85	1.90 ± 0.85	1.59 ± 0.78**
Vitamin B_2 (mg)	2.20 ± 1.04	2.21 ± 1.04	2.21 ± 1.03	2.18 ± 1.08
Vitamin B_3 (mg)	26.96 ± 12.18	26.81 ± 11.94	26.82 ± 11.92	25.59 ± 12.35***
Vitamin B_6 (mg)	2.21 ± 1.18	2.21 ± 1.15	2.21 ± 1.14	2.09 ± 1.24*
Vitamin B_{12} (µg)	5.25 ± 4.82	5.19 ± 4.73	5.19 ± 4.73	5.29 ± 4.83
Daily energy/nutrient intake from pork				
Prevalence in sample (%)	19.35 ± 38.92	16.50 ± 36.57	16.11 ± 36.52	80.65 ± 38.92
Pork (ounce-equivalent)	1.54 ± 1.37	1.66 ± 1.40	1.66 ± 1.40	/
Energy (kcal)	227.12 ± 206.93	155.53 ± 141.58	155.35 ± 141.47	/
Protein (g)	18.51 ± 14.54	15.52 ± 12.49	15.51 ± 12.48	/
Saturated fat (g)	4.01 ± 4.41	2.45 ± 2.77	2.44 ± 2.77	/
Sodium (mg)	560.59 ± 567.27	344.02 ± 381.75	343.71 ± 381.48	/
Iron (mg)	1.33 ± 1.48	0.83 ± 0.90	0.83 ± 0.90	/
Magnesium (mg)	24.43 ± 21.60	18.42 ± 16.38	18.44 ± 16.37	/
Potassium (mg)	324.82 ± 270.01	264.43 ± 229.83	264.91 ± 229.57	/
Selenium (µg)	27.77 ± 21.84	23.23 ± 18.66	23.24 ± 18.65	/
Zinc (mg)	2.18 ± 2.16	1.71 ± 1.90	1.71 ± 1.90	/
Phosphorus (mg)	196.61 ± 164.82	150.50 ± 122.3	150.71 ± 122.25	/
Vitamin B_1 (mg)	0.43 ± 0.37	0.39 ± 0.34	0.39 ± 0.34	/
Vitamin B_2 (mg)	0.24 ± 0.21	0.19 ± 0.16	0.19 ± 0.16	/
Vitamin B_3 (mg)	4.46 ± 3.61	3.72 ± 3.14	3.73 ± 3.13	/
Vitamin B_6 (mg)	0.33 ± 0.27	0.29 ± 0.24	0.29 ± 0.24	/
Vitamin B_{12} (µg)	0.64 ± 0.77	0.43 ± 0.41	0.43 ± 0.41	/

***Sex** (%)*				
Male	53.22 ± 49.72	53.41 ± 49.86	53.48 ± 49.79	47.56 ± 49.01***
Female	46.78 ± 49.72	46.59 ± 49.86	46.52 ± 49.79	52.44 ± 49.01***
***Age group** (%)*				
18–64 years of age	81.44 ± 38.74	80.55 ± 39.56	80.55 ± 39.51	82.19 ± 37.54
65 years of age and above	18.56 ± 38.74	19.45 ± 39.56	19.45 ± 39.51	17.81 ± 37.54
***Race/ethnicity** (%)*				
White, non-Hispanic	63.18 ± 48.06	63.61 ± 48.09	63.78 ± 47.98	70.63 ± 44.69***
African American, non-Hispanic	12.71 ± 33.19	13.05 ± 33.67	12.98 ± 33.55	10.48 ± 30.06**
Other race/multi-race, non-Hispanic	10.03 ± 29.94	9.82 ± 29.75	9.84 ± 29.73	6.08 ± 23.45***
Hispanic	14.08 ± 34.66	13.51 ± 34.17	13.41 ± 34.02	12.81 ± 32.79
***Education** (%)*				
High school and below	41.49 ± 49.10	42.12 ± 49.35	42.04 ± 49.28	37.72 ± 47.56**
College education and above	58.51 ± 49.10	57.88 ± 49.35	57.96 ± 49.28	62.28 ± 47.56**
***Marital status** (%)*				
Married	65.86 ± 47.25	65.82 ± 47.41	65.86 ± 47.34	62.57 ± 47.49**
Divorced, separated, or widowed	17.13 ± 37.55	17.70 ± 38.15	17.65 ± 38.06	18.75 ± 38.30
Never married	17.01 ± 37.44	16.48 ± 37.08	16.49 ± 37.05	18.68 ± 38.24
***Income to poverty ratio (IPR)** (%)*				
IPR < 130%	21.63 ± 41.03	21.10 ± 40.79	20.99 ± 40.66	21.59 ± 40.38
130% ≤ IPR < 300%	30.05 ± 45.69	30.44 ± 45.99	30.45 ± 45.94	28.41 ± 44.25
IPR ≥ 300%	48.31 ± 49.80	48.46 ± 49.96	48.56 ± 49.90	50.00 ± 49.06
***Obesity** (%)*				
Non-obese (BMI < 30)	62.16 ± 48.33	62.86 ± 48.30	62.91 ± 48.22	65.03 ± 46.79*
Obese (BMI ≥ 30)	37.84 ± 48.33	37.14 ± 48.30	37.09 ± 48.22	34.97 ± 46.79*
***Smoking** (%)*				
Non-smoker	53.79 ± 49.68	52.96 ± 49.89	53.02 ± 49.82	55.26 ± 48.79
Former or current smoker	46.21 ± 49.68	47.04 ± 49.89	46.98 ± 49.82	44.74 ± 48.79
***Self-rated health** (%)*				
Good or excellent health	81.64 ± 38.58	81.48 ± 38.83	81.56 ± 38.72	83.34 ± 36.56*
Fair or poor health	18.36 ± 38.58	18.52 ± 38.83	18.44 ± 38.72	16.66 ± 36.56*
***Chronic condition** (%)*				
Diabetes	10.79 ± 30.92	11.08 ± 31.38	11.07 ± 31.32	8.52 ± 27.40*
Arthritis	26.50 ± 43.98	27.19 ± 44.48	27.20 ± 44.42	25.26 ± 42.63
Coronary artery disease	3.30 ± 17.80	3.55 ± 18.51	3.56 ± 18.51	3.36 ± 17.69
Stroke	3.19 ± 17.51	3.19 ± 17.56	3.18 ± 17.53	2.68 ± 15.84
Cancer	10.57 ± 30.64	10.92 ± 31.18	10.94 ± 31.16	10.06 ± 29.52

Notes: The NHANES multi-wave sampling design was accounted for in the estimates. HEI-2010 denotes Healthy Eating Index-2010 with possible score ranging from 0 (lowest daily diet quality) to 100 (highest daily diet quality). Two-sample t-tests for continuous variables and chi-squared tests for dichotomous variables were conducted between pork consumers and non-consumers, with statistical significance shown in the far right column; *, $0.01 \leq P < 0.05$; **, $0.001 \leq P < 0.01$; and ***, $P < 0.001$.

Table 2 Adjusted odds ratios of pork, fresh pork, and fresh lean pork consumption, 2005–2016 NHANES

Individual characteristics	Pork	Fresh pork	Fresh lean pork
Sex			
Male	Reference	Reference	Reference
Female	0.79 (0.72, 0.87)***	0.79 (0.72, 0.88)***	0.79 (0.71, 0.88)***
Age group			
18–64 years of age	Reference	Reference	Reference
65 years of age and above	1.04 (0.89, 1.21)	1.07 (0.91, 1.26)	1.07 (0.91, 1.26)
Race/ethnicity			
White, non-Hispanic	Reference	Reference	Reference
African American, non-Hispanic	1.39 (1.19, 1.62)***	1.44 (1.22, 1.69)***	1.42 (1.21, 1.68)***
Other race/multi-race, non-Hispanic	1.95 (1.60, 2.38)***	1.86 (1.49, 2.31)***	1.85 (1.49, 2.31)***
Hispanic	1.21 (1.04, 1.41)*	1.16 (0.99, 1.35)	1.15 (0.98, 1.34)
Education			
High school and below	Reference	Reference	Reference
College education and above	0.87 (0.79, 0.97)**	0.85 (0.76, 0.95)**	0.85 (0.76, 0.95)**
Marital status			
Married	Reference	Reference	Reference
Divorced, separated, or widowed	0.86 (0.74, 1.01)	0.89 (0.76, 1.05)	0.89 (0.76, 1.05)
Never married	0.85 (0.73, 0.98)*	0.83 (0.71, 0.97)*	0.83 (0.72, 0.97)*
Income to poverty ratio (IPR)			
IPR < 130%	Reference	Reference	Reference
130% ≤ IPR < 300%	1.09 (0.96, 1.24)	1.14 (0.98, 1.33)	1.14 (0.98, 1.33)
IPR ≥ 300%	1.05 (0.93, 1.20)	1.10 (0.96, 1.26)	1.10 (0.96, 1.27)
Obesity			
Non-obese (BMI < 30)	Reference	Reference	Reference
Obese (BMI ≥ 30)	1.10 (1.00, 1.22)	1.05 (0.94, 1.16)	1.05 (0.94, 1.16)
Smoking			
Non-smoker	Reference	Reference	Reference
Former or current smoker	1.04 (0.93, 1.15)	1.06 (0.95, 1.19)	1.06 (0.95, 1.18)
Self-rated health			
Good or excellent health	Reference	Reference	Reference
Fair or poor health	1.00 (0.88, 1.14)	1.01 (0.88, 1.16)	1.01 (0.88, 1.16)
Chronic condition			
Diabetes	1.17 (0.99, 1.38)	1.19 (1.01, 1.40)*	1.19 (1.01, 1.40)*
Arthritis	1.07 (0.94, 1.21)	1.09 (0.95, 1.24)	1.09 (0.95, 1.25)
Coronary artery disease	0.83 (0.65, 1.07)	0.88 (0.69, 1.13)	0.89 (0.69, 1.14)
Stroke	1.13 (0.85, 1.50)	1.07 (0.80, 1.44)	1.07 (0.80, 1.44)
Cancer	1.11 (0.93, 1.31)	1.11 (0.92, 1.34)	1.11 (0.92, 1.34)

Notes: Logistic regressions were performed to estimate the adjusted odds ratios of pork consumption, accounting for the NHANES multi-wave complex sampling design. 95% confidence intervals are in parentheses. *, 0.01 ≤ P < 0.05; **, 0.001 ≤ P < 0.01; and ***, P < 0.001.

Table 3 Estimated effects of pork, fresh pork, and fresh lean pork consumption on daily energy/nutrient intake and diet quality among U.S. adults, 2005–2016 NHANES

Sample	Pork	Fresh pork	Fresh lean pork
Diet quality (HEI-2010)	0.15 (0.01, 0.31)*	0.20 (0.05, 0.36)*	0.22 (0.06, 0.37)**
Energy (kcal)	26.14 (11.34, 40.95)**	23.19 (7.98, 38.40)**	22.64 (7.39, 37.89)**
Protein (g)	4.04 (3.32, 4.77)***	4.01 (3.26, 4.76)***	3.99 (3.24, 4.74)***
Saturated fat (g)	0.46 (0.16, 0.77)**	0.40 (0.09, 0.71)*	0.39 (0.08, 0.70)*
Sodium (mg)	64.40 (35.83, 92.98)***	54.80 (24.95, 84.65)***	53.53 (23.64, 83.43)**
Iron (mg)	-0.05 (-0.16, 0.07)	-0.05 (-0.17, 0.07)	-0.05 (-0.17, 0.07)
Magnesium (mg)	3.74 (1.79, 5.69)***	3.64 (1.63, 5.65)**	3.64 (1.62, 5.66)**
Potassium (mg)	84.55 (67.41, 101.68)***	82.60 (65.87, 100.33)***	82.58 (64.87, 100.30)***
Selenium (µg)	6.76 (5.78, 7.74)***	6.75 (5.75, 7.75)***	6.74 (5.74, 7.74)***
Zinc (mg)	0.30 (0.18, 0.41)***	0.27 (0.15, 0.40)***	0.27 (0.15, 0.40)***
Phosphorus (mg)	30.61 (20.71, 40.51)***	30.06 (19.85, 40.27)***	29.73 (19.53, 39.92)***
Vitamin B_1 (mg)	0.17 (0.16, 0.19)***	0.18 (0.17, 0.19)***	0.18 (0.17, 0.19)***
Vitamin B_2 (mg)	0.04 (0.02, 0.05)***	0.04 (0.02, 0.05)***	0.04 (0.02, 0.05)***
Vitamin B_3 (mg)	0.78 (0.55, 1.01)***	0.78 (0.55, 1.02)***	0.79 (0.55, 1.02)***
Vitamin B_6 (mg)	0.10 (0.08, 0.12)***	0.10 (0.08, 0.12)***	0.10 (0.08, 0.12)***
Vitamin B_{12} (µg)	-0.07 (-0.16, 0.03)	-0.07 (-0.16, 0.02)	-0.07 (-0.16, 0.02)

Notes: Individual-level data came from the NHANES 2005–2016 waves. First-difference estimators were used to estimate the effects of pork consumption on daily dietary intake and diet quality among U.S. adults, adjusting for whether the consumption was on a weekday or weekend and accounting for the NHANES multiyear complex survey design. HEI-2010 denotes Healthy Eating Index-2010 with possible score ranging from 0 (lowest daily diet quality) to 100 (highest daily diet quality). 95% confidence intervals are in parentheses. *, 0.01 ≤ P < 0.05; **, 0.001 ≤ P < 0.01; and ***, P < 0.001.

Fresh and Lean Pork Intake in Relation to Functional Limitations among U.S. Older Adults, 2005–2016

Abstract

Background: Pork consumption, in particular fresh/lean pork consumption, provides protein and other essential micronutrients that older adults need daily and may hold the potential to prevent functional limitations resulting from sub-optimal nutrition.

Aim: Assess fresh/lean pork intake in relation to functional limitations among US older adults.

Methods: Individual-level data came from the National Health and Nutrition Examination Survey (NHANES) 2005–2016 waves. Nineteen validated questions assessed five functional limitation domains: activities of daily living (ADLs), instrumental activities of daily living (IADLs), leisure and social activities (LSAs), lower extremity mobility (LEM), and general physical activities (GPAs). Logistic regressions were performed to examine pork, fresh pork, and fresh lean pork intake in relation to functional limitations among NHANES older adults (N=6,135).

Results: Approximately 21%, 18%, and 16% of older adults consumed pork, fresh pork, and fresh lean pork, respectively. An increase in pork consumption by one ounce-equivalent/day was associated with a reduced odds of ADLs by 12%, IADLs by 10%, and any functional limitation by 7%. An increase in fresh pork consumption by one ounce-equivalent/day was associated with a reduced odds of ADLs by 13%, IADLs by 10%, GPAs by 8%, and any functional limitation by

8%. Similar effects were found for fresh lean pork consumption on ADLs, IADLs, GPAs, and any functional limitation.

Conclusion: This study found some preliminary evidence linking fresh/lean pork consumption to a reduced risk of functional limitations. Future studies with longitudinal/experimental designs are warranted to examine the influence of fresh/lean pork consumption on functional limitations.

Introduction

Functional limitations significantly compromise older adults' capability to execute essential daily activities, increase their risk for morbidity and mortality, and reduce their quality of life (An and Shi, 2015). To attain the full potential for the health and well-being of the US population, *Healthy People 2020* calls to address moderate-to-severe functional limitations in older adults (Healthy People 2020). Improving diet quality is a critical health promotion strategy (Gopinath et al., 2013). Underconsumption of nutrient-rich foods and overconsumption of empty calories prevents many older adults from meeting the recommendations of national dietary guidelines (US Department of Health and Human Services and US Department of Agriculture, 2015). Inadequate nutrient intake and poor diet quality expose older adults to an elevated risk for functional limitation development (An et al., 2015).

Pork plays an essential role in the US diet. Following beef and chicken, pork ranks third in annual meat consumption in the U.S. During 2014–2016, US adults averaged 50 pounds of pork consumption a year, accounting for over a quarter of overall meat intake (National Cattleman's Beef Association). Pork serves as a primary source of dietary animal protein, which is rich in micronutrients such as iron, vitamin B_{12}, folic acid, and biotin (Young 1990). Due to the aging process, older people require more protein per pound of bodyweight than their younger counterparts (Nowson and O'Connell, 2015). Insufficient protein intake has been associated with an elevated risk for functional limitations among older adults by decreasing reserve capacity, diminishing skin integrity, compromising immune function, and delaying injury healing and recovery from disease (Chernoff, 2004). Pork consumption, specifically fresh or lean pork consumption, provides protein and other critical micronutrients that older adults need daily and may hold the potential to prevent functional limitations resulting from sub-optimal nutrition (Murphy et al., 2014). On the other hand, processed pork and pork fat can be high in energy, saturated fat, trans fat, and sodium, the excess intakes of which are linked to chronic illnesses such as obesity, type 2 diabetes, hypertension, cardiovascular disease, and certain cancers (Micha et al., 2010).

Much of the recent research on meat consumption is concerned with addressing the association of processed red meat consumption and various adverse health outcomes (Wolk, 2017). However, few addresses—or even distinguishes—fresh and lean red meats, and rarely address fresh lean pork specifically. One study reported that replacing processed meat products with unprocessed ones resulted in a risk reduction for agility impairments and functional abilities of lower extremities (Struijk et al., 2018). A second study examined the effect of regular consumption of fresh lean pork on body composition and cardiovascular risk factors. A total of 164 overweight adults were randomly assigned to incorporate up to 1 kg pork/week by substituting for other foods (treatment group) or maintain their usual diet (control group). In comparison to the control group, the treatment group experienced a reduction of abdominal fat, body fat, body weight, and waist circumference (Murphy et al., 2012). A third study investigated the Mediterranean-style diet (using lean and unprocessed meat) via a randomized controlled trial. It concluded that the consumption of lean and unprocessed red meat reduced the risk of cardiometabolic disease for adults with obesity (O'Connor et al., 2018). Other research on red meat consumption offered mixed results. A recent systematic review and meta-analysis analyzed prospective studies. It concluded that increased use of unprocessed red meat is associated with increasing the risk of all-cause mortality (Schwingshackl et al., 2017). In contrast, the Singapore Chinese Health Study suggested that red meat consumption is associated with increases in the risk of end-stage renal disease (Lew et al., 2017).

Building upon the previous literature, the purpose of this study was to assess the influence of pork consumption on functional limitations among US older adults aged 65 years and older. It contributes to the literature in three aspects. First, to our knowledge, it serves as the first study to distinguish the distinct relationships between pork, fresh pork, and fresh lean pork and functional limitations. Second, it produces population-level estimates by analyzing a large-scale nationally-representative nutrition survey with a span of 12 years from 2005 to 2016. Third, it distinguishes functional limitations into different types and estimates their specific risk regarding pork consumption. The study hypothesized that pork consumption, in particular fresh and fresh lean pork consumption, would be negatively associated with functional limitations among older adults in the US.

Methods

Survey setting and participants

The National Health and Nutrition Examination Survey (NHANES) is a program of studies conducted by the National Center for Health Statistics (NCHS) to assess the health and nutritional status of children and adults. A multistage probability sampling design is used to select participants representative of the civilian, non-institutionalized US population. Detailed information regarding the NHANES sampling design, questionnaires, clinical measures, and individual-level data can be found elsewhere (Centers for Disease Control and Prevention, 2019).

Functional limitations

In the NHANES 2005–2016 waves, 19 validated questions were administered to assess five domains of functional limitations: activities of daily living (ADLs), instrumental activities of daily living (IADLs), leisure and social activities (LSAs), lower extremity mobility (LEM), and general physical activities (GPAs). Each question item evaluated the difficulty an individual had in performing a task without the aid of any equipment, and participants were required to choose from among four difficulty levels: “no difficulty,” “some difficulty,” “much difficulty,” and “unable to do.” ADLs consist of 4 activities: dressing oneself; walking between rooms on the same floor; getting in and out of bed; and using a fork, knife and drinking from a cup. IADLs consist of three activities: managing money; doing household chores; and preparing meals. LSAs include three activities: going out to movies and events; attending social events; and performing leisure activities at home. LEM consists of two activities: walking a quarter-mile and walking up ten steps. GPAs consist of seven activities: stooping, crouching and kneeling; lifting and carrying; standing up from an armless chair; standing for long periods; sitting for long periods; reaching up over one’s head; and grasping/holding small objects. Any functional limitation was defined as any difficulty in performing at least one of the activities within a given domain. A participant could have qualified for more than one functional limitation category, and individuals with no functional limitation referred to those with no difficulty in performing any activity within any of the five functional limitation domains. Six dichotomous variables for ADLs, LSAs, IADLs, LEM, GPAs, and any functional limitation were constructed, with no functional limitation being their common reference group.

Dietary interview

Except for the NHANES 1999–2000 wave where all participants were asked to complete a single 24-hour dietary recall, all subsequent waves incorporated two dietary recalls, with the first collected in-person and the second by telephone 3-10 days later. In both interviews, each food or beverage item and corresponding quantity consumed by a participant from midnight to midnight on the day before the interview was recorded. Following the dietary interview, the caloric and nutrient contents of each reported food and/or beverage item were systematically coded with the US Department of Agriculture (USDA) Food and Nutrient Database for Dietary Studies (FNDDS).

Pork consumption

Each food item consumed is assigned an 8-digit FNDDS code in the NHANES. Pork products occupy the codes 22000100–22820000. However, FNDDS codes do not differentiate fresh or lean pork. We thus linked FNDDS codes to the USDA National Nutrient Database for Standard Reference (SR), which assigns a 5-digit Nutrient Databank (NDB) number to each food item. The NDB numbers are linked to the FNDDS codes in the FNDDS link files. Pork is a unique food group classified in the SR, and each pork product is associated with a detailed text description. We identified fresh pork products using the keywords “fresh” or “raw,” and lean pork products using “lean” in the description. Fresh lean pork products are pork products that are both fresh and lean. The SR defines fresh lean pork as fresh pork containing less than 10 g of fat, 4.5 g of saturated fat, and 95 mg of cholesterol per 100 g of product. To estimate the ounce-equivalents of pork consumption, we further merged the NHANES data with the corresponding Food Patterns Equivalents Database (FPED). A new version of the FPED is developed for each NHANES wave. FPED converts the foods and beverages in the FNDDS to the USDA food patterns (FPs) components, and the FPs are measured as ounce-equivalents for protein foods. Due to the modifications of the FPs classifications in FPED over the years, we adopted the most recent version of FPs classifications that have been consistent since the NHANES 2005–2006 wave.

A pork consumer was defined as an adult NHANES participant who consumed any pork products on either dietary recall day. Analogously, a fresh or fresh lean pork consumer was defined as an adult participant who consumed any fresh or fresh lean pork products on either dietary recall day, respectively. In contrast, a pork non-consumer was defined as an adult participant who consumed no pork products on both dietary recall days.

Individual characteristics

The following individual characteristics were reported for US older adults aged 65 years and older: sex, age in years, race/ethnicity (non-Hispanic white, non-Hispanic African American, non-Hispanic other race or multi-race, and Hispanic), education (high school and below, and college and above), marital status (married, divorced/separated/widowed, and never married), household income (income to poverty ratio [IPR] < 130%, 130% ≤ IPR < 300%, and IPR ≥ 300%), smoking status (non-smoker, and former or current smoker), self-rated health (good or excellent health, and fair or poor health), chronic conditions (diabetes, arthritis, coronary artery disease, stroke, and cancer), survey wave, and body mass index (BMI). Participants' body height and weight were measured by a stadiometer and a digital scale in the MEC. Specific anthropometry procedures applied to wheelchair users, amputees, and people with comprehension or language difficulties. BMI was defined by weight in kilograms divided by height in meters squared (kg/m^2).

Sample size

This study used individual-level data from the NHANES 2005–2006, 2007–2008, 2009–2010, 2011–2012, 2013–2014, and 2015–2016 waves. Among a total of 6235 older adults aged 65 years and older who participated in the 24-hour dietary recalls, 100 that were on a special diet to lose weight at the time of the interview were excluded, resulting in a final sample of 6135 participants. Among them, 4359 reported having any functional limitation, in which 1468, 2137, 1598, 1443, and 4063 had ADLs, IADLs, LSAs, LEM, and GPAs (not mutually exclusive as one could qualify for multiple functional limitation categories), respectively.

Statistical analyses

Logistic regressions were performed to estimate the odds ratios of ADLs, IADLs, LSAs, LEM, GPAs, and any functional limitation concerning the daily quantity of pork, fresh pork, and fresh lean pork consumption, adjusting for individual characteristics including sex, age, race/ethnicity, education level, marital status, BMI, smoking status, self-rated health, chronic conditions, and survey wave. There were six dependent variables and three types of pork consumption, so that a total of 18 regressions were estimated.

The NHANES 2005–2016 multi-wave survey design was accounted for in both descriptive statistics and regression analyses. All statistical procedures were performed in Stata 15.1 SE version (StataCorp, College Station, TX). A p-value < 0.05 was considered as being statistically significant.

Ethical approval

The NHANES was approved by the NCHS Research Ethics Review Board. This study used the NHANES de-identified public data and was exempt from human subjects review by the University of Illinois at Urbana-Champaign Institutional Review Board.

Results

Table 1 reports individual characteristics of 2005–2016 NHANES older adult pork, fresh pork, and fresh lean pork consumers, and pork non-consumers. Approximately 21.0%, 18.0%, and 16.4% of older adults consumed pork, fresh pork, and fresh lean pork, respectively. The rate of

IADLs was lower among pork consumers (28.3%) than non-consumers (31.6%), whereas the prevalence of LSAs was higher among pork consumers (25.2%) than non-consumers (20.7%). The rates of ADLs, IADLs, LSAs, LEM, GPAs, and any functional limitation among pork non-consumers were 20.0%, 31.6%, 20.7%, 22.7%, 64.7%, and 69.0%, respectively. The rates of ADLs were 20.8%, 21.0%, and 21.0%, of IADLs were 28.3%, 28.5%, and 28.5%, of LSAs were 25.2%, 25.1%, and 25.0%, of LEM were 22.5%, 22.8%, and 22.8%, of GPAs were 64.0%, 63.5%, and 63.4%, and of any functional limitation were 68.9%, 68.5%, and 68.5% among pork, fresh pork, and fresh lean pork consumers, respectively.

Table 2 reports the adjusted odds ratios (ORs) of functional limitations with respect to daily consumption of pork, fresh pork, and fresh lean pork among 2005–2016 NHANES older adults. An increase in pork consumption by 1 ounce-equivalent per day was found to be associated with a reduction in the odds of limitations in ADLs by 12% (odds ratio [OR] = 0.88; 95% confidence interval [CI] = 0.78, 0.98), IADLs by 10% (OR = 0.90; 95% CI = 0.82, 0.99), and any functional limitation by 7% (OR = 0.93, 95% CI= 0.86, 0.99). An increase in fresh pork consumption by 1 ounce-equivalent per day was found to be associated with a reduction in the odds of limitations in ADLs by 13% (OR = 0.87; 95% CI = 0.78, 0.97), IADLs by 10% (OR = 0.90, 95% CI = 0.82, 0.99), GPAs by 8% (OR = 0.92; 95% CI = 0.85, 0.99), and any functional limitation by 8% (OR = 0.92, 95% CI = 0.85, 0.99). Similar effects were found for fresh lean pork consumption on ADLs, IADLs, GPAs, and any functional limitation. No association between pork consumption and LSAs or LEM was identified.

Discussion

This study provides some preliminary evidence on the relationship between fresh and fresh lean pork intake and reduced risk of functional limitations. Study findings coincide with that from a recent systematic review and meta-analysis, which found higher protein intake to be associated with improved lower-limb function as compared to lower intakes (less than 0.8 g/kg per day) for older community-dwelling adults (Coelho-Júnior et al., 2018). Pork is an indispensable part of the American diet. About 21%, 18%, and 16% of older adults consumed pork, fresh pork, and fresh lean pork on a given day, respectively. Consumption of fresh and lean pork was found to be associated with improved nutrient intakes (e.g., protein, iron, magnesium, potassium, selenium, zinc, phosphorus, and vitamins B_1, B_2, B_3, and B_6) with lesser increases in the intakes of total daily energy, saturated fat, and sodium (Sharma et al., 2013; McNeill 2014; An et al., 2019b). Anemia in older adults consistently links to decreased physical ability and muscle strength (Penninx et al., 2004). Some researchers suggest that increasing iron intakes could prevent anemia (Bianchi, 2015). A lower intake of B vitamins in women was found to contribute to the risks for functional limitations (Bartali et al., 2006). Vitamin B deficiency was also found to lead to increased incidents of peripheral neuropathy in older adults (Oberlin et al., 2013). It is possible that through improved nutritional status, pork consumption, in particular, fresh and lean port consumption, contributes to the prevention of functional limitation onset in older adults.

Given the variety of pork products, it can be crucial to differentiate their specific health impact. While overall pork consumption was found to be associated with the most substantial increase in various nutrient intakes, increased nutrient intakes attributable to fresh pork and fresh lean pork consumption were reasonably comparable (An et al., 2019b). Conversely, fresh pork and fresh lean pork intakes tended to be associated with less increase in daily intakes of total energy, saturated fat, and sodium than overall pork consumption (An et al., 2019b). Because increased fresh and fresh lean pork, rather than overall pork, intake was related to better micronutrient intakes as a function of pork consumption with lesser increases in energy, saturated fat, and sodium intake, older adults who consume pork may benefit nutritionally from fresh/lean pork intake more so than overall pork intake (An et al., 2019b). Studies comparing processed and unprocessed red meat suggest that the unprocessed lean red meat options are lower in saturated fat, trans fat, overall energy, and sodium, all of which are significant factors associated with increased risks of chronic disease and functional limitations (Posner et al., 2014). Overall, findings from this study indicate that moderate pork consumption (approximately 1.4 ounce-equivalents per day among pork consumers), in particular fresh and fresh lean pork consumption, may be beneficial to older adults for the prevention of functional decline. This finding coincides with a longitudinal study based on Chinese older adults aged 80 years and older, which documented habitual red meat intake to be associated with reduced cognitive impairment incidence and improved self-rated physical health (An et al., 2019).

No association between pork consumption and limitations in LSAs or LEM was identified. The LSAs measured in NHANES involve going out to movies and events, participating in social events, and doing leisure activities at home, which could be physically less demanding than most tasks comprising ADLs, IADLs, and GPAs. On the other hand, LEMs measured in NHANES consist of walking a quarter-mile and walking up ten steps, which mainly require lower extremity function and could be physically more demanding than most tasks required by ADLs, IADLs, and GPAs. It is possible that pork consumption disproportionally benefits ADLs, IADLs, and GPAs, which require moderate levels of physical and cognitive functioning capacities. However, study findings from this single data point are preliminary. Future studies are warranted to examine the potential heterogeneities in the influence of pork consumption on different functional limitation types.

This study has several notable limitations. First, we note that the NHANES dietary intakes are self-reported, meaning that participants may be prone to the social desirability bias (Hebert et al., 1995) and that the dietary intakes may be inclined to error. Furthermore, the participants' status related to functional limitations is also self-reported. This specific study focused on 24-hour dietary recalls for individual participants that were collected on two separate and non-consecutive days ranging from 3 to 10 days apart. As a result, the NHANES data set used for this study was not focused on enduring or continuing consumption and dietary habits. Furthermore, the exact amounts of pork consumption may be underestimated. Another limitation relates to the collection of anthropometric data within the NHANES, such that using a digital scale and stadiometer could be less accurate for people with functional limitations as compared to those who do not have functional limitations (Gadall, 2009). On the other hand, NHANES does specifically attempt to address this issue. Since this study used a cross-sectional-analyses, we could not eliminate possible confounding variables even though we controlled a significant number of individual characteristics in the regression. Consequently, our results do not infer a causal relationship of any kind, only correlational.

In conclusion, this study assessed fresh and lean pork consumption concerning functional limitations among US older adults aged 65 years and older, using data from a nationally-representative repeated cross-sectional health survey. About 21%, 18%, and 16% of older adults consumed pork, fresh pork, and fresh lean pork, respectively. Increase in daily overall pork consumption was associated with reduced risks for limitations in ADLs, IADLs, and any functional limitation; and increase in fresh and fresh lean pork consumption was associated with reduced risks for limitations in ADLs, IADLs, GPAs, and any functional limitation. This study has limitations about measurement and cross-sectional study design. Future studies with longitudinal or experimental designs are warranted to examine the influence of fresh and lean pork consumption on functional limitations among older adults.

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Table 1 Individual characteristics of 2005–2016 NHANES older adult pork, fresh pork, and fresh lean pork consumers and pork non-consumers

Individual characteristics	Pork consumers Mean ± SD	Fresh pork consumers Mean ± SD	Fresh lean pork consumers Mean ± SD	Pork non-consumers Mean ± SD
Sample size	1,240	1,101	1,001	4,895
Functional limitation status (%)				
Activities of daily living (ADLs)	20.81 ± 40.54	20.98 ± 40.91	21.04 ± 40.92	20.03 ± 39.61
Instrumental activities of daily living (IADLs)	28.28 ± 44.97	28.54 ± 45.38	28.45 ± 45.30	31.56 ± 45.99***
Leisure and social activities (LSAs)	25.23 ± 43.37	25.13 ± 43.58	25.02 ± 43.49	20.71 ± 40.10***
Lower extremity mobility (LEM)	22.52 ± 41.71	22.84 ± 42.18	22.84 ± 42.15	22.72 ± 41.47
General physical activities (GPAs)	63.99 ± 47.93	63.45 ± 48.38	63.38 ± 48.37	64.74 ± 47.28
Any functional limitation	68.91 ± 46.22	68.54 ± 46.65	68.49 ± 46.64	69.00 ± 45.77
Daily pork consumption				
Prevalence in sample (%)	20.98 ± 44.07	17.97 ± 42.31	16.41 ± 42.26	79.02 ± 44.07***
Pork (ounce-equivalent)	1.37 ± 1.22	1.44 ± 1.25	1.43 ± 1.23	
Sex *(%)*				
Male	52.50 ± 50.65	51.87 ± 50.77	51.83 ± 50.72	48.83 ± 48.17***
Female	47.50 ± 50.65	48.13 ± 50.77	48.17 ± 50.72	51.17 ± 48.17***
Age *(mean)*				
Age in years	71.44 ± 5.05	71.43 ± 5.09	71.43 ± 5.08	71.69 ± 5.07
Race/ethnicity *(%)*				
White, non-Hispanic	77.62 ± 42.28	77.61 ± 42.36	77.68 ± 42.26	83.40 ± 35.86***
African American, non-Hispanic	9.76 ± 30.10	10.22 ± 30.78	10.14 ± 30.64	7.51 ± 25.40*
Other race/multi-race, non-Hispanic	6.53 ± 25.05	6.07 ± 24.27	6.08 ± 24.25	3.58 ± 17.91**
Hispanic	6.10 ± 24.27	6.09 ± 24.31	6.10 ± 24.29	5.51 ± 21.99
Education *(%)*				
High school and below	39.70 ± 49.63	39.72 ± 49.72	39.75 ± 49.67	39.51 ± 47.11
College education and above	60.30 ± 49.63	60.28 ± 49.72	60.25 ± 49.67	60.49 ± 47.11
Marital status *(%)*				
Married	72.09 ± 45.50	71.20 ± 46.01	71.18 ± 45.97	65.66 ± 45.75***
Divorced, separated, or widowed	25.56 ± 44.24	26.48 ± 44.83	26.50 ± 44.80	31.61 ± 44.80***
Never married	2.35 ± 15.38	2.32 ± 15.29	2.32 ± 15.28	2.73 ± 15.70
Income to poverty ratio (IPR) *(%)*				
IPR < 130%	14.18 ± 35.38	14.83 ± 36.11	14.84 ± 36.09	13.58 ± 33.01
130% ≤ IPR < 300%	32.08 ± 47.34	32.67 ± 47.66	32.61 ± 47.58	34.36 ± 45.76*
IPR ≥ 300%	53.74 ± 50.57	52.50 ± 50.74	52.55 ± 50.68	52.06 ± 48.14
Body mass index *(mean)*				
BMI (kg/m^2)	27.79 ± 5.06	27.79 ± 5.12	27.79 ± 5.11	27.49 ± 4.87
Smoking *(%)*				
Non-smoker	49.70 ± 50.71	47.17 ± 50.72	47.21 ± 50.67	56.38 ± 47.79***
Former or current smoker	50.30 ± 50.71	52.83 ± 50.72	52.79 ± 50.67	43.62 ± 47.79***
Self-rated health *(%)*				
Good or excellent health	89.37 ± 31.26	88.89 ± 31.93	88.97 ± 31.79	88.19 ± 31.10
Fair or poor health	10.63 ± 31.26	11.11 ± 31.93	11.03 ± 31.79	11.81 ± 31.10
Chronic condition *(%)*				
Diabetes	19.54 ± 40.22	20.79 ± 41.24	20.81 ± 41.21	15.62 ± 34.99***
Arthritis	38.93 ± 49.45	39.43 ± 49.66	39.47 ± 49.61	42.35 ± 47.61***
Coronary artery disease	8.03 ± 27.56	8.09 ± 27.70	8.10 ± 27.69	11.42 ± 30.64**
Stroke	5.50 ± 23.12	5.88 ± 23.90	5.79 ± 23.71	4.32 ± 19.59
Cancer	20.91 ± 41.25	21.96 ± 42.06	21.89 ± 41.97	23.23 ± 40.69***

Notes: The NHANES multi-wave sampling design was accounted for in the estimates. Any functional limitation included all five functional limitation types, namely ADLs, IADLs, LSAs, LEM, and GPAs. Two-sample t-tests for continuous variables and chi-squared tests for dichotomous variables were conducted between pork consumers and non-consumers, with statistical significance shown in the far right column; *, $0.01 \le P < 0.05$; **, $0.001 \le P < 0.01$; and ***, $P < 0.001$.

Table 2 Adjusted odds ratios of functional limitations with respect to daily consumption of pork, fresh pork, and fresh lean pork, 2005–2016 NHANES

Functional limitation	Pork	Fresh Pork	Fresh Lean Pork
Activities of daily living (ADLs)	0.88 (0.78, 0.98)*	0.87 (0.78, 0.97)*	0.87 (0.78, 0.97)*
Instrumental activities of daily living (IADLs)	0.90 (0.82, 0.99)*	0.90 (0.82, 0.99)*	0.90 (0.82, 0.99)*
Leisure and social activities (LSAs)	0.93 (0.83, 1.03)	0.92 (0.82, 1.02)	0.92 (0.82, 1.02)
Lower extremity mobility (LEM)	0.98 (0.89, 1.07)	0.96 (0.87, 1.06)	0.96 (0.87, 1.05)
General physical activities (GPAs)	0.93 (0.86, 1.00)	0.92 (0.85, 0.99)*	0.92 (0.85, 0.99)*
Any functional limitation	0.93 (0.86, 1.00)*	0.92 (0.85, 0.99)*	0.92 (0.85, 0.99)*

Notes: Logistic regressions were performed to estimate the adjusted odds ratios of functional limitations, controlling for all covariates reported in Table 1 and accounting for the NHANES multi-wave complex sampling design. 95% confidence intervals are in parentheses. *, $0.01 \le P < 0.05$; and **, $0.001 \le P < 0.01$