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Meat consumption and risk of type 2 diabetes: the Multiethnic Cohort

A Steinbrecher[1], E Erber[1], A Grandinetti[2], LN Kolonel[1] and G Maskarinec[1,*]
[1]Cancer Research Center, University of Hawaii, 1236 Lauhala Street, Honolulu, HI 96813, USA:
[2]John A. Burns School of Medicine, University of Hawaii, Honolulu, HI, USA

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Abstract

Objective: To examine the association of meat consumption with diabetes risk in the Hawaii component of the Multiethnic Cohort and to assess effect modification by ethnicity.
Design: A prospective cohort study. Baseline information on diet and lifestyle was assessed by questionnaire. The cohort was followed up for incident cases of diabetes, which were identified through self-reports, medication questionnaires, or health plan linkages. Cox regression was used to calculate hazard ratios (HR) and 95 % confidence intervals for diabetes associated with quintile of meat consumption.
Setting: Hawaii, USA.
Subjects: A total of 29 759 Caucasian, 35 244 Japanese-American and 10 509 Native Hawaiian men and women, aged 45–75 years at baseline.
Results: During a mean follow-up time of 14 years, 8587 incident diabetes cases were identified. Intake of red meat was positively associated with diabetes risk in men (fifth *v.* first quintile: HR = 1·43; 95 % CI 1·29, 1·59) and women (fifth *v.* first quintile: HR = 1·30; 95 % CI 1·17, 1·45) in adjusted models. The respective HR for processed red meat intake were 1·57 (95 % CI 1·42, 1·75) and 1·45 (95 % CI 1·30, 1·62). The association for processed poultry was weaker than for processed red meat, and fresh poultry intake was not associated with diabetes risk. For men only, we observed significant interactions of ethnicity with the red and processed red meat associations, with Caucasians experiencing slightly higher risks than Japanese-Americans.
Conclusions: Our findings support the growing evidence that red and processed meat intake increase risk for diabetes irrespective of ethnicity and level of BMI.

Keywords
Type 2 diabetes
Meat
Ethnicity
Prospective study

The prevalence of type 2 diabetes mellitus is increasing worldwide; however, some ethnic groups, such as Asian-Americans or Pacific Islanders, suffer from extremely high rates compared with Caucasians[1]. In the Multiethnic Cohort (MEC), diabetes incidence rates of 15·5, 12·5 and 5·8 per 1000 person-years were found for Native Hawaiians, Japanese-Americans and Caucasians, respectively[2]. A higher BMI and lower education were associated with higher incidence rates. Established risk factors for diabetes are overweight, obesity and physical inactivity[3]; still, dietary factors might play an important role. A meta-analysis on meat intake and diabetes risk concluded that particularly red meat and processed meat increase diabetes risk[4]. Thus far, no prospective study has examined whether this association is modified by ethnicity. We examined the association of meat consumption (red meat, processed red meat, fresh poultry and processed poultry) with diabetes risk in men and women of Caucasian, Japanese-American and Native Hawaiian ancestry in the Hawaii component of the MEC.

Materials and methods

Study population

The MEC was designed to investigate the association between diet and cancer among different ethnic groups in Hawaii and California and detailed information on study design and recruitment can be found elsewhere[5]. In brief, between 1993 and 1996, more than 215 000 men and women, aged 45–75 years at recruitment, enrolled by completing a mailed questionnaire on diet, demographics, medical conditions, anthropometric measures and lifestyle factors.

The Hawaiian component of the MEC comprises 103 898 participants, primarily Caucasians, Japanese-Americans and Native Hawaiians. Response rates ranged from 28 % to 51 % in the different ethnic–sex groups, and comparison with US Census data indicated that the study population represented all levels of education. For the present analysis, subjects belonging to other ethnicities (*n* 8797), prevalent diabetes cases (*n* 10 028) and unconfirmed cases (*n* 812) were

*Corresponding author: Email gertraud@crch.hawaii.edu

excluded, as were subjects with missing covariate (n 6202) or dietary information (n 2537) and missing information on diabetes at follow-up or baseline (n 10), leaving 36 256 men and 39 256 women. Study protocols were approved by the Committee on Human Studies at the University of Hawaii and by the Institutional Review Board of Kaiser Permanente.

Data assessment

Incident cases of diabetes mellitus were identified by self-report in a follow-up questionnaire mailed to the participants between 1999 and 2003 (response rate in Hawaii 88 %), or via a medication questionnaire (including diabetes drugs) administered to 38 % of the MEC participants who agreed to a blood draw between 2001 and 2007, or by a linkage in 2007 with the two major health plans in Hawaii, Kaiser Permanente and Blue Cross/Blue Shield, that cover 90 % of the population in Hawaii[2]. After excluding 812 self-reported cases not confirmed by a health plan, a total of 8587 incident cases were identified during a median follow-up time of 13·5 years: 2251 from the follow-up questionnaire, 996 from the medication questionnaire and 5340 through the health plans. Information on vital status of all participants is updated annually by linkage with state and national death certificates.

Dietary data were collected at baseline by a validated quantitative FFQ specifically designed for use in this multiethnic population[5]. Nutrient intake was determined by linking food intake to an ethnic-specific food composition database developed and maintained at the Cancer Research Center of Hawaii. In a validation and calibration sub-study average correlation coefficients ranged from 0·26 to 0·57 for nutrients and from 0·57 to 0·75 for nutrient densities for the different sex–ethnic groups, indicating good validity[6].

Food group intake was calculated as grams per day of the basic food commodities and covered single food items as well as mixed dishes. Intakes were converted to energy densities (g/4184 kJ per d). Food groups examined for the current analysis were red meat (beef, pork and lamb), fresh poultry, processed red meat and processed poultry.

Statistical analysis

We applied Cox proportional hazard regression with follow-up time as the underlying time metric and stratified by age at cohort entry to estimate hazard ratios (HR) and 95 % confidence intervals for sex-specific quintiles of meat consumption. Linear trend tests were performed using an ordinal variable representing the median of each quintile. Follow-up time was calculated as the difference between date of cohort entry and date of diabetes diagnosis, date of death or last date when data on diabetes status were available, whichever came first[2]. The final models were adjusted for ethnicity, BMI, physical activity, education and energy intake (log-transformed). We tested for interaction of meat consumption and ethnicity and additionally calculated ethnic-specific HR of diabetes for meat consumption. No major violations of the proportional hazards assumption were observed when examined with time-dependent explanatory variables. All statistical analyses were performed using the SAS statistical software package version 9·2 (SAS Institute Inc., Cary, NC, USA).

Results

The median intake of beef or fresh poultry did not differ by ethnicity, but higher amounts of pork, red meat and processed red meat were consumed by Native Hawaiians, while Caucasians tended to consume least of these meat groups (Table 1).

Red meat and processed red meat were positively associated with diabetes risk in men (Table 2). The HR comparing extreme quintiles was 1·43 (95 % CI 1·29, 1·59) for red meat and 1·57 (95 % CI 1·42, 1·75) for processed red meat in multivariate-adjusted models. When we excluded BMI from the model, the HR for comparing extreme quintiles was 1·70 (95 % CI 1·54, 1·88) for red meat and 1·92 (95 % CI 1·73, 2·13) for processed meat. Further adjustment for fibre intake, which was recently shown to be associated with diabetes in this cohort, attenuated this association slightly with HR of 1·38 (95 % CI 1·24, 1·53) for red meat and 1·53 (95 % CI 1·37, 1·71) for processed red meat comparing highest *v.* lowest quintile (data not shown). Intake of fresh poultry was not associated with diabetes risk although HR for the second, third and fourth quintiles were slightly increased. Intake of processed poultry increased risk by 30 % for the highest intake quintile compared with the lowest.

Similar associations between meat intake and diabetes risk were found in women (Table 3), although the risk estimates tended to be lower than in men. HR for diabetes comparing the highest *v.* lowest intake quintile was 1·30 (95 % CI 1·17, 1·45) for red meat and 1·45 (95 % CI 1·30, 1·62) for processed red meat. Without adjustment for BMI, the respective HR was 1·67 (95 % CI 1·50, 1·86) and 1·84 (95 % CI 1·65, 2·06). Additional adjustment for fibre intake did not alter the multivariate-adjusted estimates: HR = 1·29 (95 % CI 1·15, 1·45) for red meat and HR = 1·45 (95 % CI 1·30, 1·65) for processed red meat (data not shown). Fresh poultry intake was not associated with diabetes, but women in the fifth quintile of processed poultry intake had a 23 % higher diabetes risk compared with the lowest quintile.

Associations for the fifth *v.* the first meat intake quintile stratified by ethnicity are shown in Fig. 1 for men and Fig. 2 for women. In men, the tests for interaction between ethnicity and red meat intake ($P_{interaction} = 0·006$) and processed red meat intake ($P_{interaction} = 0·002$) were significant, with a slightly higher risk for Caucasians and a lower risk for Japanese-Americans. We did not find a significant interaction for fresh ($P_{interaction} = 0·47$) or processed poultry ($P_{interaction} = 0·46$) in men or for any meat type in women ($P_{interaction} = 0·47$ for processed red meat, 0·32 for

Table 1 Baseline characteristics of participants in the Hawaii component of the Multiethnic Cohort by ethnicity and sex, 1993–2007

	Men						Women					
	Caucasian (*n* 15 116)		Native Hawaiian (*n* 4568)		Japanese-American (*n* 16 572)		Caucasian (*n* 14 643)		Native Hawaiian (*n* 5941)		Japanese-American (*n* 18 672)	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Age (years)												
45–54	6766	44·8	2305	50·5	5437	32·8	6901	47·1	3158	53·2	6058	32·4
55–64	4194	27·8	1334	29·2	4645	28·0	3909	26·7	1678	28·2	5686	30·5
≥65	4156	27·5	929	20·3	6490	39·2	3833	26·2	1105	18·6	6928	37·1
Diabetes status												
Non-case	14 036	92·9	3770	82·5	13 895	83·9	13 928	95·1	4998	84·1	16 298	87·3
Incident case	1080	7·1	798	17·5	2677	16·2	715	4·9	943	15·9	2374	12·7
Education (years)												
≤12	2870	19·0	2172	47·6	6472	39·1	3398	23·2	3115	52·4	7691	41·2
13–15	4377	29·0	1456	31·9	4777	28·8	5023	34·3	1789	30·1	5255	28·1
>15	7869	52·1	940	20·6	5323	32·1	6222	42·5	1037	17·5	5726	30·7
BMI (kg/m^2)												
<22	2047	13·5	318	7·0	3107	18·8	4965	33·9	969	16·3	8040	43·1
22–<25	5080	33·6	900	19·7	6439	38·9	4180	28·6	1321	22·2	5765	30·9
25–<30	6135	40·6	2019	44·2	6084	36·7	3670	25·1	1985	33·4	4002	21·4
≥30	1854	12·3	1331	29·1	942	5·7	1828	12·5	1666	28·0	865	4·6
	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR
Total energy (kJ/d)	9251	7167, 11 899	10 724	7853, 14 523	9155	7155, 11 611	7339	5720, 9422	8786	6406, 12 083	7289	5699, 9318
Red meat*	16·5	9·3, 24·7	19·9	13·2, 27·8	17·4	10·5, 25·0	12·8	6·5, 20·7	18·1	11·5, 26·2	14·7	8·7, 22·0
Processed red meat*	6·4	3·2, 10·7	9·3	5·6, 13·8	8·2	4·7, 12·3	4·1	1·9, 7·6	7·5	4·1, 11·8	6·2	3·2, 9·9
Fresh poultry*	14·4	8·7, 22·2	14·3	9·1, 21·6	15·0	9·7, 22·0	15·2	8·9, 24·3	15·1	9·7, 22·7	15·5	10·0, 22·8
Processed poultry*	0·5	0·1, 1·6	0·7	0·1, 1·6	0·6	0·1, 1·3	0·3	0·1, 1·2	0·6	0·1, 1·3	0·4	0·1, 1·1
Beef*	12·2	6·9, 18·4	12·9	8·1, 18·4	11·7	7·0, 17·2	9·5	4·8, 15·4	11·9	7·2, 17·3	9·8	5·6, 14·8
Pork*	3·0	1·1, 5·7	6·1	3·6, 8·8	4·8	2·5, 7·6	2·3	0·7, 4·8	5·4	3·0, 8·1	4·2	2·2, 6·8
Dietary fibre*	10·3	8·0, 13·1	8·1	6·3, 10·6	8·7	6·7, 11·4	12·0	9·5, 15·2	10·1	7·8, 13·2	11·3	8·8, 14·2
Physical activity (METS)	1·6	1·4, 1·8	1·7	1·5, 1·9	1·6	1·5, 1·8	1·6	1·4, 1·8	1·6	1·4, 1·8	1·6	1·4, 1·7

IQR, interquartile range; METS, metabolic equivalent of tasks.
*Nutrient intakes in g/4184 kJ per d.

Table 2 Diabetes risk as hazard ratio (HR) and 95 % confidence interval associated with quintiles of meat consumption in men, Hawaii component of the Multiethnic Cohort Study, 1993–2007

	Quintile of intake					
	1	2	3	4	5	P_{trend}
Red meat intake*	5·43	12·63	18·47	25·04	35·63	
No. of cases	690	880	1034	1077	874	
Person-years	95 770	91 300	89 399	83 708	66 739	
Adjusted HR†	1·00	1·17	1·31	1·42	1·43	
95 % CI	–	1·06, 1·29	1·19, 1·44	1·29, 1·56	1·29, 1·59	<0·0001
Processed red meat intake*	1·68	4·64	7·49	10·91	17·08	
No. of cases	537	746	930	1161	1181	
Person-years	86 251	83 816	87 706	90 242	78 902	
Adjusted HR†	1·00	1·22	1·30	1·45	1·57	
95 % CI	–	1·09, 1·37	1·17, 1·45	1·31, 1·61	1·42, 1·75	<0·0001
Fresh poultry intake*	5·98	11·65	16·83	23·60	38·18	
No. of cases	986	1087	1029	867	586	
Person-years	102 773	100 315	91 370	77 595	54 864	
Adjusted HR†	1·00	1·05	1·10	1·11	1·06	
95 % CI	–	0·96, 1·15	1·01, 1·20	1·01, 1·21	0·96, 1·18	0·19
Processed poultry intake*	0·00	0·11	0·53	1·20	2·85	
No. of cases	543	987	968	1100	957	
Person-years	69 649	94 286	90 077	91 979	80 926	
Adjusted HR†	1·00	1·19	1·19	1·27	1·30	
95 % CI	–	1·07, 1·32	1·07, 1·32	1·14, 1·40	1·17, 1·44	0·0001

*Median intake in g/4184 kJ per d.
†HR adjusted for ethnicity, education, BMI, physical activity and total energy intake (log-transformed) as well as stratified by age at cohort entry.

Table 3 Diabetes risk as hazard ratio (HR) and 95 % confidence interval associated with quintiles of meat consumption in women, Hawaii component of the Multiethnic Cohort Study, 1993–2007

	Quintile of intake					
	1	2	3	4	5	P_{trend}
Red meat intake*	3·99	9·89	15·32	21·54	31·78	
No. of cases	570	745	865	974	878	
Person-years	103 951	104 175	100 031	97 159	80 773	
Adjusted HR†	1·00	1·06	1·17	1·25	1·30	
95 % CI	–	0·95, 1·18	1·06, 1·31	1·13, 1·39	1·17, 1·45	<0·0001
Processed red meat intake*	1·05	3·12	5·42	8·46	13·86	
No. of cases	465	635	792	1027	1113	
Person-years	97 302	95 474	97 422	102 005	93 885	
Adjusted HR†	1·00	1·20	1·24	1·37	1·45	
95 % CI	–	1·07, 1·35	1·10, 1·39	1·22, 1·53	1·30, 1·62	<0·0001
Fresh poultry intake*	6·46	12·65	18·37	26·40	43·24	
No. of cases	912	1050	977	697	396	
Person-years	126 807	119 115	103 289	83 881	52 998	
Adjusted HR†	1·00	1·12	1·18	1·09	1·01	
95 % CI	–	1·02, 1·22	1·07, 1·29	0·98, 1·20	0·90, 1·14	0·95
Processed poultry intake*	0·00	0·10	0·42	1·06	2·42	
No. of cases	496	884	892	990	770	
Person-years	83 890	107 572	105 903	105 656	83 068	
Adjusted HR†	1·00	1·19	1·18	1·20	1·23	
95 % CI	–	1·06, 1·32	1·06, 1·32	1·08, 1·34	1·10, 1·38	0·03

*Median intake in g/4184 kJ per d.
†HR adjusted for ethnicity, education, BMI, physical activity and total energy intake (log-transformed) as well as stratified by age at cohort entry.

fresh poultry and 0·24 for processed poultry), except for consumption of red meat with a borderline significant interaction ($P_{interaction} = 0·05$).

Discussion

In the current analysis of the Hawaii component of the MEC, we found a positive association between intakes of red meat, processed red meat and processed poultry with risk of diabetes in men and women independent of BMI status. Fresh poultry consumption was not associated with diabetes risk.

Strengths of the present study are the large sample size, the prospective design with long follow-up time, and the extensive data collection allowing adjustment for a variety of known confounders such as BMI. However, the possibility of residual confounding cannot be excluded.

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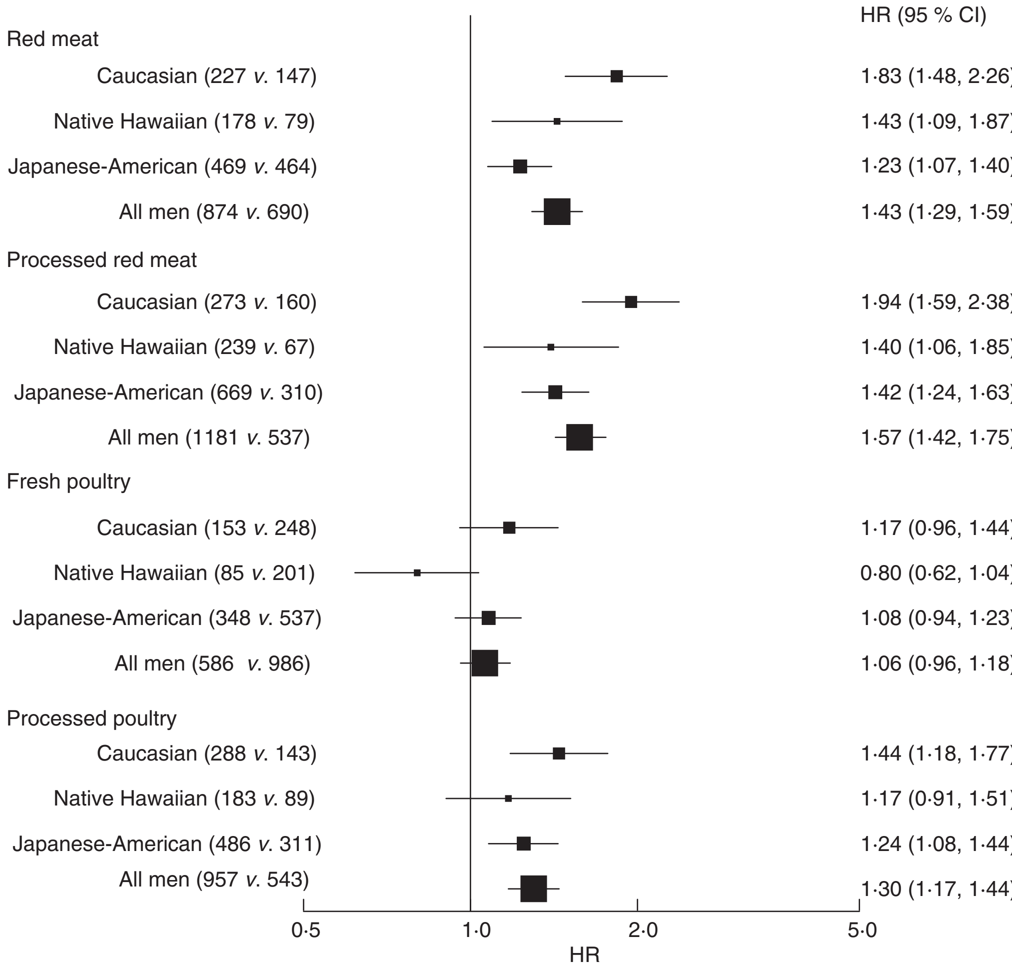

Fig. 1 Diabetes risk (hazard ratio (HR) and 95 % confidence interval) comparing highest *v.* lowest quintile of meat consumption by ethnicity in men, Hawaii component of the Multiethnic Cohort Study, 1993–2007. HR adjusted for education, BMI, physical activity and total energy intake (log-transformed) as well as stratified by age at cohort entry; numbers in parentheses represent the number of diabetes cases in the highest *v.* lowest quintile of meat consumption

The study FFQ was specifically designed for use in this multiethnic cohort, and reproducibility and validity of nutrient intake densities were found to be satisfactory and comparable to those of other similar studies[6]. Moreover, mixed dishes containing meat were disaggregated into their component ingredients and considered in the estimation of total meat intake. However, misreporting of certain foods might have biased our results, although due to the prospective design, disease status could not have influenced reporting of meat intake. Since we did not have repeat measurements of diet, changes in diet over time could not be considered in the analysis. Furthermore, we were not able to distinguish the effect of meat from intakes of its major constituents, such as animal fat, animal protein and haem Fe. Although diabetes status was ascertained by several questionnaires and linkage with health plans, information on type of diabetes was not available; however, given the median age of 59 years of the participants at baseline, more than 90 % of cases were likely to have had type 2 diabetes. Despite the comprehensive case identification approach, some MEC participants may have diabetes that has not been detected yet.

Our results agree with several prospective studies on meat intake and diabetes risk. In a recent meta-analysis[4], the summary risks comparing high *v.* low intake were 1·21 (95 % CI 1·07, 1·38) for red meat and 1·41 (95 % CI 1·25, 1·60) for processed meat. The magnitude of these estimates corresponds well with those from our study, although caution is needed for such comparisons due to different units in exposure measurement. Furthermore, the type of red meat consumed (i.e. beef or pork) and the proportion of poultry in comparison to red meat intake likely differs among countries. For example, in a Finnish study[7], intakes of red meat (mean intake in non-cases: 79·6 g/d) and processed meat (52·0 g/d) were considerably higher than poultry intake (2·6 g/d), while intakes of poultry and red meat were nearly equal in our study.

A few studies have examined the association between intake of fresh poultry and diabetes risk, with one reporting no association[8] and several others observing

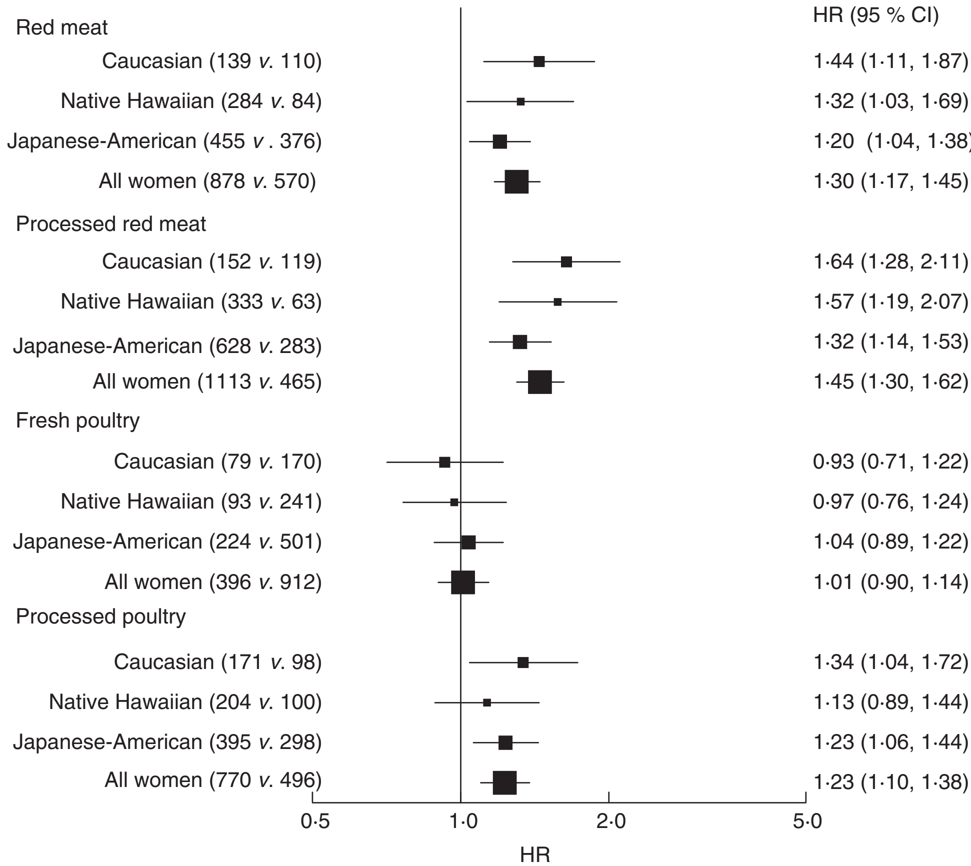

Fig. 2 Diabetes risk (hazard ratio (HR) and 95 % confidence interval) comparing highest *v.* lowest quintile of meat consumption by ethnicity in women, Hawaii component of the Multiethnic Cohort Study, 1993–2007. HR adjusted for education, BMI, physical activity and total energy intake (log-transformed) as well as stratified by age at cohort entry; numbers in parentheses represent the number of diabetes cases in the highest *v.* lowest quintile of meat consumption

an inverse association(7,9,10). The slightly elevated risk for the second, third and fourth intake quintile might be due to chance, errors in intake measurements and close correlation between the different types of meat intake. To our knowledge, no other study has examined the association between intake of processed poultry and diabetes.

In an earlier analysis of the MEC, we found an inverse association between dietary fibre intake and diabetes risk in men but not in women(11). As red meat and processed red meat were negatively correlated with fibre intake, we additionally adjusted the present analysis for fibre intake to exclude the possibility of confounding. The HR for red and processed meat in men decreased slightly but remained significant, indicating an effect of meat irrespective of fibre intake. Nevertheless, one has to consider that the positive association of meat consumption and diabetes risk might not be attributable to meat intake per se, but rather to a dietary pattern like the so-called 'Western' pattern, which combines high meat intake, especially processed red meat and processed poultry, with refined grains and sweets(12).

We found no strong indication for effect modification by ethnicity. Tests for interaction were statistically significant only for red and processed red meat consumption in men, which might be explained by ethnically different meat preparation practices or differences in the choice of red meat types. However, the HR for the three ethnic groups did not differ meaningfully and thus the statistical significance might be driven more by the large sample size or the small standard deviations than an underlying biological difference.

One hypothesis for a role of meat intake in diabetes aetiology is that meat consumption increases fat intake, especially saturated fat intake, and thus might act indirectly by increasing body weight, an established risk factor for diabetes(3). Our analysis without adjustment for BMI supported this hypothesis. However, when adjusting for BMI, we still found a significant positive association, indicating that other mechanisms might be important. For example, heating foods such as meat can lead to high levels of advanced glycation end-products, which have been associated with inflammatory responses in human subjects(13). Red meat is a source of haem Fe; higher body Fe stores might impair insulin sensitivity(14) and increase the risk of diabetes(15) by promoting oxidative stress causing tissue damage(16). Processed meat might contain preservatives, additives or other chemicals, such as nitrates, nitrites and heterocyclic amines, formed during food preparation. Nitrites, for example, might be converted to nitrosamines, which exert pancreatic β-cell toxicity[17]. Unfortunately, we had no data on food preservation methods to perform separate analysis for these compounds.

In conclusion, our findings add to the growing evidence for a positive association of red meat and processed meat intake with diabetes risk. We found this association to be consistent over the different ethnic strata of the MEC, despite the higher incidence rates of diabetes in Native Hawaiians and Japanese-Americans compared with Caucasians. Besides the known role of body weight, these results highlight the importance of diet and food choices in diabetes aetiology.

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