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Cancer mortality in workers employed in cattle, pigs, and sheep slaughtering and processing plants

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ABSTRACT

Objectives: We studied mortality in two separate cohorts of workers in abattoirs (N = 4996) and meat processing plants (N = 3642) belonging to a meatcutters' union, because they were exposed to viruses that cause cancer in food animals, and also to chemical carcinogens at work.

Methods: Standardized mortality ratios (SMRs) and proportional mortality ratios (PMRs) were estimated for each cohort as a whole and in subgroups defined by race and sex, using the US general population mortality rates for comparison. Study subjects were followed up from January 1950 to December 2006, during which time over 60% of them died.

Results: An excess of deaths from cancers of the base of the tongue, esophagus, lung, skin, bone and bladder, lymphoid leukemia, and benign tumors of the thyroid and other endocrine glands, and possibly Hodgkin's disease, was observed in abattoir and meat processing workers. Significantly lower SMRs were recorded for cancer of the thymus, mediastinum, pleura, etc., breast cancer, and non-Hodgkin's lymphoma.

Conclusion: This study confirms the excess occurrence of cancer in workers in abattoirs and meat processing plants, butchers, and meatcutters, previously reported in this cohort and other similar cohorts worldwide. Large nested case–control studies are now needed to examine which specific occupational and non-occupational exposures are responsible for the excess. There is now sufficient evidence for steps to be taken to protect workers from carcinogenic exposures at the workplace. There are also serious implications for the general population which may also be exposed to some of these viruses.

1. Introduction

Workers in the meat industry include persons who work in abattoirs (slaughterhouses) where cattle, pigs, and sheep are slaughtered for human consumption, and those who work in meat processing plants where no killing is done, but the carcasses of these animals killed elsewhere are brought in for processing (by being cut into special smaller pieces, by being cured, spiced, or cooked into various products, or used to manufacture meat-related products such as meat pies, etc.). In large abattoirs, meat processing is also carried out. These food animals and their raw or inadequately cooked products are naturally infected with viruses that cause cancer in the animals. The viruses include, the bovine leukemia virus (BLV), a retrovirus that causes lymphosarcoma in cattle and sheep (Burny and Mammerickx, 1987); jaagsietke sheep retrovirus (JSRV) that causes adenocarcinoma of the lung in sheep (Palmarini and Fan, 2001); ovine nasal adenocarcinoma virus (ONAV) a retrovirus that causes nasal adenocarcinoma in sheep (Cousens et al., 1999; Cousens et al., 2009); caprine nasal adenocarcinoma virus (CNAV) another retrovirus that causes nasal adenocarcinoma in goats (Ortin et al., 2003); and the bovine papilloma viruses (BPVs) that cause cancer of the alimentary tract, bladder cancer, fibromas, fibrosarcomas, meningiomas and chondromas, and warts, in cattle (Campo, 1987; Lancaster and Olson, 1982). It is not known whether these viral agents cause cancer in humans also.

Workers in these plants have one of the highest human exposures to these viruses, and we therefore reason that if these viruses do cause cancer in humans, this should be readily evident in this highly exposed group. Accordingly, we and others have conducted mortality and cancer incidence studies of butchers and meatcutters, and workers in slaughterhouses and meat processing plants (Besson et al., 2006; Boffetta et al., 2000; Coggon et al., 1989; Coggon and Wield, 1995; Doerken and Rehpenning, 1982; Fox et al., 1982; Fritschi et al., 2003; Griffith, 1982; Guberan et al., 1993; Gustavsson et al., 1987; Johnson et al., 1995a; Lagorio et al., 1995; Lynge et al., 1983; McLean et al., 2004; Milham, 1982; Reif et al., 1989). With the exception of studies by Coggon and Wield, 1995; Milham, 1982, the overwhelming majority of the studies have reported an excess occurrence of various cancers, including cancer of the lung, buccal cavity and pharynx, esophagus, bladder, kidney, bone, stomach, larynx, colon/rectum, and prostate.

We previously studied mortality on two occasions in a cohort of workers employed in abattoirs and meat processing plants where cattle, pigs, or sheep were killed and/or processed. Follow-up was from 1949 to

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1980 and 1949 to 1989 (Johnson and Fischman, 1982; Johnson et al., 1986a,b; Johnson, 1989; Johnson et al., 1995a). An excess of cancers of the lung, buccal cavity and pharynx, esophagus, bladder, kidney, bone, and colon was recorded in the cohort. We describe here a further follow-up of this cohort up to the end of 2006, but this time excluding subjects who worked exclusively in predominantly pork processing plants.

2. Methods

The cohort was identified from a local meatcutters' union in Baltimore, and consisted of 4996 workers who were employed in plants where cattle, pigs, and sheep were killed or killed and processed (heretofore referred to as abattoirs), and a total of 3642 who worked in processing plants that handled these same animals, but where no killing was performed. Carcasses of animals killed elsewhere several days previously are brought in, to these plants for processing. Workers studied were employed prior to and after 1949, up to the end of 1979. In the study reported here, they were followed up from January 1, 1950 till December 31, 2006. Various methods of follow-up were utilized, including the National Death Index (NDI), Social Security Administration (SSA), Maryland State Department of Vital Records, Maryland State Department of Motor Vehicles, Health Care Financing Administration, Veterans Administration, Pension Benefit Information (a private company that identifies deaths using various federal record systems), personal contact by telephone, and internet tracing methods such as Private Eye and Ancestry.com.

A total of 3045 deaths (61%) were recorded among the 4996 workers in abattoirs versus 2314 (64%) among the 3642 workers in processing plants. Deaths were coded to the 9th ICD Revision. Standardized mortality ratios (SMRs) and proportional mortality ratios (PMRs) were estimated using the OCMAP Plus software for analyzing cohort mortality studies from the University of Pittsburgh, using the United States general population rates for comparison. In the SMR analysis, each study population was stratified by calendar time, race, sex, age (5-year intervals) and plant. Person-years accumulation started from the date the plant was unionized for those who were already working in the plant prior to it being unionized, or from the date they joined the union (date of employment) if the plant had already been unionized by the time they were employed. Person-years accumulation was terminated on the date of death for deceased persons. Subjects not identified as deceased were assumed to be alive at the end of the study, and their person-years accumulation terminated on December 31, 2006. Expected deaths were estimated by multiplying the respective person-years accumulated by the corresponding US population rates, and summed up over all strata to get the total expected number of deaths. The SMR is the total observed number of deaths divided by the total expected. A similar method of stratification was used in the PMR analysis, except that the expected deaths were obtained by multiplying the proportion of deaths due to a specific cause in the US population by the corresponding total number of deaths in the study population.

A total of 15 subjects in abattoirs and 17 in processing plants were excluded from the analysis — Table 1. While all 5359 deceased subjects had complete information on race, gender, and date of birth, the remaining 3279 subjects (38%) not identified as deceased had no information on race, and their race was imputed based on the racial distribution of deceased subjects. We had previously reported that the racial distribution of deceased workers in this union was similar to that of half of the membership sampled during the first follow-up (Johnson et al., 1986a).

3. Results

The number of subjects, deaths, and person-years are given in Table 2. As can be seen, the 8638 workers that comprise the study population contributed a total of 337,854.1 person-years, i.e., each study subject contributed an average of 39.1 person-years of observation, and 62% of them died during the study period. Whites contributed 81.1% of the person-years and non-whites 18.9%; males contributed 74.8% of the person-years and females 25.2%. There were 593 subjects born in 1906 or earlier, who would have been at least 100 years old at the end of follow-up in 2006. Of these, 543 (92%) were known to be deceased.

Table 1
Subjects excluded from the analysis.

	Abattoirs or abattoirs with processing activities	Processing plants only
Missing date of employment or union membership	11	15
Hired at age less than 10 years	2	0
Died before the study started	0	2
Cause of death unknown	2	0
Total	15	17

We examined mortality for a total of 52 cancer sites and 10 non-malignant tumor sites (Table 3). The main SMR results are presented in Tables 4–6 for causes with more than one death, for which a statistically significant result was obtained in either of the two cohorts as a whole, or in both combined, or in any race/sex subgroups. The results for the majority of the causes investigated (Table 3) are not presented in Tables 4–6 because no statistically significantly increased or decreased SMRs were observed for them.

3.1. Abattoir workers — Table 4

All-cause mortality was significantly increased in white males only, SMR = 1.2 (95% CI, 1.1–1.2) and significantly depressed in non-white males, SMR = 0.9 (95% CI, 0.8–1.0). All-cancer mortality was similarly significantly increased in white males only, SMR = 1.1 (95% CI, 1.0–1.2). The SMR for esophageal cancer appears elevated in all race/sex subgroups except non-white females, and in white females the increase was statistically significant, SMR = 3.8 (95% CI, 1.2–8.8). The SMR for lung cancer was 1.3 in all subgroups except non-white males in whom it was 1.0; only the SMR for white males was significant, SMR = 1.3 (95% CI, 1.1–1.5). The SMR for other malignant neoplasm of the skin was significantly elevated in whites, SMR = 2.5 (95% CI, 1.0–5.2), but no deaths were recorded in non-whites. Similarly, the SMR for bladder cancer was significantly elevated in whites, SMR = 1.6 (95% CI, 1.1–2.4). The SMR for benign neoplasm of the thyroid and other unspecified endocrine organs was significantly elevated in whites, SMR = 10.8 (95% CI, 1.3–38.9). Significantly *lower* SMRs were recorded for cancer of the thymus, heart, mediastinum, pleura, etc., in white males, and cancer of the breast in females.

3.2. Processing plant workers — Table 5

All-cause mortality was significantly increased in white males and females, SMR = 1.2 (95% CI, 1.2–1.3), SMR = 1.2 (95% CI, 1.1–1.3), respectively. All-cancer mortality was significantly or borderline significantly elevated in all race/sex subgroups except non-white females. Cancer of the base of the tongue was significantly elevated in males, SMR = 3.7 (95% CI, 1.6–7.3), and no death was recorded in females. Cancer of the esophagus was significantly elevated in males, SMR = 1.7 (95% CI, 1.1–2.6), and no deaths were recorded in females. The SMR for lung cancer was significantly elevated in all race/sex groups ranging from 1.4 to 2.0, except non-white females. A borderline significantly increased risk of bladder cancer was observed in white females only, SMR = 3.1 (95% CI, 1.0–7.2).

3.3. Abattoir workers and meat processing plant workers combined — Table 6

The only new significant results when the abattoir and meat processing plant cohorts were combined together that were not evident when these two cohorts were examined separately, were for cancer of the bone and articular cartilage, and non-Hodgkin's lymphoma. The SMR for bone and cartilage cancer was significantly elevated only in non-white males in the combined population, SMR = 5.1 (95% CI, 1.1–15.0), based on 5 deaths, while non-significantly increased SMRs were observed in white and non-white males in both individual cohorts (not shown), with no death recorded in females. In the combined analysis, the SMRs for non-Hodgkin's lymphoma (NHL) were significantly reduced in females, SMR = 0.4 (95% CI, 0.1–1.0), in whites, SMR = 0.6 (95% CI, 0.4–0.9), and in all subjects, SMR = 0.6 (95% CI, 0.4–0.9). Decreased SMRs for NHL although not significant, were nevertheless observed in all race/sex subgroups in abattoirs and meat processing plants, except the SMR for non-white males in abattoirs which was 1.2 (95% CI, 0.2–3.4).

3.4. PMR results

With regard to the PMR results, statistically significantly increased PMRs were observed for Hodgkin's disease in abattoir workers overall, PMR = 2.5 (95% CI, 1.3–4.8), while in processing plants the corresponding PMR was not significant, PMR = 1.2 (95% CI, 0.4–3.7). The PMR for lymphoid leukemia was elevated only in non-white males in processing plants, PMR = 3.8 (95% CI, 1.5–9.5). The PMR for thyroid cancer was elevated in white females in abattoirs, PMR = 4.9 (95% CI, 1.4–17.2), and white females in processing plants, PMR = 2.2 (95% CI, 0.3–15.0), with only one other death recorded in white males in abattoirs. The numbers of deaths involved for these PMR results were very small, thus none of the corresponding SMRs were statistically significant, except the SMR of 3.5 (95% CI 1.0–9.0) for lymphoid leukemia in non-white men in processing plants that was of borderline

Table 2
Distribution of number of subjects, number deceased, and person-years by race and gender.

	Abattoirs or abattoirs with meat processing activities									Meat processing plants								
	Whites			Non-whites			Total			Whites			Non-whites			Total		
	Male	Female	Total	Male	Female	Total	Males	Female	All race/sex	Males	Female	Total	Males	Female	Total	Males	Female	Total
No. of subjects[a]	3251	903	4154 [83%]	811	31	842 [17%]	4062 (81%)	934 (19%)	4996	1786	952	2738 [75%]	821	83	904 [25%]	2607 (72%)	1035 (28%)	3642
No. dead	2031	527	2558 [84%]	476	11	487 [16%]	2507 (82%)	538 (18%)	3045	1166	568	1734 [75%]	535	45	580 [25%]	1701 (74%)	613 (26%)	2314
Person-years[a]	125,039	39,996	165,035 [84%]	29,693	1336	31,029 [16%]	154,732 (79%)	41,332 (21%)	196,064	68,210	40,886	109,096 [77%]	29,711	2983	32,694 [23%]	97,921 (69%)	43,869 (31%)	141,790

[a] Numbers of subjects and person-years by race were estimated.

Table 3
Causes of death studied (Neoplasms — 9th ICD Revision).

Malignant neoplasms	
1 Malignant neoplasms combined	(ICD 140–208)
2 Malignant neoplasm of lip	(ICD 140)
3 Malignant neoplasm of tongue	(ICD 141)
4 Malignant neoplasm of parotid gland; other and unspecified major salivary glands	(ICD 142)
5 Malignant neoplasm of gum	(ICD 143)
6 Malignant neoplasm of floor of mouth	(ICD 144)
7 Malignant neoplasm of palate and other and unspecif parts of mouth	(ICD 145)
8 Malignant neoplasm of tonsil;	(ICD 146)
9 Malignant neoplasm of nasopharynx	(ICD 147)
10 Malignant neoplasm of pyriform sinus; hypopharynx	(ICD 148)
11 Malignant neoplasm of other and ill-defined sites in the lip, oral cavity and pharynx	(ICD 149)
12 Malignant neoplasm of esophagus	(ICD 150)
13 Malignant neoplasm of stomach	(ICD 151)
14 Malignant neoplasm of small intestine	(ICD 152)
15 Malignant neoplasm of colon	(ICD 153)
16 Malignant neoplasm of rectosigmoid junction; rectum; anus and anal canal	(ICD 154)
17 Malignant neoplasm of liver and intrahepatic bile ducts	(ICD 155)
18 Malignant neoplasm of gallbladder; other and unspecified parts of biliary tract	(ICD 156)
19 Malignant neoplasm of pancreas	(ICD 157)
20 Malignant neoplasm of peritoneum and retroperitoneum	(ICD 158)
21 Malignant neoplasm of nasal cavity and middle ear; accessory sinuses	(ICD 160)
22 Malignant neoplasm of larynx	(ICD 161)
23 Malignant neoplasm of trachea, bronchus and lung	(ICD 162)
24 Malignant neoplasm of thymus; heart, mediastinum and pleura; mesothelioma; malignant neoplasm of other and ill-defined sites in the respiratory system and intrathoracic organs	(ICD 163–165)
25 Malignant neoplasms of bone and articular cartilage	(ICD 170)
26 Malignant neoplasm of other connective and soft tissue	(ICD 171)
27 Malignant melanoma of skin	(ICD 172)
28 Other malignant neoplasms of skin	(ICD 173)
29 Malignant neoplasm of breast	(ICD 174, 175)
30 Malignant neoplasm corpus uteri; malignant neoplasm of uterus, part unspecified; of placenta or chorionepithelioma	(ICD 179, 181,182)
31 Malignant neoplasm of cervix uteri	(ICD 180)
32 Malignant neoplasm of ovary	(ICD 183)
33 Malignant neoplasm of prostate	(ICD 185)
34 Malignant neoplasm of testis	(ICD 186)
35 Malignant neoplasm of penis	(ICD 187)
36 Malignant neoplasm of bladder	(ICD 188)
37 Malignant neoplasm of kidney; renal pelvis; ureter	(ICD 189.0, 189.1, 189.2)
38 Malignant neoplasm of eye and adnexa	(ICD 190)
39 Malignant neoplasm of brain; malignant neoplasm of meninges; spinal cord, cranial nerves and other parts of CNS; malignant neoplasm of peripheral nerves; and autonomic nervous system	(ICD 191–192)
40 Malignant neoplasm of thyroid gland	(ICD 193)
41 Malignant neoplasm of adrenal gland; other endocrine glands and related structures	(ICD 194)
42 Malignant neoplasm of other **and** ill-defined sites; malignant neoplasm without specification of site	(ICD 195,199)
43 Malignant neoplasms of lymphoid, haemotopoietic and related tissue	(ICD 200–208)
44 Follicular (nodular) non-Hodgkin's lymphoma; diffuse non-Hodgkin's lymphoma; peripheral and cutaneous T-cell lymphomas; other and unspecified types of non-Hodgkin's lymphoma	(ICD 200, 202)
45 Hodgkin's disease	(ICD201)
46 Malignant immunoproliferative Dis; multiple myeloma and malignant plasma cell neoplasms	(ICD 203)
47 Lymphoid leukemia	(ICD 204)
48 Myeloid leukemia	(ICD 205)
49 Monocytic leukemia	(ICD 206)
50 Other leukemias of specified cell type; leukemia of unspecified cell type	(207, 208)
51 Myelofibrosis	(ICD 289.8)
52 Myelodysplastic syndromes	(ICD 742.5)
Benign neoplasms	
53 Benign neoplasm of lip, oral cavity and pharynx; other parts of digestive system	(ICD 210–211)
54 Benign neoplasm of respiratory andintrathoracic organs	(ICD 212)
55 Benign neoplasm of mesothelial tissue; soft tissue of retroperitoneum, and peritoneum; other benign neoplasms of connective and other soft tissue	(ICD 211.8, 214–215)
56 Benign neoplasm of breast	(ICD 217)
57 Leiomyoma of uterus	(ICD 218)
58 Benign neoplasm of ovary	(ICD 220)
59 Benign neoplasm of meninges, brain and other parts of CNS	(ICD 225)
60 Benign neoplasm of thyroid gland and other and unspecified endocrine glands	(ICD 226–227)
61 Haemangioma and lymphangioma, any site	(ICD 228)
62 Polycythaemia vera	(ICD 238.4)

significance. Apart from these differences, the PMR results were very similar to the SMR results as is evident in Tables 4–6.

4. Discussion

Other than race, there were few missing data (Table 1). The findings of this study are important because 1) the average follow-up for study subjects was 39 years (Table 2), which is adequate for investigating diseases with long latency period such as cancers; 2) more than 60% of the workers studied were deceased, which should give a good and fairly representative pattern of mortality in this occupational group; 3) the union records from which the study population was derived were exceptionally complete; 4) 92% of study subjects aged at least 100 years old by the end of follow-up were known to be deceased, hence indicating that follow-up was quite successful in identifying deceased subjects. 5) We examined deaths from 52 separate cancer sites, and 10 non-malignant tumor sites. This is more than previously reported.

As seen from the main results in Tables 4–6, the SMR results in which race was imputed agree very closely with the PMR results in which information on race was present for all subjects included in the analyses. This close agreement suggests that no serious bias in the SMRs resulted from the missing data on race in non-deceased subjects. It should be noted that the risk estimates given by the SMRs in this study are conservative, as lost subjects were assumed to be alive.

We separate out the results for abattoir and processing plant workers because abattoir workers are expected to have higher exposures to oncogenic viruses of cattle and sheep than processing plant workers. The survival of microorganisms is greatest in live animals and soon after slaughtering, and thereafter, it is expected to decrease as these agents get exposed to environmental factors such as light, heat and dryness.

It is not possible from this type of study design to determine the cause of any excess or deficit of any specific cancer observed in this study. An observed excess may be real and represent effects of occupational and non-occupational exposures, or may be a chance finding resulting from multiple comparisons. Similarly, differences in risks observed for different race/sex subgroups may be real and associated with specific occupational

Table 4
Standardized mortality ratios for selected tumors for the period 1950 to 2006 — Baltimore cattle, pig, and sheep *abattoir* workers.

Cause of death [malignant and non-malignant tumors]	White males	Non-white males	All males	White females	Non-white females	All females	All whites	All non-whites	All groups
	N = 3251	N = 811	N = 4062	N = 903	N = 31	N = 934	N = 4154	N = 842	N = 4996
	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]
All malignant tumors	507	125	632	140	1	141	647	126	773
ICD 140–208	1.1 (1.0–1.2)*	0.9 (0.8–1.1)	1.1 (1.0–1.2)	1.0 (0.9–1.2)	0.2 (0.0–1.3)	1.0 (0.9–1.2)	1.1 (1.0–1.2)*	0.9 (0.8–1.1)	1.1 (1.0–1.1)
	1.0 [0.9–1,0]	1.1 [0.9–1.3]	1.0 [0.9–1.0]	1.0 [0.8–1.1]	0.4 [0.1–1.9]	0.9 [0.8–1.1]	1.0 [0.9–1.0]	1.1 [0.9–1.2]	1.0 [0.9–1.0]
Esophagus	15	9	24	5	0	5	20	9	29
ICD 150	1.2 (0.7–2.0)	1.3 (0.6–2.6)	1.4 (0.8–1.9)	3.8 (1.2–8.8)*	– (0.0–40.7)	3.5 (1.1–8.2)*	1.5 (0.9–2.3)	1.4 (0.6–2.6)	1.4 (1.0–2.1)
	1.0 [0.6–1.6]	1.6 [0.8–3.1]	1.1 [0.8–1.7]	3.4 [1.5–7.8]*	–	3.3 [1.5–7.6]*	1.2 [0.8–1.9]	1.6 [0.8–3.0]	1.3 [0.9–1.9]
Trachea, bronchus, lung	200	40	240	38	1	39	238	41	279
ICD 162	1.6 (1.1–1.5)*	1.0 (0.7–1.3)	1.2 (1.1–1.4)*	1.3 (1.0–1.8)	1.3 (0.0–7.1)	1.3 (1.0–1.8)	1.3 (1.2–1.5)*	1.0 (0.7–1.3)	1.3 (1.1–1.4)*
	1.1 [0.9–1.2]	1.1 [0.8–1.4]	1.1 [0.9–1.2]	1.1 [0.8–1.5]	2.2 [0.3–13.7]	1.1 [0.8–1.5]	1.1 [1.0–1.2]	1.1 [0.8–1.4]	1.1 [1.0–1.2]
Thymus, heart,	1	0	1	1	0	1	2	0	2
mediastinum,	0.1 (0.0–0.8)*	– (0.0–2.1)	0.1 (0.0–0.7)*	1.8 (0.0–9.8)	– (0.0–286.2)	1.7 (0.0–9.6)	0.2 (0.0–1.0)*	– (0.0–2.1)	0.3(0.0–0.8)*
pleura, etc.	0.2 [0.0–0.9]*	–	0.1 [0.0–0.8]*	2.5 [0.4–16.3]	–	2.4 [0.4–15.8]	0.3 [0.1–1.2]	–	0.3 [0.1–1.0]*
ICD 163–165									
Other malignant	6	0	6	1	0	1	7	0	7
neoplasm of skin	2.5 (0.9–5.4)	– (0.0–8.0)	2.1 (0.8–4.5)	2.8 (0.1–15.4)	– (0.0–453.2)	2.6 (0.1–15.1)	2.5 (1.0–5.2)*	– (0.0–7.9)	2.1 (0.9–4.4)
ICD 173	2.2 [1.0–4.8]*	–	1.9 [0.9–4.2]	2.8 [0.4–18.2]	–	2.8 [0.4–18.0]	2.3 [1.1–4.6]*	–	2.0 [1.0–4.1]
Breast	1	0	1	15	0	15	16	0	16
ICD	1.8 (0.0–9.9)	– (0.0–19.1)	1.3 (0.0–7.4)	0.6 (0.3–1.0)	– (0.0–5.2)	0.6 (0.3–1.0)*	0.6 (0.4–1.0)	– (0.0–4.1)	0.6 (0.4–1.0)*
	1.6 [0.2–10.9]	–	1.2 [0.2–8.8]	0.6 [0.4–0.9]*	–	0.6 [0.3–0.9]*	0.6 [0.4–0.9]*	–	0.6 [0.4–0.9]*
Bladder	21	1	22	3	0	3	24	1	25
ICD 188	1.6 (1.0–2.5)*	0.5 (0.0–2.5)	1.8 (0.9–2.2)	1.7 (0.3–4.9)	– (0.0–63.6)	1.6 (0.3–4.8)	1.6 (1.1–2.4)*	0.4 (0.0–2.5)	1.5 (1.0–2.2)
	1.5 [1.0–2.3]	0.5 [0.1–3.7]	1.4 [0.9–2.1]	1.6 [0.5–5.0]	–	1.6 [0.5–4.9]	1.5 [1.0–2.2]*	0.5 [0.1–3.6]	1.4 [0.9–2.1]
Non-malignant tumors									
Benign neoplasm	1	0	1	1	0	1	2	0	2
of thyroid, other	7.2 (0.2–40.1)	– (0.0–47.3)	4.6 (0.1–25.7)	21.5 (0.5–119.6)	– (0.0–1294.4)	20.2 (0.5–112.7)	10.8 (1.3–38.9)*	– (0.0–45.6)	7.5 (0.9–27.1)
unspec. endocrine	6.4 [1.2–35.2]*	–	4.5 [0.8–26.8]	20.6 [5.2–81.3]*	–	19.7 [4.9–78.9]*	9.8 [3.2–30.1]*	–	7.3 [2.2–23.8]*
ICD 226–227									
All causes	2031	476	2507	527	11	538	2558	487	3045
	1.2 (1.1–1.2)*	0.9 (0.8–1.0)*	1.1 (1.1–1.1)*	1.0 (0.9–1.1)	0.6 (0.3–1.1)	1.0 (0.9–1.1)	1.1 (1.1–1.2)*	0.9 (0.8–1.0)*	1.1 (1.0–1.1)*

* Statistically significant at the 95% confidence level and figures in parentheses are confidence intervals.

Table 5
Standardized mortality ratios for selected tumors for the period 1950 to 2006 — Baltimore cattle, pig, and sheep *processing plant* workers.

Cause of death [malignant and non-malignant tumors]	White males	Non-white males	All males	White females	Non-white females	All females	All whites	All non-whites	All Groups
	N = 1786	N = 821	N = 2607	N = 952	N = 83	N = 1035	N = 2738	N = 904	N = 3642
	Obs. SMR (95% CI)	Obs. SMR (95% CI)	Obs. SMR (95% CI)	Obs. SMR (95% CI)	Obs. SMR (95% CI)	Obs. SMR (95% CI)	Obs. SMR (95% CI)	Obs. SMR (95% CI)	Obs. SMR (95% CI)
All malignant tumors ICD 140–208	271 1.1 (1.0–1.2) 0.9 [0.8–1.0]*	151 1.2 (1.0–1.4)* 1.2 [1.0–1.3]*	422 1.1 (1.0–1.2)* 1.0 [0.9–1.1]	149 1.2 (1.0–1.4) 0.9 [0.8–1.0]	4 0.5 (0.1–1.2) 0.4 [0.2–0.8]*	153 1.1 (0.9–1.3) 0.8 [0.8–1.0]*	420 1.1 (1.0–1.2)* 0.9 [0.8–1.0]*	155 1.1 (1.0–1.3) 1.1 [1.0–1.2]	575 1.1 (1.0–1.2)* 0.9 [0.9–1.0]
Base of tongue, other and unspec. tongue ICD 141	4 3.1 (0.9–8.1) 2.5 [1.0–6.5]	4 4.4 (1.2–11.4)* 4.3 [1.8–10.6]*	8 3.7 (1.6–7.3)* 3.2 [1.7–6.2]*	0 – (0.0–10.3) –	0 – (0.0–144.8) –	0 – (0.0–9.6) –	4 2.5 (0.7–6.3) 2.0 [0.8–5.1]	4 4.3 (1.2–11.1)* 4.2 [1.7–10.3]*	8 3.1 (1.4–6.2)* 2.7 [1.4–5.2]*
Esophagus ICD 150	8 1.2 (0.5–2.3) 0.9 [0.5–1.8]	15 2.3 (1.3–3.9)* 2.3 [1.4–3.7]*	23 1.7 (1.1–2.6)* 1.5 [1.0–2.3]*	0 – (0.0–3.0) –	0 – (0.0–19.9) –	0 – (0.0–2.6) –	8 1.0 (0.4–2.0) 0.8 [0.4–1.5]	15 2.3 (1.3–3.8)* 2.2 [1.4–3.6]*	23 1.6 (1.0–2.4) 1.3 [0.9–2.0]
Trachea, bronchus, lung ICD 162	118 1.4 (1.2–1.7)* 1.1 [0.9–1.3]	60 1.5 (1.1–1.9)* 1.4 [1.1–1.7]*	178 1.4 (1.2–1.7)* 1.2 [1.0–1.4]*	54 1.0 (1.5–2.6)* 1.4 [1.1–1.9]*	1 0.6 (0.0–3.6) 0.5 [0.1–3.0]	55 1.9 (1.4–2.5)* 1.3 [1.0–1.7]*	172 1.6 (1.3–1.8)* 1.2 [1.0–1.4]*	61 1.4 (1.1–1.8)* 1.3 [1.0–1.7]*	233 1.5 (1.3–1.7)* 1.2 [1.1–1.4]*
Bladder ICD 188	9 1.3 (0.6–2.4) 1.1 [0.6–2.2]	2 1.0 (0.1–3.7) 1.1 [0.3–4.2]	11 1.2 (0.6–2.2) 1.1 [0.6–2.0]	5 3.1 (1.0–7.2) 2.6 [1.1–6.0]*	0 – (0.0–31.8) –	5 2.9 (0.9–6.7) 2.4 [1.0–5.6]*	14 1.6 (0.9–2.7) 1.4 [0.9–2.4]	2 1.0 (0.1–3.5) 1.0 [0.2–3.9]	16 1.5 (0.9–2.4) 1.4 [0.8–2.2]
All causes	1166 1.2 (1.2–1.3)*	535 1.0 (1.0–1.1)	1701 1.2 (1.1–1.2)*	568 1.2 (1.1–1.3)*	45 1.3 (0.9–1.7)	613 1.2 (1.1–1.3)*	1734 1.2 (1.2–1.3)*	580 1.1 (1.0–1.2)	2314 1.2 (1.1–1.2)*

* Statistically significant at the 95% confidence level and figures in parentheses are confidence intervals.

exposures (it is known that there were gender and racial differences in jobs performed in this cohort — workers who killed in abattoirs were mostly black, and women were mostly engaged in wrapping meat). Alternatively, an observed excess risk that appears confined to a particular race/sex subgroup(s) may be due to non-occupational exposures, or may be due to chance, or may result from inadequate sample size in the other race/sex subgroups like non-white females. Also, it is possible that mortality rates for specific causes of death are disproportionately higher or lower for specific race/sex subgroups in the comparison US general population. These factors make it difficult therefore to assess the significance of the findings from this type of study design.

The excess occurrence of cancers of the lung, esophagus and bladder was seen in both abattoir and processing plant workers, while that for cancer of the base of the tongue and possibly lymphoid leukemia was confined to processing plants. Table 7 gives the findings reported in the literature for cancer mortality and incidence studies among well-defined groups of butchers, meat cutters, and meat workers in slaughtering and processing plants. As can be seen, in nearly all the studies, a significant excess of lung cancer was recorded, while studies that investigated multiple causes of death (including a previous follow-up of this study population) also reported excess of cancer of the mouth, esophagus and bladder, in addition to lung cancer. Although non-occupational factors such as tobacco smoking could well explain these findings, for lung cancer, a previous pilot nested case-control study of this same cohort found that the lung cancer excess in abattoir workers was evident even after controlling for tobacco smoking, and was highest for subjects who worked in stockyards and in the killing and dressing departments (Johnson, 1991). A similar association of lung cancer occurrence with exposure to warm or freshly killed meat among workers in pig slaughtering and processing plants or in butchers, has been reported by others (Coggon et al., 1989; Guberan et al., 1993). Moreover in a case–cohort study of workers in poultry slaughtering and processing plants (submitted for publication), the highest risk of lung cancer after controlling for tobacco smoking and other confounders, was in workers who killed, in those who had contact with the blood of animals, and in those working in a stockyard (i.e., exposures associated with the greatest exposure to oncogenic viruses). It is to be noted also, that some of the workers in our study handled sheep, and therefore had potential for exposure to jaagsiekte sheep retrovirus that causes lung cancer in sheep (Palmarini and Fan, 2001). With regards to lung cancer also, all three systematic reviews of published studies involving several different study designs conducted to date consistently concluded that an excess of lung cancer exists in workers in the meat industry (Kristensen and Lynge, 1993; McLean and Pearce, 2004, Johnson and Choi, submitted for publication). Interestingly, a prospective study of a national sample of retired persons in the United States found significantly increased risk of cancer of the esophagus, colo-rectum, liver and lung in persons with intake of red meat at the highest quintile compared to those with intake at the lowest quintile (Cross et al., 2007). This finding indicates that as mentioned above, non-occupational factors could also be of importance in explaining the excess risk of some of these diseases in workers. Alternatively, this could indicate that subjects in the general population are also exposed to oncogenic viruses that infect these food animals at levels that are causing similar cancer excesses in the general population.

It is of note that the workers in this study had potentially increased exposure to both human and animal papilloma viruses, and papilloma viruses are known to cause tumors of the alimentary and/urinary tracts in cattle as well as in humans (Campo, 1987; Gissmann, 1984). Papilloma viruses have also been hypothesized as a cause of cancer of the oral cavity in humans (Scully, 2002). Hence the excess occurrence of cancers of the base of the tongue, esophagus, and bladder in the current study and in the studies by Boffetta et al. (2000), Fritschi et al. (2003) and Besson et al. (2006) may be related to exposure to papilloma viruses.

The excess of malignant neoplasm of the skin observed in abattoir workers, is consistent with the known fact that meat workers are known to have a high prevalence of warts, which are due to human papilloma viruses (Gissmann, 1984; Jablonska et al., 1988), and consistent with the fact that bovine papilloma viruses are known to cause skin tumors such as fibromas, fibrosarcomas and chondromas in other animals (Lancaster and Olson, 1982).

The excess of bone and cartilage cancer was seen in men in abattoirs and processing plants but not in women, possibly due to the small number of women. At this time these findings are tentative, as the numbers involved for these cancers are too few for any firm conclusions to be made.

Other than viruses, other possible occupational candidates for explaining any excess cancer occurrences in meat workers include exposure to polycyclic aromatic hydrocarbons and heterocyclic amines (PAH) during smoking and cooking of meat, nitrosamines during curing, and APH, benzene, and phthalates during wrapping of meat (Jakszyn et al., 2004; Johnson et al., 1999; Nordholm et al., 1986; Smith et al., 1983;

Table 6
Standardized mortality ratios for selected tumors for the period 1950 to 2006 — Baltimore cattle, pig, and sheep *abattoir* and *meat processing plant workers* combined.

Cause of death [malignant and non-malignant tumors]	White ales	Non-white males	All males	White females	Non-white females	All females	All whites	All non-whites	All groups
	N = 5037	N = 1632	N = 6669	N = 1855	N = 114	N = 1969	N = 6892	N = 1746	N = 8638
	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]	Obs. SMR (95% CI) PMR [95% CI]
All malignant tumors ICD 140–208	778 1.1 (1.0–1.2)* 0.9 [0.9–1.0]*	276 1.1 (0.9–1.2) 1.1 [1.0–1.2]*	1054 1.1 (1.0–1.2)* 1.0 [0.9–1.0]	289 1.1 (1.0–1.2) 0.9 [0.8–1.0]	5 0.4 (0.1–0.9)* 0.4 [0.2–0.7]*	294 1.1 (0.9–1.2) 0.9 [0.8–1.0]*	1067 1.1 (1.0–1.2)* 0.9 [0.9–1.0]*	281 1.0 (0.9–1.2) 1.1 [1.0–1.2]	1348 1.1 (1.0–1.1)* 1.0 [0.9–1.0]
Base of tongue, other and unspec. tongue ICD 141	5 1.4 (0.5–3.2) 1.2 [0.5–2.8]	4 2.2 (0.6–5.7) 2.4 [0.9–6.1]	9 1.7 (0.8–3.2) 1.5 [0.8–2.9]	1 1.3 (0.0–7.5) 1.1 [0.2–8.1]	0 – (0.0–97.8) –	1 1.3 (0.0–7.2) 1.1 [0.2–7.8]	6 1.4 (0.5–3.0) 1.2 [0.5–2.6]	4 2.2 (0.6–5.6) 2.3 [0.9–6.0]	10 1.6 (0.8–3.0) 1.4 [0.8–2.7]
Esophagus ICD 150	23 1.2 (0.8–1.8) 1.0 [0.6–1.4]	24 1.9 (1.2–2.8)* 2.0 [1.3–2.9]*	47 1.5 (1.1–1.9)* 1.3 [1.0–1.7]	5 2.0 (0.6–4.6) 1.6 [0.7–3.9]	0 – (0.0–13.4) –	5 1.8 (0.6–4.1) 1.5 [0.6–3.6]	28 1.3 (0.9–1.9) 1.0 [0.7–1.5]	24 1.8 (1.2–2.7)* 1.9 [1.3–2.8]*	52 1.4 (1.1–2.0)* 1.3 [1.0–1.7]*
Trachea, bronchus, lung ICD 162	318 1.4 (1.2–1.5)* 1.1 [1.0–1.2]	100 1.2 (1.0–1.5) 1.2 [1.0–1.5]*	418 1.3 (1.2–1.5)* 1.1 [1.0–1.2]*	92 1.5 (1.3–2.0)* 1.3 [1.0–1.5]*	2 0.9 (0.1–3.1) 0.8 [0.2–2.9]	94 1.6 (1.3–2.0)* 1.3 [1.0–1.5]*	410 1.4 (1.3–1.6)* 1.1 [1.0–1.2]*	102 1.2 (1.0–1.5) 1.2 [1.0–1.5]*	512 1.4 (1.2–1.5)* 1.1 [1.0–1.2]*
Thymus, heart, mediastinum, pleura, etc. ICD 163–165	3 0.1 (0.1–0.8)* 0.2 [0.1–0.9]*	0 – (0.0–1.2) –	3 0.2 (0.0–0.7)* 0.3 [0.1–0.8]*	1 0.9 (0.0–5.2) 1.1 [0.2–8.0]	0 – (0.0–96.3) –	1 0.9 (0.0–5.0) 1.1 [0.2–7.7]	4 0.4 (0.1–0.9)* 0.4 [0.2–1.0]	0 – (0.0–1.2) –	4 0.3 (0.1–0.7)* 0.3 [0.1–0.8]*
Bone and articular cartilage	2 1.1 (0.1–4.1) 1.1 [0.3–4.4]	3 5.1 (1.1–15.0)* 6.2 [2.3–16.7]*	5 2.1 (0.7–5.0) 2.2 [0.9–5.1]	0 – (0.0–6.7) –	0 – (0.0–132.2) –	0 – (0.0–6.3) –	2 0.9 (0.1–3.1) 0.8 [0.2–3.3]	3 4.9 (1.0–14.3)* 5.9 [2.2–15.9]*	5 1.7 (0.6–4.0) 1.7 [0.7–4.1]
Other malignant neoplasm of skin ICD 173	7 1.9 (0.7–3.8) 1.6 [0.8–3.4]	1. 1.1 (0.0–6.0) 1.1 [0.2–8.0]	8 1.7 (0.7–3.4) 1.5 [0.8–3.1]	1 1.3 (0.0–8.0) 1.3 [0.2–9.4]	0 – (0.0–145.4) –	1 1.4 (0.0–7.7) 1.3 [0.2–9.1]	8 1.8 (0.8–3.5) 1.6 [0.8–3.1]	1 1.0 (0.0–5.8) 1.1 [0.2–7.8]	9 1.7 (0.8–3.2) 1.5 [0.8–2.9]
Breast ICD	1 1.1 (0.0–6.4) 1.0 [0.1–7.0]	0 – (0.0–9.9) –	1 0.8 (0.0–4.5) 0.7 [0.1–5.2]	38 0.8 (0.6–1.1) 0.7 [0.5–0.9]*	2 0.9 (0.1–3.3) 0.8 [0.2–3.0]	40 0.8 (0.6–1.1) 0.7 [0.5–0.9]*	39 0.8 (0.6–1.1) 0.7 [0.5–0.9]*	2 0.8 (0.1–2.8) 0.7 [0.2–2.6]	41 0.8 (0.7–2.6) 0.7 [0.5–0.9]*
Bladder ICD 188	30 1.5 (1.0–2.2)* 1.4 [1.0–1.9]	3 0.7 (0.2–2.1) 0.8 [0.3–2.5]	33 1.4 (0.9–1.9) 1.3 [0.9–1.8]	8 2.3 (1.0–4.6)* 2.1 [1.1–4.2]*	0 – (0.0–21.2) –	8 2.2 (1.0–4.4) 2.0 [1.0–4.0]*	38 1.6 (1.2–2.2)* 1.5 [1.1–2.0]*	3 0.7 (0.1–2.0) 0.8 [0.2–2.3]	41 1.5 (1.1–2.0)* 1.4 [1.0–1.9]*
Follicular (nodular) NHL, NHL/T-cell lymph., other NHL	17 0.7 (0.4–1.0) 0.6 [0.3–0.9]*	5 1.0 (0.3–2.3) 1.0 [0.4–2.5]	22 0.7 (0.4–1.1) 0.6 [0.4–0.9]*	4 0.4 (0.1–1.0) 0.3 [0.1–0.9]*	0 – (0.0–14.0) –	4 0.4 (0.1–1.0)* 0.3 [0.1–0.8]*	21 0.6 (0.4–0.9)* 0.5 [0.3–0.7]*	5 0.9 (0.3–2.2) 1.0 [0.4–2.3]	26 0.6 (0.4–0.9)* 0.5 [0.4–0.8]*
Non-malignant tumors									
Benign neoplasm of thyroid, other unspec. endocrine ICD 226–227	1 4.7 (0.1–26.0) 4.1 [0.7–24.7]	0 – (0.0–24.1) –	1 2.7 (0.0–15.1) 2.6 [0.4–16.9]	1 11.0 (0.3–61.1) 9.7 [2.0–47.6]*	0 – (0.0–416.8) –	1 10.0 (0.3–55.7) 8.9 [1.8–44.7]*	2 6.5 (0.8–23.6) 5.7 [1.7–19.4]*	0 – (0.0–22.8) –	2 4.3 (0.5–15.4) 4.0 [1.1–14.3]*
All causes	3197 1.2 (1.1–1.2)*	1011 1.0 (0.9–1.0)	4208 1.1 (1.1–1.2)*	1095 1.1 (1.1–1.2)*	56 1.1 (0.8–1.4)	1151 1.1 (1.1–1.2)*	4292 1.2 (1.1–1.2)*	1067 1.0 (0.9–1.0)	5359 1.1 (1.1–1.2)*

* Statistically significant at the 95% confidence level and figures in parentheses are confidence intervals.

Table 7
Summary of the findings for cancer in full cohort studies of meat workers in the literature.

Reference	Description of study	Findings
Johnson and Fischman (1982)	PMR study of 223 death certificates in the Baltimore meatcutters' union	Lung cancer PMR = 1.54 Bladder cancer PMR = 2.24 Lymphoma and reticulum cell sarcoma PMR = 2.67 Multiple myeloma PMR = 2.74 Myeloid leukemia PMR = 3.75
Doerken and Rehpenning (1982)	Comparison of lung cancer occurrence in butchers and bakers in Germany	Cancer of the respiratory tract: 36 of 398 *butchers* versus 15 of 399 *bakers* ($p<0.01$)
Fox et al. (1982)	Lung cancer occupational mortality in butchers in England and Wales, Denmark, and Sweden	England and Wales 1970–1972 (mortality) Lung cancer SMR = 1.16 1966–1967 (cancer incidence) Lung cancer SIR = 1.27 1968–1970 (cancer incidence) Lung cancer SIR = 1.20 Denmark 1970–1975 *Butchers in slaughterhouses* Lung cancer SMR = 2.53 *Other butchers* Lung cancer SMR = 1.65 *Unskilled workers in slaughterhouses* Lung cancer SMR = 0.85 Sweden 1961–1973 *Butchers in slaughterhouses* Lung cancer SMR = 1.78 *Other butchers* Lung cancer SMR = 1.30 *Others in slaughterhouses* Lung cancer SMR = 1.48
Griffith GW (1982)	Lung cancer occupational mortality in butchers in England and Wales (1959–1963)	1951 *Meat and fish curers and smokers* Lung cancer SMR = 2.00 *Slaughterhouse workers* Lung cancer SMR = 1.31 *Proprietors etc. of retail stores for grocery, meat, fish, poultry and other foods* Lung cancer SMR = 1.51 1959–1963 Butchers and meatcutters Lung cancer SMR = 1.27
Milham (1982)	Death certificate study of lung cancer deaths in Washington State	Lung cancer PMR = 1.07 for butchers and meatcutters in slaughterhouses Lung cancer PMR = 0.97 for butchers and meatcutters not in slaughterhouses
Lynge et al. (1983)	Record linkage study in Denmark of butchers,	1970–1975 *Butcher's shop* *Self-employed*: lung cancer SMR = 1.59 *Skilled*: lung cancer SMR = 2.53 *Slaughterhouse* *Skilled butchers*: lung cancer SMR = 1.73 *Unskilled*: lung cancer SMR = 0.85 1975–1980 *Butcher's shop* *Self-employed*: lung cancer SMR = 1.75 *Skilled*: lung cancer SMR = 0.85 *Slaughterhouse* *Skilled butchers*: lung cancer SMR = 1.51 *Unskilled*: lung cancer SMR = 1.09
Coggon et al. (1989)	Study mortality in *England* in 1) two bacon factories that slaughtered pigs and manufactured pork and beef products. 2) Abattoirs and meat distribution centers that handled beef, pork, lamb	Liver cancer SMR = 5.6 (1.2) Lung cancer SMR = 1.3 (1.0) Exposure to warm meat, lung cancer SMR = 1.8 (1.2)
Guberan et al. (1993)	Mortality and incidence of cancer among Geneva self-employed butchers and their wives in *Switzerland*	*Mortality* All causes mortality SMR = 1.2 (1.1–1.3) in butchers All causes mortality SMR = 1.2 (1.1–1.4) in pork butchers All cancers SMR = 1.3 (1.1–1.5) in butchers All cancers SMR = 1.3 (1.0–1.6) in pork butchers Colon/rectum cancer SMR = 2.4 (1.4–3.8) in pork butchers Larynx cancer SMR = 3.0 (1.3–5.9) in butchers Lung cancer SMR = 1.8 (1.1–2.6) in pork butchers Prostate cancer SMR = 2.0 (1.3–3.0) in butchers *Incidence* All cancers SIR = 1.9 (1.5–2.4) Colon/rectum cancer SIR = 1.9 (1.1–3.0) in butchers

(continued on next page)

Table 7 *(continued)*

Reference	Description of study	Findings
Guberan et al. (1993)		Colon/rectum cancer SIR = 3.9 (2.3–6.1) in pork butchers Lung cancer SIR = 2.3 (1.4–3.7) in pork butchers Prostate cancer SIR = 1.7 (1.1–2.7) in butchers Prostate cancer SIR = 1.9 (1.0–3.4) in pork butchers Liver cancer SIR = 4.1 (1.4–9.4)
Coggon and Wield (1995)	Mortality of butchers identified from census in England and Wales	No significantly increased SMR was observed
Johnson et al. (1995a)	Mortality in union workers in abattoirs and processing plants handling cattle, pigs, sheep in Baltimore, United States.	*Abattoir* Lung cancer SMR = 1.4 (1.2–1.6) Esophageal cancer SMR = 1.7 (1.0–2.6) Kidney cancer SMR = 2.0 (1.2–3.2) Processing plants Lung cancer SMR = 1.5 (1.3–1.8) Esophageal cancer SMR = 1.7 (1.0–2.8) Buccal cavity and pharynx SMR = 2.0 (1.2–3.2) Bone cancer SMR = 4.2 (1.1–11) Pig processing plants Lung cancer SMR = 2.3 (1.1–4.0) Cattle processing plants Lung cancer SMR = 1.5 (1.2–1.7) Buccal cavity cancer SMR = 2.2 (1.3–3.4) Esophagus cancer SMR = 2.6 (1.4–4.6) for non-white males only Bone cancer SMR = 4.4 (1.2–11.3)
Boffetta et al. (2000)	Record linkage cancer incidence study of butchers and meat workers identified from census in *Sweden*	Stomach cancer SIR = 1.1 (1.0) Rectum cancer SIR = 1.2(1.0) Larynx cancer SIR = 1.7 (1.2) Lung cancer SIR = 1.3 (1.2) Prostate cancer SIR = 1.1 (1.0) Bladder cancer SIR = 1.2(1.0) Oral cavity, pharynx SIR = 1.6 (1.0)
Fritschi et al. (2003)	Mortality and cancer incidence in members of a meat workers union in *Australia* employed in poultry processing, abattoirs, supermarket meat rooms etc.	All cause SMR = 1.2 (1.1–1.3) Lung cancer SIR = 1.6 (1.0–2.6) Head and neck SIR = 1.9 (1.0–3.2)*
McLean et al. (2004)	Mortality and cancer incidence in meat workers in one mutton and beef plant and two sheep plants in New Zealand.	*Mortality overall* Lung cancer SMR = 1.8 (1.1–2.7) Thyroid cancer SMR = 15.6 (1.9–56.2) *Incidence overall* Lung cancer SIR = 1.7 (1.1–2.5) *Incidence by job* *Slaughterboard department* Lung cancer SIR = 1.87 (1.05–3.10) *Processing department* Lung cancer SIR = 2.91 (1.10–6.37) *Exposure to raw meat* Lung cancer SIR = 1.77 (1.05–2.81) *Exposure to urine* Lung cancer SIR = 1.72 (1.09–2.61) *Exposure to feces* Lung cancer SIR = 1.97 (1.26–2.95) *Exposure to blood* Lung cancer SIR = 1.91 (1.21–2.90) *Processing department* Lymphohaematopoietic cancer SIR = 6.25 (1.25–20.03) for 15+ duration of employment
Besson et al. (2006)	Death certificate study among butchers or meatcutters in 24 states in the US.	Oral cavity cancer OR = 1.5 (1.1) Pharynx cancer OR = 1.6 (1.0) Esophagus cancer OR = 1.2 (1.0) Bladder cancer OR = 1.2 (1.0)

Vainiotalo and Matveinen, 1993). The role of these other exposures in cancer occurrence in meat workers has never been adequately investigated and therefore needs to be evaluated.

The two deaths from cancer of the thymus, heart, mediastinum, pleura, etc. are too few to warrant comments on the observed deficit at this time. Likewise, it is not clear whether there is a deficit of deaths from breast cancer in females.

McLean et al. (2004) in their study of abattoir and processing plants workers most of whom handled sheep reported excess occurrence of thyroid cancer, SMR = 15.6 (95% CI, 1.9–56.2) — Table 7. The present study also observed 2 deaths from thyroid cancer in white females in abattoirs, SMR = 5.1 (95% CI, 0.6–18.3) and one death in white females in processing plants, SMR = 2.7 (95% CI, 0.1–15.2) (not shown). The corresponding PMRs were 4.9 (95% CI, 1.4–17.2), and 2.2 (95% CI, 0.3–15.0). The SMR for benign neoplasm of the thyroid gland in whites in abattoirs was 10.8 (95% CI, 1.3–38.9). Thus these findings are consistent with those of McLean et al. (2004).

Others have reported excess of tumors of the hemopoietic and lymphatic systems in meat workers (Bethwaite et al., 2001; Loomis and Savitz, 1991; McLean et al., 2004). Only Hodgkin's disease and lymphoid leukemia appear to be possibly in excess in this cohort. An excess occurrence of cancers of the larynx and prostate was reported by Guberan et al. (1993) and Boffetta et al. (2000). In the present study, the only elevated SMRs observed for these sites were the SMRs for cancer of the larynx of 1.9 (95% CI, 0.9–3.4) and 2.3 (95% CI, 0.1–12.8) for white males and white females in abattoirs, respectively. The SMRs for prostate cancer were not elevated in any subgroup (not shown).

Although as mentioned above it is not possible to determine the cause (s) of the excess cancer occurrence in these meat workers, it is to be noted that exposure to microbial agents by the airborne route or through contact with contaminated carcasses or animals is well known in abattoirs and meat processing plants, and workers work in production lines that bring them in contact with hundreds or thousands of animals daily (Rahkio and Korkeala, 1997). Furthermore high injury rates from lacerations and puncture wounds from knives and sharp bone splinters contribute to these workers having among the highest rates of injury across all industries (Cai et al., 2005). Thus there is ample opportunity for infectious agents including oncogenic viruses to enter the body of workers through the skin or by inhalation. Thus it is possible that animal oncogenic viruses could play an important role in the occurrence of the excess of at least some, if not all, of these cancers. What are needed now are, further follow-up and the conduct of large cohort and nested case–control studies of adequate statistical power that can investigate exposures in greater detail while adequately controlling for confounding factors, so that specific exposures can be validly implicated. For now, it is clear from this large study and others reported in the literature that workers in the meat industry are at increased risk of developing and dying from cancer. Thus steps should begin to be taken to protect the workers from known carcinogenic exposures in the workplace that include oncogenic viruses and other microbial agents, and chemical carcinogens associated with curing, smoking, and cooking of meat. The findings of this study also have public health implications, since 1) subjects in the general population are also exposed to these microbial agents that infect and cause cancer in food animals, as demonstrated by the presence of antibodies in their blood to these viruses (Buehring et al., 2003; Choudat et al., 1996; Johnson et al., 1995b,c); and 2) the study reported on here is also showing excess occurrence of some of the same cancers observed to be associated with the ingestion of red meat (Cross et al., 2007). Thus further research in this area should be strongly encouraged.

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