

HUMAN NUTRITION

Title: Systematic Reviews of Observational and Experimental Human Studies Related to Pork Intake and Type 2 Diabetes, Insulin-Resistance Syndrome or Its Components – **NPB #12-159**

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Industry Summary:

The objective of this research was to perform a systematic review of the scientific literature related to pork intake and type 2 diabetes, insulin-resistance syndrome (metabolic syndrome) or its components. Using scientific literature search tools, studies that could be relevant to the topic were identified and reviewed for appropriateness in meeting the inclusion and exclusion criteria. A total of eight relevant observational studies (studies where subjects are observed over time without intervention) and eight relevant intervention studies (human studies with experimental intervention, such as change in the diet) were identified. These studies provide important data to assess the association of pork intake with type 2 diabetes and metabolic syndrome. Conclusions, based on the review, are presented in the peer-reviewed publication:

<https://www.dovepress.com/systematic-review-of-clinical-studies-related-to-pork-intake-and-metab-peer-reviewed-article-DMSO>

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Keywords: Blood Glucose, Diabetes, Insulin Resistance, Meat, Metabolic Syndrome

Scientific Abstract:

The objective of this research was to perform a systematic review of the scientific literature related to pork intake and type 2 diabetes, insulin-resistance syndrome (metabolic syndrome) or its components. Using scientific literature search tools, studies that could be relevant to the topic were identified and reviewed for appropriateness in meeting the inclusion and exclusion criteria. A total of eight relevant observational studies (studies where subjects are observed over time without intervention) and eight relevant intervention studies (human studies with experimental intervention, such as change in the diet) were identified. These studies provide important data to assess the association of pork intake with type 2 diabetes and metabolic syndrome. Conclusions, based on the review, are presented in the peer-reviewed publication:

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Introduction:

Disclaimer

This report summarizes work performed to-date and presents the findings resulting from that work. The findings presented herein are made to a reasonable degree of scientific certainty. Exponent reserves the right to supplement this report and to expand or modify opinions based on review of additional material as it becomes available through any additional work or review of additional work performed by others.

Context and Background

As part of a research grant agreement between, Exponent, Inc. and the National Pork Board (NPB), “An evidence-based review of meat consumption and Type 2 diabetes”, NPB Project #12-159, Exponent has been asked to provide this “Final Report of the Project” to the NPB to summarize the objective findings of its literature review. In addition to this report, one manuscript was submitted and subsequently accepted by a peer-reviewed scientific journal for publication, where Exponent provided a critical review of this literature, as well as its conclusion on the topic based on the evidence reviewed.

Specifically, in its Spring 2012 Request for Proposals, the NPB requested the following:

“Produce, if possible, a systematic, evidence-based literature review regarding the role of meat for prevention and treatment of Type 2 diabetes and Metabolic Syndrome, particularly on controlling blood glucose levels and lipoprotein profile within normal limits.

- This review could compare/contrast the epidemiological studies evaluating the relationship between meat and Type 2 diabetes with clinical studies and, if possible, make evidence based conclusions regarding the role of meat intake on Type 2 diabetes.
- Consider specific definitions of meat (species, lean, processed, etc.) and populations studied, independent effects of various meats, and effects of meat preparation / cooking methods.”

According to the United States (US) Centers for Disease Control and Prevention (CDC)(1):

“Diabetes is a group of diseases marked by high levels of blood glucose resulting from defects in insulin production, insulin action, or both. Diabetes can lead to serious complications and premature death, but people with diabetes, working together with their support network and their health care providers, can take steps to control the disease and lower the risk of complications.”

“Type 2 diabetes was previously called non–insulin-dependent diabetes mellitus (NIDDM) or adult-onset diabetes. In adults, type 2 diabetes accounts for about 90% to 95% of all diagnosed cases of diabetes. It usually begins as insulin resistance, a disorder in which the cells do not use insulin properly. As the need for insulin rises, the pancreas gradually loses its ability to produce it. Type 2 diabetes is associated with older age, obesity, family history of diabetes, history of gestational diabetes, impaired glucose metabolism, physical inactivity, and race/ethnicity. African Americans, Hispanic/Latino Americans, American Indians, and some Asian Americans and Native Hawaiians or other Pacific Islanders are at particularly high risk for type 2 diabetes and its complications. Type 2 diabetes in children and adolescents, although still rare, is being diagnosed more frequently among American Indians, African Americans, Hispanic/Latino Americans, and Asians/Pacific Islanders.”

“Diabetes affects 25.8 million people, 8.3% of the U.S. population” And “Diabetes is the leading cause of kidney failure, nontraumatic lower-limb amputations, and new cases of blindness among adults in the United States. Diabetes is a major cause of heart disease and stroke. Diabetes is the seventh leading cause of death in the United States.”

Additionally, the 2010 Dietary Guidelines Advisory Committee reported that (2):

“Prospective cohort studies suggest that intake of animal protein products, mainly processed meat, may have a link to type 2 diabetes, although results are not consistent.”

Objectives:

Thus, Exponent conducted two separate systematic reviews of the literature. One focused on observational prospective cohort studies and one focused on experimental human (clinical) studies of the association between meat intake and type 2 diabetes (T2D), with a focus on pork and pork products intake.

Materials & Methods:

Observational Studies

A comprehensive literature search was conducted in MEDLINE to identify articles on red and processed meat consumption and T2D published through February 2013. Peer-reviewed prospective cohort studies, including nested case-control studies, evaluating the association between meat consumption and T2D were identified using a combination of the following keywords: [Red meat OR Processed meat OR Pork AND type 2 diabetes]. Relevant meta-analyses that summarized prospective cohort studies were also included in this report for informational purposes. Case-control, cross-sectional, and ecological studies were excluded from this report.

As expected, the definitions of red meat and processed meat vary across studies, and this irregularity is due to differences in food composition databases and questionnaires, researcher distinctions, and geographic variability in meat consumption practices, among other factors. In light of these differences, the term “red meat” was generally used to describe intake of beef, pork, or lamb, while “processed meats” included ham, bacon, sausage, or hot dogs. Furthermore, this review is limited to pork and pork products intake. Studies that reported data for a broad classification of meat, such as ‘total meat’ categories, which included poultry or fish, were excluded. Moreover, studies that reported information pertaining to constituents of meat, such as fat or protein from animal sources, heterocyclic amine or nitrosamine exposure, or heme iron were also excluded. Included studies were required to report relative risk estimates (i.e., rate ratios, hazard ratios) and 95% confidence intervals (CI) for intake categories of pork or pork products and T2D. Published studies included in this review were written in English. All eight studies meeting the above criteria were included.

Qualitative information and quantitative data were extracted from each study that met the criteria for inclusion. Specifically, we extracted the following information: author and year of study, geographic study location, the name of the cohort, study size, years of follow-up, red or processed meat definition, method of exposure and outcome assessment, intake metric units, analytical comparison of meat intake metrics, number of exposed cases, relative risk estimates (RRs), 95% CIs, and the variables that were statistically adjusted for.

Experimental Studies

This systematic review was conducted following the guidelines of the Cochrane Handbook for Systematic Review of Interventions and of the PRISMA Statement (3- 5). The review protocol, which is available in Appendix A, was finalized on 1/20/13 and, after testing the proposed search terms, revised on 2/1/13. Because the number of publications available was unknown before the search, the aim was to review at first the association of the outcomes of interest with pork intake, but if fewer than five studies had been identified, the search would have been expanded progressively to red meat; meat (red meat and poultry); meat or seafood; animal protein; or any protein until at least five studies were identified. The a priori study inclusion and exclusion criteria are reported below:

Inclusion criteria:

- Clinical studies (randomized or not / controlled or before-after comparison) that include at least one intervention, listed in PubMed, and published or pre-published (PubMed date) before 2013
- The intervention should consist of changes in consumption of pork and meat products containing at least 50% pork (when this information is available)
- The intervention can be of any duration or frequency, including a one-time exposure
- The study was performed in humans of any age, race, ethnicity, medical condition
- The associations between pork intake and health outcomes are reported
- At least one of the reported outcomes is directly related to T2D risk, management, or complications, including insulin resistance, glucose tolerance, glycemic control, or metabolic syndrome
- The publication is in the English language

Exclusion criteria:

- The publication is not on the topic of interest
- The publication does not contain original data (most reviews and editorials)
- The publication describes ambiguous methods or reported results are presented in a form that does not allow data extraction; the authors have been contacted, but sufficient data were not provided
- The intervention related to pork is only part of other interventions (other dietary components, other lifestyles or drug interventions)
- The outcomes are only subjective (quality of life, clinician perception)

The literature search was conducted using both PubMed and EMBASE databases.

For PubMed, the final combination of search terms was: (("Diabetes Mellitus"[Mesh] OR "Hyperglycemia"[Mesh] OR "Blood Glucose"[Mesh] OR "Insulin/blood"[Mesh] OR "Insulin

Resistance"[Mesh] OR Diabetes OR Diabetic OR Prediabet* OR Hyperglycemi* OR "Glucose Tolerant" OR "Glucose Tolerance" OR "Glucose Intolerant" OR "Glucose Intolerance" OR "Insulin Resistant" OR "Insulin Resistance" OR "Metabolic Syndrome" or "Syndrome X") AND ("Meat"[Mesh] OR Meat*[Title/Abstract] OR Pork[Title/Abstract] OR Bacon[Title/Abstract] OR Ham[Title/Abstract] OR Hams[Title/Abstract] OR Sausage*[Title/Abstract] OR "Hot Dog*" [Title/Abstract] OR Frankfurter*[Title/Abstract] OR Lunchmeat*[Title/Abstract] OR Salami[Title/Abstract] OR Pepperoni[Title/Abstract] OR Prosciutto[Title/Abstract] OR Pancetta[Title/Abstract])) Filters: Humans; English. Note that after pretesting the key words, some of the free text terms were restricted to title or abstract content to avoid a large number of publications with an author or a city with the same name. The search was limited to studies published in 2012 or before with no lower bound.

For EMBASE, the following combination of search terms was used with the same publication time restriction: 'diabetes mellitus'/exp OR 'diabetes'/exp OR 'hyperglycemia'/exp OR 'hyperglycemic' OR 'glucose intolerance'/exp OR 'glucose intolerant' OR 'insulin resistance'/exp OR 'insulin resistant' OR 'prediabetes'/exp OR 'prediabetic' OR 'metabolic syndrome'/exp AND ('meat'/exp OR 'pork'/exp OR 'bacon' OR 'frankfurter' OR 'hot dog' OR 'lunchmeat' OR 'ham' OR 'sausage'/exp OR 'salami' OR 'pepperoni' OR 'prosciutto' OR 'pancetta') AND [humans]/lim AND [english]/lim AND [embase]/lim.

The title and, when available and necessary, the abstract of each identified publication was reviewed independently by two researchers. Full texts were requested for the publications that weren't excluded in the first screening step and further reviewed by the two independent reviewers (Figure). Discrepancies were resolved by consensus or by a third researcher.

Data abstraction was performed independently by two reviewers, using the following fields, modified for the aims of the present review from the Cochrane guidelines (3): study identification (ID), reviewer ID, citation, study design, total study duration, randomization procedure, blinding, total study population, age, sex, study setting and country, major inclusion / exclusion criteria, total number of intervention groups, specific intervention(s), intervention(s) details, outcomes measured and timing, outcomes definitions, participants in each intervention group, missing participants, results by outcome, other (not specified *a priori*) outcomes, study authors conclusions, other study authors comments, reference to other relevant studies, funding source. Additionally, the studies reviewers' comments, questions asked to the study authors, and any additional analyses based on the provided data were recorded.

Results:

Observational Studies

Summary of Individual Studies

In a prospective study of 42,504 men enrolled in the Health Professionals Follow-up Study, van Dam, et al. examined the relationship between dietary fat and meat intake, including pork products, and risk of T2D (6). Participants with a prior history of T2D, cardiovascular disease, or cancer at baseline were excluded from the analysis. To assess dietary intake, the authors used a 131-item food frequency questionnaire (FFQ) administered to participants in 1986, 1990, and 1994; cases of T2D were self-reported and partially validated via a supplemental questionnaire and review of medical records for a sample of participants. After 12 years of follow-up, the authors reported a statistically significant association for individual consumption of bacon (RR = 1.33, 95% CI: 1.11-1.58) and total processed meat intake (RR = 1.46, 95% CI: 1.14-1.86), which included bacon, hot dogs, and other processed meats (e.g. sausage, salami, bologna). Hot dogs (RR=1.26, 95% CI: 1.00-1.60) and "other processed meat" (RR=1.18, 95% CI: 0.99-1.41) consumption were also positively, but not

significantly, associated with T2D risk; no association was observed between consumption of unprocessed red meat and T2D (RR = 1.05, 95% CI: 0.85–1.30). Consumption of beef, pork, or lamb as a main dish or mixed dish was not significantly associated with risk of T2D. The authors note that “frequent consumption of processed meat was associated with an increased risk of type 2 diabetes”.

Schulze, et al. examined meat intake and T2D among 91,296 women enrolled in the Nurses’ Health Study 2 (7). Incident case information was collected via biennial questionnaires, and the authors attempted to validate cases using supplemental questionnaires that discussed diagnosis, treatment, and history of ketoacidosis. Red or processed meat was correlated with higher body mass index (BMI) and lower physical activity and with a higher prevalence of smoking, family history of T2D, and history of hypertension. Women with higher red or processed meat intakes had higher intakes of total energy and fat, a higher “Western” pattern score, and lower intakes of cereal fiber, carbohydrates, and magnesium. These factors were statistically adjusted for in the analyses. In the multivariate adjusted models, total red meat intakes as well as intake of hamburgers, beef or lamb as a main dish, pork as a main dish, and beef, lamb, or pork as a sandwich or mixed dish were positively associated with T2D; however, these associations were attenuated after adjusting for BMI and additional dietary factors. In the most adjusted model, the RRs across categories of red meat intake (<1/week, 1/week, 2-4/week, and ≥5/week) were 1.00, 1.24 (95% CI: 0.82-1.89), 1.44 (95% CI: 0.94-2.23), and 1.59 (95% CI: 1.01-2.49) reciprocally. Similarly, while not significant, the risk estimates of pork as main dish consumption became progressively strong with increased intake (RR=1.14, 95% CI: 0.78-1.66 in the ≥2/week category compared to 1.02, 95% CI: 0.85-1.20 in the 1/week category). With regard to processed meat consumption, the authors reported that increased processed meat intake was significantly associated with progressively higher risk of T2D (RR for extreme categories: 1.86; 95% CI: 1.35-2.57). The authors concluded that “diets high in processed meat increase risk of Type 2 diabetes”.

Fung, et al. evaluated dietary patterns, including the independent effects of pork products and red meat intake, in an analysis of approximately 70,000 women enrolled in the Nurses’ Health Study (no subjects overlap with the previous study)(8). Dietary information was collected by a FFQ at various time points throughout the study (1984, 1986, 1990, and 1994). Only incident cases of T2D were evaluated and cases were ascertained via self-report. Statistically significant crude RRs were observed when comparing the highest and lowest intake categories of bacon (RR = 1.42, 95% CI: 1.26-1.59), hot dogs (RR = 1.33, 95% CI: 1.17-1.51), processed [sandwich] meats (RR = 1.40, 95% CI: 1.23-1.59), total processed meat (RR = 1.60, 95% CI: 1.39-1.83), red meat (RR = 1.36, 95% CI: 1.18–1.56), and total processed and red meats (RR = 1.55, 95% CI: 1.34-1.80). However, after adjusting for a Western dietary pattern in the multivariate models, the associations between various meat intake categories and T2D were attenuated, but generally remained significant: (bacon: RR = 1.33, 95 % CI: 1.17-1.50; hot dogs: RR = 1.23, 95% CI: 1.08-1.41; processed meats: RR = 1.29, 95% CI: 1.12-1.48; total processed meat: RR = 1.48, 95% CI: 1.27-1.73; red meat: RR = 1.22, 95% CI: 1.05–1.41; and total processed and red meats: RR = 1.39, 95% CI: 1.18-1.65). The authors concluded that “a diet high in red and processed meats, refined grains, and other characteristics of the Western pattern was associated with an elevated risk of type 2 diabetes mellitus in women. Red and processed meats were also independently associated with an increased risk. Therefore, it may be prudent to reduce the consumption of these food items to decrease the risk of type 2 diabetes”.

Song, et al. prospectively evaluated approximately 37,000 women, aged ≥45 years, enrolled in the Women’s Health Study and completed a 131-item semi-quantitative FFQ in 1993 (9). Cases were self-reported and supplemental questionnaires were administered to augment diagnostic reporting. In addition, a sample of primary care physicians were contacted, which resulted in partial case validation of the study population. After controlling for dietary nutrients, the comparison of women who consumed ≥2 servings/week to those who consumed <1 serving/week yielded modest, but statistically significant multivariate-adjusted risk estimates for T2D of 1.17 (95% CI: 1.02-1.35) for bacon and 1.24 (95% CI: 1.05-1.45) for hot dogs, respectively. Similarly,

five or more servings of total processed meat, vs. <1 serving per week, was significantly associated with T2D (RR = 1.38, 95% CI: 1.11-1.71). Though, the comparison of the highest quintile total processed meat consumption vs. the lowest quintile of intake provided a slightly significant association (RR = 1.19, 95% CI: 1.00-1.42). In contrast to processed meats, a non-significant association was observed between risk of T2D and women who consumed five or more servings of red meat per week (vs. < 1 per week) (RR = 1.25, 95% CI: 0.94–1.67). A similar association was observed when red meat intake was evaluated in quintiles (RR = 1.24, 95% CI: 1.00–1.54; 5th vs. 1st quintile). The authors also analyzed heme iron and T2D, resulting in a statistically significant RR of 1.46 (95% CI: 1.20–1.78). However, it was stated that this result “should be interpreted with caution” because the high correlation between red meat intake and heme iron intake substantially limits the statistical capability to separate out the independent effects of heme iron from other components of red meat. The authors reported that a “higher consumption of red meat, especially total processed meat, was associated with an increased risk of developing type 2 diabetes in middle-aged and older U.S. women, independent of known diabetes risk factors”.

In an evaluation of 74,493 women in the Shanghai Women’s Health Study, Villegas, et al. evaluated the relationship between meat intake, including pork products, and T2D and whether any potential associations were modified by body weight (10). Participants had no prior history of T2D and outcome was self-reported based on specified criteria throughout follow-up. Dietary intake was assessed via a 77-item FFQ that was partially validated using a sub-sample of participants. Inverse associations (statistically significant for quintiles 3 and 4) were reported for all intake categories of red meat, after adjusting for factors, such as BMI, physical activity, alcohol, hypertension and income among others. When evaluating pork products, specifically bacon/smoked meat or Chinese sausage, there were no statistically significant associations observed for a higher risk of T2D (bacon/smoked meat: RR = 0.95, 95%CI: 0.79-1.16 and Chinese sausage: RR = 0.93, 95%CI: 0.79-1.10). When types of meat processing were considered, the authors found that for salted or preserved meat consumption, never compared to ≥ 1 serving/month, was associated with slightly elevated but non-significant risk of T2D (RR = 1.13, 95%CI: 0.93-1.32). Total processed meat was associated with a higher risk of T2D among obese participants. Specifically, obese participants in the highest intake category had a higher risk of developing T2D (RR = 3.46, 95%CI: 2.67-4.48) when compared to normal weight participants who did not consume processed meats. Although associations for red meat were markedly stronger among persons with a BMI of 30 or higher, no significant interaction between red meat and BMI was observed. Moreover, statistically significant inverse associations between red meat intake and T2D were reported among women with “normal” BMI. Specific to processed meat consumption, the risk of T2D for participants who consumed total processed meat compared to those who did not was 1.15 (95%CI: 1.01-1.32). The multivariate adjusted RRs associated with frequency of total processed meat consumption were 1.25 (95%CI: 1.06-1.47) for <1 serving/month and 1.18 (95%CI: 0.99-1.37) for ≥ 1 serving per month. In conclusion, the authors reported that “processed meat consumption was associated with a higher risk of T2D, independent of other T2D risk factors. Higher consumption of total unprocessed meat was associated with a higher risk of T2D among obese women, although this was not the case for poultry”.

Vang, et al. evaluated animal product consumption among a sample of the Adventist Mortality Study and Adventist Health Study (11). A total of 8,401 individuals who completed questionnaires in 1960 and 1976 were included in the analysis. The dietary questionnaire appeared to be oriented towards animal products, thus, information on other important dietary components (e.g., sugars) was not ascertained. T2D case ascertainment was based on disease history reporting in the 1976 self-administered questionnaire. Pork was analyzed by evaluating frankfurters, whereby a non-significant risk estimate was observed for the relationship between T2D and weekly consumption of frankfurters (odds ratio [OR] = 1.29, 95%CI: 0.94-1.76), while weekly consumption of both salted fish and frankfurters was significantly associated with a higher risk of developing T2D during follow-up (OR = 1.38, 95% CI: 1.05-1.82). Red meat was analyzed together with poultry, and the odds ratio for one or more servings of red meat/poultry per week was 1.27 (95% CI: 1.06–1.53), although this finding was

only adjusted for age and sex. Individuals who consumed red meat poultry, and fish were 29% more likely (OR = 1.29, 95% CI: 1.08-1.55) to develop T2D during follow-up than those who did not consume those meat products. Multivariate adjusted findings were not reported although the authors mentioned that associations were not markedly altered.

Männistö, et al. evaluated meat consumption and T2D among participants (n = 25,943) in the Alpha-Tocopherol, Beta-Carotene Cancer Prevention Study (12). In Finland, where the study was conducted, patients needing treatment for T2D are entitled to reimbursement of their medication expenses, and a medical certificate is required from the attending physician. For the present study, this certificate was verified for every case. It is unclear, however, whether each eligible case actually obtained a medical certificate for reimbursement. The FFQ was extensive, covering 276 food items and mixed dishes. In general, the highest consumers of total meat also consumed more total energy, alcohol, milk, and coffee, and were also more likely to have higher BMI and were less physically active. The relative risk for the highest intake quintile of red meat was 1.22 (95% CI: 0.97–1.53) and the test for trend was not statistically significant (p-trend=0.21). In fact, stronger positive associations were reported in the 2nd and 3rd intake quintiles than in the 4th and 5th quintiles, indicating no evidence of dose-response. The association between pork intake (highest quintile) and T2D was non-significant but slightly inverse (RR = 0.97, 95% CI: 0.78-1.20), while a slightly elevated, but non-significant, risk estimate of 1.22 (95% CI: 0.99-1.50) was observed for beef. The association for processed meat intake was modestly stronger than for red meat intake (RR = 1.37, 95% CI: 1.11-1.71). The authors also evaluated the association between the consumption of total meat, processed meat and risk of T2D and reported that this association was not modified by BMI (P-value for interaction \geq 0.30). The authors concluded that “reduction of the consumption of processed meat [. . .] which was associated with a 35% increased risk of type 2 diabetes [. . .] may help prevent the global epidemic of type 2 diabetes”.

Over an 8-year follow-up period among 2,001 Native Americans enrolled in the Strong Heart Family Study, Fretts, et al. evaluated the association between meat consumption and risk of incident T2D (13). Dietary intake information was assessed through an interviewer-administered and validated Block 119-item FFQ distributed at baseline. Individuals also participated in a baseline evaluation including a physical examination, medication review, laboratory testing, and a personal interview. Incident T2D cases were identified through a follow-up exam where plasma glucose concentrations met the American Diabetes Association criteria for the diagnosis of T2D or there was record of insulin or oral anti-diabetic medication use. When comparing the upper and lower quartiles of processed red meat intake, the findings suggested a statistically significant and positive association between incident T2D and processed red meat (OR=1.63; 95%CI: 1.21-2.63; p-trend=0.03). However, upon adjustment for BMI in addition to other dietary factors already accounted for, the association was attenuated toward the null and no longer statistically significant. While processed red meat was only found to be associated with incident T2D in the absence of BMI, this association persisted when evaluating specifically spam intake (OR=1.86; 95%CI: 1.17-2.95; p-trend=0.01). On the other hand, the comparison of upper and lower quartiles in fully adjusted models analyzing the relationship between unprocessed red meat intake (OR=0.88, 95% CI: 0.57-1.35), breakfast sausage (OR=1.09, 95% CI: 0.72-2.66), hot dogs (OR=0.88, 95% CI: 0.56-1.38), lunch meat (OR=1.44, 95% CI: 0.98-2.12), hamburgers (OR=0.69, 95% CI: 0.43-1.12), beef (OR=0.93, 95% CI: 0.60-1.44), and pork (OR=1.18, 95% CI: 0.77-1.82) with incident T2D did not reveal any significant associations. The authors noted that the “consumption of processed meat, such as Spam, but not unprocessed red meat, was associated with higher risk of diabetes in AIs [American Indians]”.

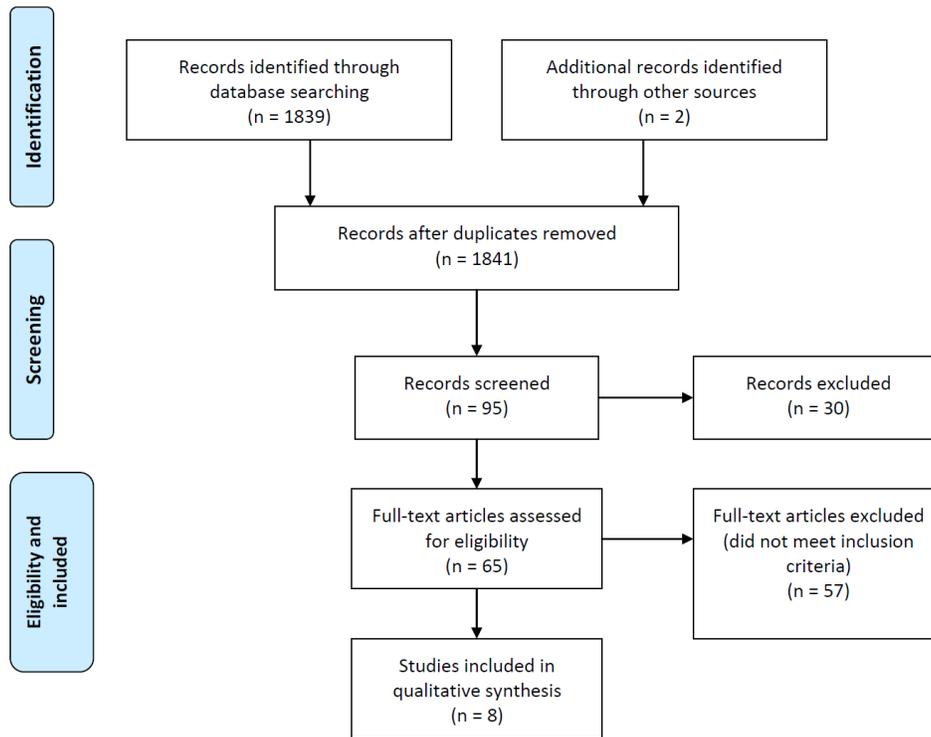
Summary of Published Meta-Analyses

None of the meta-analyses reviewed reported specific association between T2D and pork or pork products intake.

Experimental Studies

A total of eight studies were identified that met the inclusion criteria and are summarized below.

Figure: PRISMA flowchart



Summary of Medium-Term Studies

Three of the identified studies included a dietary intervention to increase pork intake, as compared to other protein sources, for 11 days (14); three months (15), or six months (16).

In a randomized controlled study, Murphy, et al. studied the effects of increased consumption of lean pork on body composition and cardiovascular risk factors (16). Overweight adults who typically consumed less than one meal of pork per week were randomized to consume five (women) or seven (men) 150 g servings of pork per week as part of their otherwise typical diet (pork group, n=84) or to continue consuming their normal diet (control group, n=80). Subjects in the pork group met with study personnel every two weeks to monitor body weight and collect frozen pork products for consumption during the study. Subjects in the control group were followed up with phone calls at an unspecified frequency to discuss progress. A total of 72 subjects completed the study in each group. At baseline, there were no significant differences between groups in any measures. At the end of the six-month intervention, there were no significant differences between the two groups for glucose, insulin, systolic or diastolic blood pressure, high-density lipoprotein cholesterol (HDL-C), or triglycerides. The change in waist circumference was significantly different between groups, with a mean decrease from baseline to six months of approximately 0.5 cm in the pork group and an increase of approximately 0.8 cm in the control

group ($p < 0.01$) with similar patterns for body weight. The authors concluded that “this pilot study demonstrated that regular inclusion of lean fresh pork in the diet in place of other meats may improve body composition without adversely affecting risk factors for diabetes and CV disease”.

Flynn, et al. conducted a crossover intervention study to compare the effects of beef, poultry/fish, or pork on blood lipids (15). The study began as a randomized crossover study of 129 healthy adults consuming either beef or poultry/fish as the only meat in an otherwise self-selected diet for three months each. The subjects were then invited to participate in a study extension in which they consumed pork as the only meat for a three-month period following a six-week washout period. A total of 76 adults completed all three interventions. During each intervention, subjects were provided with five edible ounces of raw meat (beef, poultry/fish, pork). Fasting blood samples were collected at baseline, after three months, after six months, after the six-week washout period (i.e., at baseline of the pork intervention), and at the end of the three-month pork intervention. Baseline triglycerides and HDL-C levels prior to any intervention were significantly different than values after the washout period prior to the pork intervention. The investigators reported that, based on analysis of variance, only HDL-C differed significantly across the meat intervention groups, with “inconsistent changes both upward and downward”. No additional details of the analysis or results were provided. HDL-C levels at the end of the pork intervention were higher than levels at the beginning of the pork consumption period in all four study subjects groups (by sex and beef consumed in first or second intervention).

Using a crossover study design, Chu, et al. assessed the effects of five protein sources (pork, beef, fish, soybean, and poultry) on protein balance and lipid levels (14). Thirteen healthy adults were enrolled in the 55-day study. During each of five 11-day periods, the subjects consumed in random order a diet with one of the five protein sources. Protein products at lunch and dinner provided standard portion sizes of each protein source: pork: ham, sausage; beef: bologna, frankfurters; fish: canned tuna, fish sticks; soybean: soy bologna, soy links; poultry: turkey bologna, canned chicken. Each subject consumed isocaloric meals throughout the study, with amounts of bread and condiments varied to meet each individual’s energy needs. The pork, beef, and soybean diets provided significantly less protein than the fish and poultry diets, while the pork diet provided significantly less fat than the beef diet though more fat than the fish, soybean and poultry diets. All meals were consumed in a metabolic kitchen. Across the five test diets or compared to baseline, there were no significant differences in fasting measures of glucose, HDL-C or triglycerides.

Summary of Short-Term Studies

Five studies examined effects of pork consumed as part of a meal; four studies measured post-prandial blood insulin and glucose responses (17-20), and one study measured only the post-prandial glucose response (21).

Frid, et al. compared the effects of whey or pork proteins consumed as part of high-glycemic index meals on subsequent blood insulin and glucose levels (18). Fourteen adults diagnosed with T2D but not taking diabetes medications were enrolled in this crossover study. On one occasion following an overnight fast, the subjects consumed a breakfast consisting of bread, ham and lactose dissolved in water. Four hours later, they consumed a lunch consisting of mashed potatoes, meatballs, ham, and lactose dissolved in water. On the other test occasion, subjects consumed a combination of lactose and whey dissolved in water in place of the ham at breakfast and lunch. The ham and whey-based meals delivered equal amounts of carbohydrate, protein, lactose, and liquid matched by meal occasion (breakfast, lunch). Compared to fasting baseline levels, incremental glucose and insulin area under the curve (AUC) were calculated for the three hours following each meal. The insulin AUC response following ham was significantly less than following whey (37.5 ± 5.7 vs. 44.3 ± 6.1 nmol·min/L and 21.5 ± 3.3 vs. 32.1 ± 4.2 nmol·min/L after breakfast and lunch, respectively, $p < 0.05$). The glucose AUC did not differ following breakfast with ham or whey (450 ± 54.2 vs. 449 ± 65.8 mmol·min/L, $p = 1.0$), but the glucose AUC after a lunch including ham was significantly higher than after a lunch including

whey (403 ± 35.0 vs. 320 ± 35.5 mmol·min/L, $p < 0.05$). The study authors observed that: “After breakfast no significant difference was observed between the whey meal and the reference meal containing ham when examining blood glucose. However, the glycemia was significantly decreased after lunch, most probably related to the higher insulin response, when whey was included in the meal.”

Villaume, et al. conducted two studies using a similar crossover design to assess the effects of pork compared to egg proteins on plasma glucose and insulin responses. Eight non-obese healthy adults participated in the first study (19). Following an overnight fast, the subjects consumed in random order a breakfast including either ham or hard-boiled egg. Each breakfast also provided coffee, sugar, bread and butter. The insulin 4-hour AUC was significantly higher after the ham than after egg ($10,827 \pm 1273$ vs. $9,216 \pm 1010$ uU·min/L, $p < 0.025$). There was no difference in the blood glucose AUC response after the ham and egg-based meals (1303 ± 40 vs. 1349 ± 50 mmol·min/L), though following the ham-based meal, blood glucose levels were significantly higher at 30, 40, and 50 minutes and significantly lower at 150, 180, 210, and 240 minutes compared to the egg-based meal ($p < 0.05$). The authors concluded that: “Our results show that replacement of [ham] by [egg] in isocaloric breakfasts produced a modulation of [blood glucose] response in normal subjects. The mean [blood glucose] response was characterized by a flattening of the peak and an increase in late BG. The improved glucose tolerance of normal subjects when [egg] was ingested instead of [ham] has never been described.”

The study was repeated with eleven obese adults (20). In these subjects, no significant differences in insulin levels following the pork- or egg-containing meals were observed. Glucose levels at 15, 20, and 30 minutes following the pork-containing meal were significantly higher than following the egg-containing meal, while the opposite was true at 180 minutes ($p < 0.05$). The authors did not report the insulin or glucose AUC values.

Charlton, et al. studied the effect of different protein sources consumed at breakfast on acute satiety and appetite hormones in 30 women using a crossover design (17). On three separate days following an overnight fast, each participant consumed in random order a toasted breakfast sandwich made with pork, beef, or chicken. The test meals were matched for carbohydrate and protein, while fat content was 14% higher in the chicken compared to the pork and beef meals. Measurements were completed for 29 women after the pork test meal and for 26 women after the beef and chicken test meals. No significant differences in the insulin or glucose 3-hour AUC were observed between protein sources. The authors concluded that: “This study positions pork, beef, and chicken as equal in their effect on satiety and release of appetite-related intestinal hormones and of insulin.”

Chan, et al. compared glucose responses of diabetic adults following consumption of various traditional Chinese foods (21). Following an overnight fast, eight of the subjects consumed porridge with pork or with shrimp Shao Mai on two separate mornings. The meals were matched for protein and carbohydrate, though differed in fat; the fat content of the shrimp-containing meal was 21.3 g versus 1.6 g in the pork meal. Glucose 4-hour AUC responses did not differ significantly between the pork and the shrimp-based meals.

Discussion:

Discussion and critical review of the literature is available in the peer-reviewed publication:

<https://www.dovepress.com/systematic-review-of-clinical-studies-related-to-pork-intake-and-metab-peer-reviewed-article-DMSO>

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