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Enduring health effects of asbestos use in Belgian industries: a record-linked retrospective cohort study of cause-specific mortality (2001-2010).

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3392 words

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Abstract

Objective: To investigate cause-specific mortality among asbestos workers and potentially exposed workers in Belgium and evaluate potential excess in mortality due to established and suspected asbestos-related diseases.

Design: This retrospective cohort study is based on an individual record linkage between the 1991 Belgian census and cause-specific mortality information for Flanders and Brussels (2001-2009).

Setting: Belgium (Flanders & Brussels region)

Participants: The study population consists of 1 397 699 male workers (18-65 years) with 72 074 deaths between October 1st 2001 and January 1st 2010. Using a classification of high-risk industries, mortality patterns between 2 056 asbestos workers, 385 046 potentially exposed workers and the working population have been compared.

Outcome measures: Standardised mortality ratios and 95% confidence intervals were calculated for manual and non-manual workers.

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Results: Our findings show clear excess in asbestos-related mortality in the asbestos industry with SMRs for mesothelioma of 4071 (CL 2327-6611) among manual workers and of 4489 (CL 1458-10476) among non-manual workers. Excess risks in asbestos-related mortality are also found in the chemical industry, the construction industry, the electrical generation and distribution industry, the basic metals manufacturing industry, the metal products manufacturing industry, the railroad industry and the shipping industry. Oral cancer mortality is significantly higher for asbestos workers (SMR 383; CL 124-894), railroad workers (SMR 192; CL 112-308), shipping workers (SMR 172; CL 102-271) and construction workers (SMR 125; CL 100-153), indicating a possible association with occupational asbestos exposure.

Conclusions: The study identifies vulnerable groups of Belgian asbestos workers, demonstrating the current-day health repercussions of historical asbestos use. Results support the hypothesis of a possible association between the development of oral cancer and occupational asbestos exposure.

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Strengths and limitations of this study

- Mortality among Belgian workers is investigated using exhaustive census-linked cause-specific mortality data at the individual level.
- The availability of a large national database allows the study of industries with a relatively small number of workers.
- Asbestos exposure data is not available for Belgium and could not be included in this study. However, high-risk industries are selected based on an extensive literature review and the strong etiological relation between mesothelioma and asbestos exposure. A further differentiation was made between manual and non-manual workers.
- Occupational information is only available for one point in time. Workers exposed before the census date may have been included in the reference population (e.g. job change) or may have left the active population (e.g. health reasons). Our results may underestimate the true influence of occupational asbestos exposure.

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Introduction

Belgium has the fourth highest mesothelioma mortality rates in the world, after the UK, Australia and Italy. Since 2006, over 200 Belgians die from mesothelioma each year.[1] Mesothelioma is considered to be a potent and sensitive indicator for asbestos exposure,[2] but further research on other asbestos-related diseases is imperative to understand the full extent of the asbestos problem in Belgium. This study focuses on the primary source of asbestos exposure: the workplace.

Asbestos minerals do not occur naturally in Belgium. With the start of one of Europe's largest asbestos companies, Eternit, in the early 1900s, Belgium rapidly became an important supplier of asbestos products. Large amounts of raw asbestos fibres were imported for manufacturing purposes since the 1930s.[3] Belgian asbestos industries used a mix of different types of asbestos, usually consisting of 90-99% chrysotile and 10-1% crocidolite.[4] The use of relatively small amounts of amosite has also been reported.[5]

Asbestos use culminated during the 1960s-1970s with Belgium having the highest asbestos consumption level per capita in the world.[6] Since then, overall exposure levels have gradually decreased as a result of private and public health control measures, including the mandatory use of dust masks and the installation of exhaust systems in the workplace.[7] Airborne occupational exposure limits for asbestos were implemented in 1980 to control exposure intensity and duration.[8] Nonetheless, these measures did not avert all fatal health effects due to asbestos exposure.

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Despite declining asbestos exposure levels, occupational exposure in i.a. asbestos products manufacturing, shipbuilding and construction remained relatively common until the end of the 1990s. Industrial asbestos use was reduced dramatically with a first major ban in 1998. The use and transaction of all types of asbestos were finally banned in 2001.

The few Belgian studies on asbestos health risks in the workplace are based on industry findings, biomedical data or on information delivered by victim compensation funds.[4,5,9,10] Considering the typical long latency periods of asbestos-related diseases and most occupational asbestos research dating back to the 1960s-1970s, results may not reflect the true public health consequences of industrial asbestos use. Selection bias, differences in diagnostic criteria, and low civil awareness of compensation measures make the representativeness of these data sources questionable.

International studies on the health of asbestos workers focus mainly on well-established asbestos-related diseases, namely asbestosis, malignant mesothelioma and lung cancer. Recently, the International Agency for Research on Cancer has acknowledged a causal effect in the development of laryngeal cancer and ovarian cancer.[11] The association between asbestos exposure and several other malignancies remains controversial.

Present study investigates cause-specific mortality among asbestos workers and potentially exposed workers to evaluate potential excess in mortality due to established and suspected asbestos-related diseases. For the first time, mortality

follow-up data and individual employment information for a large study population are available to determine the impact of asbestos exposure on Belgian male workers.

Methods

Study design

An anonymous record linkage has been performed between detailed occupational information from the 1991 Belgian census and cause-specific mortality data from October 1st 2001 to January 1st 2010. The record linkage is based on a primary link between the 1991 Belgian census and registration records of all deaths and migrations between the census date (March 1st 1991) and January 1st 2010. Then, cause-specific mortality information was derived from death certificates for the period 2001-2010 and added to the dataset. As a result, there is a 10-year time lag between occupational information and cause-specific mortality data. Death certificates are only available for Flanders and the Brussels Capital Region, where the majority of Belgian asbestos firms are located. [1]

The study includes all occupationally active men (18-65 years) in 1991 that did not die or emigrate before October 1st 2001. Based on the 1991 census, we have identified 1 537 805 workers. Prior to October 1st 2001, 3.5% of these workers emigrated and 3.6% died. Due to missing occupational information, 30 922 workers could not be classified. The study population consists of 1 397 699 Flemish and Brussels workers with 72 074 deaths between October 1st 2001 and January 1st 2010.

Classification of high-risk industries

The comprehensive character of the census data provides a snapshot of the occupational distribution. Consequently, the risks of persons who have been at least potentially exposed to asbestos can be compared with all other occupational groups. Information about exposure circumstances is not available. Because of the widespread use of asbestos fibres in Belgium, careful consideration is required to distinguish occupational asbestos exposure from environmental or secondary exposure. We propose a two-stage method to determine the industries most at risk of asbestos-related health effects.

First, malignant mesothelioma mortality is used as a marker for asbestos exposure (ICD-10 C45). This highly fatal cancer develops in the protective linings of the lungs, chest wall, abdomen and heart and is caused almost exclusively by asbestos exposure. Even low levels of asbestos exposure can induce malignant mesothelioma.[12] Industrial sectors with at least three mesothelioma deaths during the period 2001-2010 are selected using the Statistical Classification of Economic Activities in the European Community (NACE).

In a second stage, an extensive review of international and national studies on occupational asbestos exposure is conducted to ascertain at least potential asbestos use in these industries. Databases PubMed and Unicat (Union Catalogue of Belgian Libraries) are examined. Keywords include “occupation*”, “industr*”, “asbestos”, “health”, “mortality”, “Belg*”. Additional searches are conducted using the names of the selected industries. Only peer-reviewed articles and government documents are

considered. We make no restrictions in time or language. If industrial asbestos use is established in at least one of the studies, the industry is included in further analyses.

Finally, we can distinguish three broad categories. Table 1 presents detailed information on the activities for the analysed industries in each category. Category A includes workers in asbestos industries. Category B includes workers in high-risk industries with potential asbestos exposure. Category C consists of the active population in all other industries. A further differentiation is made between manual workers and all other occupational types in high-risk industries. Manual workers include blue-collar workers and self-employed persons[1]. Table 2 provides an overview of the number of manual and non-manual workers per industry together with all-cause mortality and mesothelioma mortality.

It is important to bear in mind an undetermined level of asbestos exposure for all categories of workers. Questions on occupational history are not included in the 1991 census. Hence, this research design cannot consider exposure duration or exposure in previous workplaces. In addition, workers may have been exposed to asbestos via the environment or indirect contact.

[1] Self-employed persons constitute a small, but relevant population in the construction industry (9% of manual workers), automotive industry (5% of manual workers; mainly in repair and maintenance work) and metal products manufacturing (3% of manual workers).

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Table 1 Types of industrial activities, per category

	Industry	Industrial activity
A	Asbestos industry	Asbestos cement manufacturing
		Asbestos products manufacturing
B	Automotive industry	Manufacture and assembly of car parts
		Manufacture and assembly of motor cycle parts
		Repair and maintenance
	Chemical industry	Manufacture of basic chemicals
		Manufacture of pesticides and other agrochemical products
		Manufacture of paints and similar coatings
		Manufacture of soap, cosmetics and detergents
		Manufacture of other chemical products
		Manufacture of man-made fibres
		Manufacture of basic pharmaceutical products
	Construction	General construction & demolition
		Construction of buildings and utilities
		Civil engineering: roads and water supply
		Installation companies
		Final construction work
	Electricity generation and distribution	Electricity generation and distribution
	Electro-technical products manufacturing	Manufacture of electrical appliances
		Assembly and installation electro-technical products
	Manufacture of basic metals	Manufacture of basic iron and steel and ferro-alloys
		Manufacture of steel tubes, pipes and related fitting
		Manufacture of other products of first processing of steel
		Manufacture of basic non-ferrous metals
	Metal products manufacturing	Casting of metal
		Manufacture of fabricated metal products
		Manufacture and assembly structural metal parts
		Manufacture of boilers and reservoirs
		Grinderies and other
	Railroad industry	Railway carriage construction
		Repair and maintenance
		Activities related to railway transport
	Shipping industry	Shipyards, ship repair and maintenance
		Activities related to inland, maritime & short sea shipping
	Textile industry	Wool, cotton and other
		Carpet, felt and linoleum
		Other activities
C	Reference population	All other workers

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Table 2 Mesothelioma deaths and total number of deaths for manual and non-manual workers by industry*

	Industry	N	M	D	N	M	D	N	M	D
A	Asbestos industry	1743	16	121	313	5	18	2056	21	139
B	Automotive industry	52789	8	1856	12057	1	261	64846	9	2417
	Chemical industry	21875	14	957	18647	4	882	40522	18	1839
	Construction	100297	48	5341	22387	16	1333	122684	64	6674
	Electricity generation and distribution	2164	6	133	4489	7	277	6653	13	410
	Electro-technical products manufacturing	15854	3	571	12920	6	462	28774	9	1033
	Manufacture of basic metals	17174	11	748	5209	3	263	22383	14	1011
	Metal products manufacturing	29960	9	1211	6603	2	298	36563	11	1509
	Railroad industry	10840	7	467	12352	3	547	23192	10	1014
	Shipping industry	12255	15	784	3380	1	204	15635	16	988
	Textile industry	20008	3	1043	3786	2	159	23794	5	1202
C	Reference population	-	-	-	-	-	-	1010597	249	53838

* Number of workers (N); Number of mesothelioma deaths (M); and Number of overall deaths (D)

Data analysis

Analyses are performed separately for manual and non-manual workers. Standardised mortality rates (SMRs) are calculated with reference to workers in all other industries (Category C). Lower and upper 95% confidence levels (CL) are computed assuming that the observed deaths are Poisson variates. If the observed number of deaths is less than 100, exact limits were calculated directly from the Poisson distribution. For larger numbers, we use the Byar approximation method.[13]

Data for the study period 2001-2010 are combined because of the small number of cases per year for some of the industries under investigation. Analyses are based on the underlying cause of death as recorded on the death certificate. Cause-specific mortality is coded using the Tenth Revision of the International Classification of Diseases (ICD-10).

Results

A total of 996 men died due to mesothelioma between 2001 and 2010. Although previous occupational asbestos exposure is possible, 545 mesothelioma deaths in the non-active population have been discarded from the classification process. 194 deaths occurred among men past the retirement age of 65 in 1991 (n=173 137) and 351 deaths occurred among non-active men aged 18 to 65 (n=510 681). The selection of high-risk industries is based on a total of 439 mesothelioma deaths in the active population (n=1 428 621).

Table 3 compares mesothelioma and all-cause mortality in the active and non-active population for men at working ages in 1991. From 2001 to 2010, 21 asbestos workers and 169 potentially exposed workers died due to mesothelioma. In the reference population, we find 249 mesothelioma deaths. The high overall mortality among non-active men before age 65 indicates a “healthy worker effect”. Healthy workers remain in the workforce whereas persons with health problems are more inclined to quit prematurely. We will restrict further analysis to the active population in 1991.

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Table 3 Mesothelioma and all-cause mortality in 2001-2010 by activity status for men aged 18-65 year in 1991*

Characteristics		N	M	D
Active population	Asbestos workers	2056	21	139
	Potentially exposed workers	385046	169	18097
	All other workers	1010597	249	53838
	Missing information	30922	12	2460
Non-active population	Pre-retirement	190090	265	52575
	Unemployed	86131	45	9012
	Disabled	25046	25	6220
	Students	119742	0	642
	Other	30734	2	1241
	Missing information	58938	14	4912

* Number of men (N); Number of mesothelioma deaths (M); and Number of overall deaths (D)

The results of the cause-specific mortality analysis for asbestos workers and potentially exposed workers are presented in table 4, with the SMRs and 95% confidence levels for manual and non-manual workers for the period 2001-2010.

Asbestos-related mortality

Asbestos workers

Mesothelioma mortality is over 40 times higher among manual workers in the asbestos industry than among all other workers (SMR 4 071; CL 2 327-6 611). Manual workers also experience 75% more lung cancer deaths than expected (SMR 175; CL 108-268). Results on laryngeal cancer mortality are inconclusive as the ratio is based on only one observed death. No asbestosis deaths occurred among manual workers during the period 2001-2010.

We also find significant excess in asbestos-related mortality for jobs that do not involve direct contact with asbestos fibres. Non-manual workers in the asbestos industry have 45 times higher mesothelioma mortality than expected (SMR 4 489; CL

1 458-10 476). Laryngeal cancer mortality is almost 15 times higher than expected (SMR 1 425; CL 173-5 148).

Potentially exposed workers

Workers from the automotive industry, the electrical products manufacturing industry or the textile industry do not seem to experience significant excess in mortality due to asbestos-related diseases (not shown in table 4).

Mesothelioma mortality is significantly higher among manual workers in the electrical generation and distribution industry (SMR 863; CL 317-1 878), the railroad industry (SMR 352 CL 141-725), the chemical industry (SMR 293; CL 160-492), the basic metals manufacturing industry (SMR 291; CL 145-520) and the construction industry (SMR 227; CL 168-302). Manual workers in the metal products manufacturing industry have a SMR of 187 (CL 85-354).

Lung cancer deaths are significantly higher than expected among construction workers (SMR 153; CL 144-163), shipping workers (SMR 141; CL 119-167) and metal products manufacturing workers (SMR 138; CL 119 -158) in manual labour jobs.

With regard to laryngeal cancer mortality, observed deaths among manual workers in the construction industry are twice as large as expected (SMR 203; CL 155-260).

Among all potentially exposed workers in manual labour, four cases of asbestosis deaths have been recorded. Three deaths occurred among construction workers, resulting in an elevated SMR for asbestosis (SMR 401; CL 83-1171). One worker in metal products manufacturing died due to asbestosis.

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The results for non-manual workers show significant excess in asbestos-related mortality in two industries with potential asbestos exposure. We find significant excess in mesothelioma mortality and asbestosis mortality in the construction industry with SMRs of 260 (CL 149-422) and 843 (CL 102-3043), respectively. Mesothelioma mortality is more than four times higher among non-manual workers in the electricity generation and distribution industry (SMR 430; CL 173-885).

Electricity generation and distribution is also one of three industries with a significant deficit in lung cancer mortality for non-manual workers (SMR 66; CL 46-93). The SMRs for lung cancer in the chemical industry and the basic metal manufacturing industry are 67 (CL 55-81) and 57 (CL 38-82), respectively.

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Table 4 Standardised mortality ratios and confidence intervals per cause of death in selected industries[††]

	Asbestos industry				Chemical industry				Construction industry				Electrical generation and distribution industry			
	Manual		Non-manual		Manual		Non-manual		Manual		Non-manual		Manual		Non-manual	
	SMR	**CL**	**SMR**	**CL**	**SMR**	**CL**	SMR	CL	**SMR**	**CL**	SMR	CL	**SMR**	**CL**	**SMR**	**CL**
All deaths	150	125-180	80	47-126	97	91-103	80	75-86	119	116-122	100	95-106	98	82-116	87	77-98
All neoplasms	174	133-223	129	68-220	97	88-107	86	78-95	125	120-130	105	97-114	122	96-153	91	76-108
Malign. head and neck	315	115-685	436	53-1576	82	50-129	74	44-117	148	126-173	114	78-160	64	8-233	86	32-187
Oral cancer	383	124-894	0	0-985	95	53-157	43	17-88	125	100-153	116	73-176	95	12-344	86	23-219
Laryngeal cancer	182	5-1015	1425	173-5148	60	16-155	153	76-274	203	155-260	95	41-187	0	0-326	95	12-344
Other head and neck	0	0-5637	0	0-21873	0	0-469	0	0-431	168	55-393	244	30-883	0	0-3440	0	0-1516
Malign. digestive system	76	31-157	38	1-209	98	80-118	94	78-112	111	102-121	93	78-109	105	61-169	95	67-132
Oesophageal cancer	128	16-463	0	0-739	95	56-150	107	67-162	131	108-158	75	44-118	76	9-275	149	68-284
Stomach cancer	84	2-471	0	0-899	117	68-188	63	30-115	118	93-148	127	81-189	197	54-504	21	1-118
Colon cancer	38	1-214	0	0-380	104	71-146	87	59-123	106	90-125	75	51-105	43	5-156	118	63-202
Rectal cancer	226	27-818	0	0-1168	121	64-206	99	51-173	121	92-157	133	80-208	192	40-562	55	7-197
Liver cancer	0	0-290	0	0-984	72	33-136	98	54-165	94	70-123	77	41-131	109	13-393	70	14-203
Pancreas cancer	54	1-298	183	5-1020	79	47-125	108	72-156	99	80-120	100	68-142	122	33-312	104	45-204
Other digestive	0	0-3427	0	0-10249	186	23-673	72	2-402	160	69-314	114	14-411	0	0-1864	0	0-763
Malign. respiratory system	173	107-265	29	1-159	104	88-121	69	57-83	153	143-162	103	89-118	116	75-172	66	45-92
Lung cancer	175	108-268	29	1-161	103	88-121	67	55-81	153	144-163	104	90-119	118	76-174	66	46-93
Other respiratory	0	0-2094	0	0-8166	112	14-406	278	90-649	114	52-217	47	1-264	0	0-1301	0	0-579
Malign. urogenital system	159	58-346	163	20-590	82	58-113	86	63-113	103	90-118	94	73-120	144	69-264	113	68-177
Prostate cancer	175	36-511	0	0-498	85	51-135	99	66-145	101	82-123	82	55-119	153	50-357	100	43-196
Testicular cancer	0	0-13840	0	0-92164	0	0-1140	0	0-1726	203	42-594	683	83-2469	0	0-13444	0	0-7289
Bladder cancer	103	3-573	322	8-1792	85	41-156	70	34-129	120	92-153	99	57-158	111	13-402	92	25-237
Kidney cancer	188	23-680	324	8-1806	77	37-142	76	38-135	88	66-116	105	62-166	160	33-468	160	64-329
Malign. other	260	161-398	310	125-639	97	79-119	106	88-127	104	94-114	125	107-146	154	95-235	116	82-160
Mesothelioma	4071	2327-6611	4489	1458-10476	293	160-492	75	21-193	227	168-302	260	149-422	863	317-1878	430	173-885
Other	65	21-152	93	11-337	87	69-108	108	89-129	98	88-107	119	100-139	116	65-191	99	67-142
Non-neoplasms	130	96-173	36	10-93	95	86-105	76	69-84	112	107-116	94	87-102	80	59-105	84	70-100
Circulatory system	131	86-191	32	4-117	94	83-107	78	68-89	113	107-119	100	90-110	86	58-122	87	68-109
Respiratory system	238	114-437	70	2-391	89	65-119	56	39-77	118	104-132	91	72-114	51	14-131	95	56-150
Asbestosis	0	0-21850	0	0-59137	0	0-1809	0	0-1487	401	83-1171	843	102-3043	0	0-11166	0	0-4692
Other diseases	91	46-163	30	1-166	99	83-116	81	68-96	108	101-116	85	73-99	80	45-129	75	52-104
External cod	141	73-247	64	2-357	104	86-125	71	55-91	127	118-138	111	93-133	66	27-137	87	52-135

[†] Abbreviations: Standardised mortality ratio (SMR); 95% confidence level (CL) † Reference population: manual and non-manual workers in all other industries

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Table 4 Standardised mortality ratios and confidence intervals per cause of death in selected industries (continued)[‡§]

	Manufacture of basic metals				Metal products manufacturing				Railroad industry				Shipping industry			
	Manual		Non-manual		Manual		Non-manual		Manual		Non-manual		Manual		Non-manual	
	SMR	CL	SMR	CL	SMR	CL	SMR	CL	SMR	CL	SMR	CL	SMR	CL	SMR	CL
All deaths	101	94-109	81	72-92	114	108-121	84	75-94	112	102-122	99	91-108	124	116-133	94	82-108
All neoplasms	100	90-112	87	72-103	113	103-123	87	73-103	126	110-143	93	81-105	121	108-134	100	81-122
Malign. head and neck	46	21-87	104	45-206	141	99-194	37	8-109	199	128-293	102	59-166	150	95-225	43	5-156
Oral cancer	44	16-96	96	31-225	132	85-196	37	4-132	192	112-308	110	57-192	172	102-271	32	1-179
Laryngeal cancer	54	11-158	133	27-388	163	84-285	42	1-235	206	83-424	93	25-238	113	37-264	0	0-216
Other head and neck	0	0-588	0	0-1410	137	3-766	0	0-1302	285	7-1589	0	0-700	0	0-706	741	19-4131
Malign. digestive system	102	81-125	101	72-138	87	71-106	99	70-134	98	72-131	92	70-119	101	79-126	76	46-119
Oesophageal cancer	103	59-168	78	25-183	107	67-162	74	24-174	106	51-196	91	45-163	112	61-187	50	6-181
Stomach cancer	109	56-191	62	13-182	145	91-220	78	21-201	98	36-213	61	20-143	128	66-223	96	20-280
Colon cancer	86	52-132	136	76-225	79	51-117	121	66-202	82	39-151	124	77-190	116	74-172	96	39-198
Rectal cancer	158	84-270	27	1-148	55	20-120	129	42-301	117	38-273	52	11-151	85	31-186	42	1-235
Liver cancer	74	30-152	91	25-234	79	38-145	22	1-122	96	31-225	85	31-186	60	20-141	106	22-311
Pancreas cancer	105	62-165	140	0-71	65	36-107	133	66-238	106	51-196	87	43-156	87	46-149	59	12-172
Other digestive	134	3-744	0	0-778	0	0-281	0	0-693	0	0-757	179	5-999	0	0-425	0	0-1074
Malign. respiratory system	113	94-134	58	39-83	136	118-156	91	67-120	120	94-151	95	75-118	141	118-166	104	72-146
Lung cancer	112	94-134	57	38-82	138	119-158	90	66-119	122	96-153	95	75-118	141	119-167	106	73-147
Other respiratory	146	18-526	183	5-1022	0	0-152	171	4-952	0	0-408	106	3-593	91	2-508	0	0-867
Malign. urogenital system	80	52-117	116	70-181	108	80-143	91	52-148	147	94-218	97	62-146	132	94-180	115	61-197
Prostate cancer	100	55-169	65	21-153	98	59-152	108	49-205	90	33-195	98	47-181	203	135-293	145	63-285
Testicular cancer	0	0-1621	0	0-7102	0	0-604	0	0-4339	0	0-3023	0	0-2645	0	0-2329	0	0-8691
Bladder cancer	70	26-152	117	38-273	88	42-162	89	24-229	210	96-398	32	4-117	90	36-185	105	22-308
Kidney cancer	61	22-132	202	92-383	145	88-227	65	13-190	171	78-325	153	77-274	59	19-137	70	8-253
Malign. other	103	81-129	95	64-135	105	86-126	77	51-112	135	102-175	85	62-113	101	78-129	126	83-183
Mesothelioma	291	145-520	178	37-522	187	85-354	118	14-425	352	141-725	112	23-327	475	266-784	97	2-540
Other	93	72-118	90	60-131	101	82-122	75	48-110	125	92-164	83	61-112	81	60-107	128	83-187
Non-neoplasms	99	88-110	73	60-88	112	103-122	83	70-98	104	90-120	103	91-117	121	109-134	88	71-108
Circulatory system	100	86-115	79	62-100	112	99-125	90	71-111	116	96-139	111	94-129	119	103-137	90	68-118
Respiratory system	150	112-197	66	34-115	139	108-176	70	38-117	154	101-224	93	59-138	134	97-179	61	26-120
Asbestosis	0	0-3205	0	0-5046	710	18-3957	1654	42-9217	0	0-6301	0	0-4079	0	0-2773	0	0-7192
Other diseases	80	65-99	65	44-92	105	90-122	76	55-104	73	54-97	94	75-117	120	99-144	95	64-135
External cod	115	93-141	100	64-147	126	108-145	77	50-114	89	65-119	108	84-139	155	125-190	102	59-163

[‡] Abbreviations: Standardised mortality ratio (SMR); 95% confidence level (LL); Upper 95% confidence level (UL) § Reference population: manual and non-manual workers in all other industries

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Other causes of death

Results indicate significantly more oral cancer deaths among manual workers in four high-risk industries. Oral cancer mortality is almost four times higher among asbestos workers (SMR 383; CL 124-894). Railroad workers experience about two times more oral cancer deaths with a SMR of 192 (CL 112-308). Shipping workers have a SMR of 172 (CL 102-271). For construction workers, we find 25% more deaths than expected (SMR 125; CL 100-153).

Significant excess in mortality is found for two other types of malignancies. The SMR for oesophageal cancer mortality among construction workers in manual labour jobs equals 131 (CL 108-158). Prostate cancer deaths are two times higher among manual workers in shipping (SMR 203; CL 135-293).

Findings also indicate excess in mortality due to diseases of the circulatory system for construction workers and shipping workers in manual jobs. Looking at the circulatory diseases separately, we only find significant excess in deaths due to ischemic heart disease for construction workers (SMR 118; CL 109-127, not shown in table).

For mortality due to respiratory diseases, we find elevated SMRs for manual workers in the asbestos industry, the construction industry, the basic metals manufacture industry, the metal products manufacture industry, the railroad industry and the shipping industry. This is due to relatively high numbers of deaths from chronic obstructive pulmonary diseases (COPD). Mortality due to COPD is significantly higher for construction workers (SMR 127; CL 109-147), basic metals manufacturing

workers (SMR 166; CL 116-230), metal products manufacturing workers (SMR 172; CL 128-226) and shipping workers (SMR 176; CL 124-243) (not shown in table).

Construction workers in manual labour jobs experience excess in mortality due to other diseases, because of a significantly higher number of deaths from alcoholic liver disease (SMR 138; CL 115-164, not shown in table).

Discussion

Cause-specific mortality among high-risk workers and all other workers is compared to determine the current impact of asbestos exposure on Belgian workers' mortality. In addition to asbestos workers, 10 types of industrial workers are identified as potentially exposed. Results indicate significant excess in asbestos-related mortality in the asbestos industry and in seven of the selected industries, i.e. the chemical industry, the construction industry, the electrical generation and distribution industry, the basic metals manufacturing industry, the metal products manufacturing industry, the railroad industry and the shipping industry. Contrary to other reports,[14–20] we did not find significant excess risks for asbestos-related mortality in the automotive industry, the textile industry and the electro-technical industry.

Results clearly show a very high impact of asbestos exposure on asbestos workers. Mesothelioma mortality is 41 times higher among manual workers and 45 times higher among non-manual workers than in the reference population. Significant excess in laryngeal cancer and lung cancer mortality is found for non-manual workers and manual workers, respectively. Working in the asbestos industry seems to entail serious asbestos-related health risks, regardless of the occupational type. It

is likely that asbestos exposure in this industry is not confined to specific work-related tasks, but also includes site-related environmental exposure.

Among potentially exposed workers, significant excess in mesothelioma mortality is found for manual work in the chemical industry, the basic metal manufacturing industry and the railroad industry. Surprisingly, both manual and non-manual workers in the electricity generation and distribution industry have a significantly higher number of mesothelioma deaths. This may indicate more widespread asbestos exposure in this industry than expected.

Shipping workers in manual labour jobs experience significantly higher mesothelioma and lung cancer mortality. Results also show increased mortality risks for mesothelioma and lung cancer among manual workers in metal products manufacturing, with significant excess in lung cancer deaths.

The construction industry is the only industry with elevated SMRs for all four established asbestos-related diseases. In addition to manual workers, non-manual workers in the construction industry experience significantly higher numbers of mesothelioma and asbestosis deaths.

Cause-specific mortality is further scrutinised to identify additional excess in mortality among high-risk workers and evaluate a potential association with asbestos exposure. The results for four high-risk industries corroborate a possible association between asbestos exposure and the development of oral cancer. Manual workers in the asbestos industry, the construction industry, the shipping industry and the railroad industry have significantly higher oral cancer mortality. Although tobacco and alcohol consumption are considered to be major causes, a substantial

proportion of cases cannot be attributed to these agents.[21] Occupational asbestos exposure has been reported as a possible causal factor for oral cancer types,[22–24] and specifically for pharyngeal cancer.[25] Historical exposure circumstances should be explored further in order to answer why specifically these workers experience high oral cancer mortality.

Reports of elevated prostate cancer risks related to occupational asbestos exposure are scarce.[26,27] Krstev and colleagues find significant excess prostate cancer mortality among unexposed shipping workers.[28] Therefore, a causal effect of asbestos exposure is doubtful.

Results for lung cancer and laryngeal cancer mortality need to be interpreted with caution, as several carcinogens play an important causal role in the development of these diseases. Potential confounding factors for laryngeal cancer are smoking and alcohol use. Tobacco consumption, a major risk factor for lung cancer, could even have a multiplicative effect combined with asbestos.[29] Considering the use of various carcinogens (i.a. nickel, cadmium, PAHs) in the selected high-risk industries, concomitant occupational exposure is highly likely. Because of insufficient data, potential confounders could not be considered in our analyses. Results do show that manual workers in construction, in basic metal manufacturing, in metal products manufacturing and in shipping have significantly higher mortality due to COPD, caused predominantly by smoking. Construction workers also experience significant excess in mortality due to alcoholic liver disease and oesophageal cancer. Although mesothelioma and asbestosis mortality provide clear indications of considerable asbestos-related health effects in these industries, further research is needed to

estimate the effect of asbestos exposure on lung cancer and laryngeal cancer mortality.

The main advantage of this study is the availability of census-linked cause-specific mortality data. The anonymous linkage at individual level minimises the nominator-denominator bias. Furthermore, even industries with relatively small working populations could be included in this study due to the large number of persons in the dataset.

The study design has some limitations. Occupational information is only available for a specific time period. Our findings may be confounded by exposure during previous jobs. Persons who have already quit asbestos-related industries at the time of the 1991 census cannot be identified. The most heavily exposed workers may have already left the workforce due to health reasons. As only actively employed workers are studied, healthy worker effects may bias our results. Based on the number of mesothelioma deaths in the non-active population, we believe that a considerable proportion of occupational asbestos victims remain unnoticed.

As a result of job changes prior to the census date, it is also possible that occupationally exposed workers are included in the reference population. Although workers in the reference population are at least partially exposed to asbestos in the environment or through indirect contact, the number of mesothelioma deaths is larger than anticipated. As recent studies estimate that 8.3% to 11% of all mesothelioma deaths are attributable to non-occupational asbestos exposure, [30,31] our results may still underestimate the true influence of occupational asbestos exposure.

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Assumptions on asbestos exposure are industry-based. Although occupational type is considered, individual exposure information is not available and the number of high-risk workers is surely overestimated. It is possible that asbestos exposure occurs in some industries only among specific groups of workers in specific workstations and the effect of occupational asbestos exposure remains unnoticed. This may explain why no significant effects were found for asbestos-related mortality in the automotive industry, the textile industry and the electro-technical industry.

The distinction between manual and non-manual workers is based on the physical or intellectual nature of the work as stated in the labour agreement between employer and employee. This criterion is highly subject to interpretation. Reports have been made of workers doing the same job, but with different statuses (blue-collar vs. white-collar status).[32,33]

In conclusion, cause-specific mortality reveals the repercussions of historical asbestos use on Belgian workers. Not only asbestos workers experience increased asbestos-related mortality. The study also identifies eight high-risk industries with significantly elevated asbestos-related mortality, which have been previously overlooked in Belgian asbestos research. Furthermore, observations in four high-risk industries indicate a possible association between occupational asbestos exposure and the development of oral cancer. This study contributes to the large amount of international evidence on the adverse health effects of occupational asbestos exposure. Workers should be informed about the risks of past exposure and all forms of asbestos use should be banned.

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Conflict of interest

The authors declare no conflicts of interest.

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Enduring health effects of asbestos use in Belgian industries

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Enduring health effects of asbestos use in Belgian industries: a record-linked cohort study of cause-specific mortality (2001-2009)

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Enduring health effects of asbestos use in Belgian industries: a record-linked cohort study of cause-specific mortality (2001-2009).

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3 715 words

Enduring health effects of asbestos use in Belgian industries

Abstract

Objective: To investigate cause-specific mortality among asbestos workers and potentially exposed workers in Belgium and evaluate potential excess in mortality due to established and suspected asbestos-related diseases.

Design: This cohort study is based on an individual record linkage between the 1991 Belgian census and cause-specific mortality information for Flanders and Brussels (2001-2009).

Setting: Belgium (Flanders & Brussels region)

Participants: The study population consists of 1 397 699 male workers (18-65 years) with 72 074 deaths between 1 October 2001 and 31 December 2009. Using a classification of high-risk industries, mortality patterns between 2 056 asbestos workers, 385 046 potentially exposed workers and the working population have been compared.

Outcome measures: Standardised mortality ratios and 95% confidence intervals are calculated for manual and non-manual workers.

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Results: Our findings show clear excess in asbestos-related mortality in the asbestos industry with SMRs for mesothelioma of 4 071 (CI 2 327-6 611) among manual workers and of 4 489 (CI 1 458-10 476) among non-manual workers. Excess risks in asbestos-related mortality are also found in the chemical industry, the construction industry, the electrical generation and distribution industry, the basic metals manufacturing industry, the metal products manufacturing industry, the railroad industry, and the shipping industry. Oral cancer mortality is significantly higher for asbestos workers (SMR 383; CI 124-894), railroad workers (SMR 192; CI 112-308), shipping workers (SMR 172; CI 102-271), and construction workers (SMR 125; CI 100-153), indicating a possible association with occupational asbestos exposure. Workers in all four industries have elevated mortality rates for cancer of the mouth. Only construction workers experience significantly higher pharyngeal cancer mortality (SMR 151; CI 104-212).

Conclusions: The study identifies vulnerable groups of Belgian asbestos workers, demonstrating the current-day health repercussions of historical asbestos use. Results support the hypothesis of a possible association between the development of oral cancer and occupational asbestos exposure.

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Strengths and limitations of this study

- Mortality among Belgian workers is investigated using exhaustive census-linked cause-specific mortality data at the individual level.
- The availability of a large national database allows the study of industries with a relatively small number of workers.
- Asbestos exposure data is not available for Belgium and could not be included in this study. However, high-risk industries are selected based on an extensive literature review and the strong etiological relation between mesothelioma and asbestos exposure. A further differentiation is made between manual and non-manual workers.
- Occupational information is only available for one point in time. Workers exposed before the census date may have been included in the reference population (e.g. job change) or may have left the active population (e.g. health reasons). Potential confounders after the census date are not taken into account. Our results may underestimate the true influence of occupational asbestos exposure.

Introduction

Belgium has the fourth highest mesothelioma mortality rates in the world, after the UK, Australia and Italy. Since 2006, over 200 Belgians die from mesothelioma each year.[1] Mesothelioma is considered to be a potent and sensitive indicator for asbestos exposure,[2] but further research on other asbestos-related diseases is imperative to understand the full extent of the asbestos problem in Belgium. This study focuses on the primary source of asbestos exposure: the workplace.

Asbestos minerals do not occur naturally in Belgium. With the start of one of Europe's largest asbestos companies, Eternit, in the early 1900s, Belgium rapidly became an important supplier of asbestos products. Large amounts of raw asbestos fibres were imported for manufacturing purposes since the 1930s.[3] Belgian asbestos industries used a mix of different types of asbestos, usually consisting of 90-99% chrysotile and 10-1% crocidolite.[4] The use of relatively small amounts of amosite has also been reported.[5]

Asbestos use culminated during the 1960s-1970s with Belgium having the highest asbestos consumption level per capita in the world.[6] Since then, overall exposure levels have gradually decreased as a result of private and public health control measures, including the mandatory use of dust masks and the installation of exhaust systems in the workplace.[7] Airborne occupational exposure limits for asbestos were implemented in 1980 to control exposure intensity and duration.[8] Nonetheless, these measures did not avert all fatal health effects due to asbestos exposure.

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Despite declining asbestos exposure levels, occupational exposure in e.g. asbestos products manufacturing, shipbuilding, and construction remained relatively common until the end of the 1990s. Industrial asbestos use was reduced dramatically with a major ban on all asbestos types in 1998. Some exceptions for chrysotile products remained until 2001, when the use and transaction of all types of asbestos were finally banned.

The few Belgian studies on asbestos health risks in the workplace are based on industry findings, biomedical data, or information delivered by victim compensation funds.[4,5,9,10] Considering the typical long latency periods of asbestos-related diseases and most occupational asbestos research dating back to the 1960s-1970s, results may not reflect the true public health consequences of industrial asbestos use. Selection bias, differences in diagnostic criteria, and low civil awareness of compensation measures make the representativeness of these data sources questionable.

International studies on the health of asbestos workers focus mainly on well-established asbestos-related diseases, namely asbestosis, malignant mesothelioma, and lung cancer. Recently, the International Agency for Research on Cancer has acknowledged a causal effect in the development of laryngeal cancer and ovarian cancer.[11] The association between asbestos exposure and several other malignancies remains controversial.

Present study investigates cause-specific mortality among asbestos workers and potentially exposed workers to evaluate potential excess in mortality due to established and suspected asbestos-related diseases. For the first time, mortality

follow-up data and individual employment information for a large study population are available to determine the impact of asbestos exposure on Belgian male workers.

Methods

Study design

An anonymous record linkage has been performed between detailed occupational information from the 1991 Belgian census and cause-specific mortality data from 1 October 2001 to 31 December 2009. The record linkage was based on a primary link between the 1991 Belgian census and registration records of all deaths and migrations between the census date (1 March 1991) and 31 December 2009. Then, cause-specific mortality information was derived from death certificates for the period 2001-2009 and added to the dataset. As a result, there is a 10-year time lag between occupational information and cause-specific mortality data.

Death certificates are not available for all three Belgian regions. The cause-specific mortality data only covers Flanders and the Brussels Capital Region, where the majority of Belgian asbestos firms were located.[1] According to data from the Scientific Institute for Public Health, all-cause mortality in Flanders and Brussels accounts for 65% of all Belgian male deaths in 2003-2010. Approximately 80% of all male mesothelioma mortality occurs among Flemish and Brussels men.[12]

Based on the 1991 census, we have identified 1 537 805 occupationally active men (18-65 years) in Flanders and the Brussels Capital Region. Prior to October 1st 2001, 3.5% of these workers emigrated and 3.6% died. Due to missing occupational information, 30 922 workers could not be classified.

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The study investigates 72 074 deaths between 1 October 2001 and 31 December 2009 among a cohort of 1 397 699 Flemish and Brussels men with valid occupational information at the time of the 1991 census.

Classification of high-risk industries

The comprehensive character of the census data provides a snapshot of the occupational distribution. Consequently, the risks of persons who have been at least potentially exposed to asbestos can be compared with all other occupational groups. Information about exposure circumstances is not available. Because of the widespread use of asbestos fibres in Belgium, careful consideration is required to distinguish occupational asbestos exposure from environmental or secondary exposure. We have combined the distribution of mesothelioma deaths in Belgian industries with an extensive literature review to determine the industries most at risk of asbestos-related health effects.

Malignant mesothelioma mortality was used as a marker for asbestos exposure (ICD-10 C45). This highly fatal cancer develops in the protective linings of the lungs, chest wall, abdomen and heart and is caused almost exclusively by asbestos exposure. Even low levels of asbestos exposure can induce malignant mesothelioma.[13] Industrial sectors with at least three mesothelioma deaths during the period 2001-2009 were selected using the Statistical Classification of Economic Activities in the European Community (NACE).

We have cross-referenced these findings with the published literature. An extensive review of international and national studies on occupational asbestos exposure was conducted to ascertain at least potential asbestos use in these industries. Databases

PubMed and Unicat (Union Catalogue of Belgian Libraries) have been examined. Keywords included “occupation*”, “industr*”, “asbestos”, “health”, “mortality”, “Belg*”. Additional searches were conducted using the names of the selected industries. Only peer-reviewed articles and government documents were considered. We have made no restrictions in time or language. If industrial asbestos use was established in at least one of the studies, the industry was included in further analyses.

Finally, industries with at least three mesothelioma deaths in the period 2001-2009 and with conclusive evidence of asbestos use were considered as high-risk industries. Three broad categories can be distinguished. Table 1 presents detailed information on the activities for the analysed industries in each category. Category A includes workers in asbestos industries. Category B includes workers in industries with potential asbestos exposure. Category C consists of workers in all industries excluded from categories A or B.

A further differentiation was made between manual workers and all other occupational types in high-risk industries. The 1991 census includes information on the type of performed labour: self-employed, blue-collar, white-collar, management, etc. We defined manual workers as blue-collar workers and self-employed persons[1].

Table 2 provides an overview of the number of manual and non-manual workers per industry together with all-cause mortality and mesothelioma mortality. Out of 704 458 manual workers in 1991, 40% were active in high-risk industries. All other

[1] Self-employed persons constitute a small, but relevant population in the construction industry (9% of manual workers), automotive industry (5% of manual workers; mainly in repair and maintenance work) and metal products manufacturing (3% of manual workers).

occupational types in these industries account for approximately 15% of all 693 241 non-manual workers.

It is important to bear in mind an undetermined level of asbestos exposure for all categories of workers. Questions on occupational history are not included in the 1991 census. Hence, this research design cannot consider exposure duration or exposure in previous workplaces. In addition, workers may have been exposed to asbestos via the environment or indirect contact.

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Table 1 Types of industrial activities, per category

	Industry	Industrial activity
A	Asbestos industry	Asbestos cement manufacturing
		Asbestos products manufacturing
B	Automotive industry	Manufacture and assembly of car parts
		Manufacture and assembly of motor cycle parts
		Repair and maintenance
	Chemical industry	Manufacture of basic chemicals
		Manufacture of pesticides and other agrochemical products
		Manufacture of paints and similar coatings
		Manufacture of soap, cosmetics and detergents
		Manufacture of other chemical products
		Manufacture of man-made fibres
		Manufacture of basic pharmaceutical products
	Construction	General construction & demolition
		Construction of buildings and utilities
		Civil engineering: roads and water supply
		Installation companies
		Final construction work
	Electricity generation and distribution	Electricity generation and distribution
	Electro-technical products manufacturing	Manufacture of electrical appliances
		Assembly and installation electro-technical products
	Manufacture of basic metals	Manufacture of basic iron and steel and ferro-alloys
		Manufacture of steel tubes, pipes and related fitting
		Manufacture of other products of first processing of steel
		Manufacture of basic non-ferrous metals
	Metal products manufacturing	Casting of metal
		Manufacture of fabricated metal products
		Manufacture and assembly structural metal parts
		Manufacture of boilers and reservoirs
		Grinderies and other
	Railroad industry	Railway carriage construction
		Repair and maintenance
		Activities related to railway transport
	Shipping industry	Shipyards, ship repair and maintenance
		Activities related to inland, maritime & short sea shipping
	Textile industry	Wool, cotton and other
		Carpet, felt and linoleum
		Other activities
C	Reference population	All other workers

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Table 2 Mesothelioma deaths and total number of deaths for manual and non-manual workers by industry*

		Manual workers			Non-manual workers			Total		
	Industry	N	M	D	N	M	D	N	M	D
A	Asbestos industry	1743	16	121	313	5	18	2056	21	139
B	Automotive industry	52789	8	1856	12057	1	261	64846	9	2417
	Chemical industry	21875	14	957	18647	4	882	40522	18	1839
	Construction	100297	48	5341	22387	16	1333	122684	64	6674
	Electricity generation and distribution	2164	6	133	4489	7	277	6653	13	410
	Electro-technical products manufacturing	15854	3	571	12920	6	462	28774	9	1033
	Manufacture of basic metals	17174	11	748	5209	3	263	22383	14	1011
	Metal products manufacturing	29960	9	1211	6603	2	298	36563	11	1509
	Railroad industry	10840	7	467	12352	3	547	23192	10	1014
	Shipping industry	12255	15	784	3380	1	204	15635	16	988
	Textile industry	20008	3	1043	3786	2	159	23794	5	1202
C	Reference population	-	-	-	-	-	-	1010597	249	53838

* Number of workers (N); Number of mesothelioma deaths (M); and Number of overall deaths (D)

Data analysis

Analyses are performed separately for manual and non-manual workers. Standardised mortality rates (SMRs) are calculated by 5-year age group with reference to workers in all other industries (Category C). Lower and upper 95% confidence levels (CI) are computed assuming that the observed deaths are Poisson variates. If the observed number of deaths is less than 100, exact limits are calculated directly from the Poisson distribution. For larger numbers, we use the Byar approximation method.[14]

Data for the study period 2001-2009 are combined because of the small number of cases per year for some of the industries under investigation. Analyses are based on the underlying cause of death as recorded on the death certificate. Cause-specific mortality is coded using the Tenth Revision of the International Classification of Diseases (ICD-10).

Results

A total of 996 men died due to mesothelioma from 2001 through 2009. Although previous occupational asbestos exposure is possible, 545 mesothelioma deaths in the non-active population have been discarded from the classification process. 194 deaths occurred among 173 137 men past the retirement age of 65 in 1991 and 351 deaths occurred among 510 681 non-active men aged 18 to 65. The selection of high-risk industries is based on a total of 439 mesothelioma deaths in the active population (n= 1 397 699).

Table 3 compares mesothelioma and all-cause mortality in the active and non-active population for men at working ages in 1991. From 2001 to 2009, 21 asbestos workers and 169 potentially exposed workers died due to mesothelioma. 249 mesothelioma deaths occurred in the reference population. The high overall mortality among non-active men before age 65 indicates a “healthy worker effect”. Healthy workers remain in the workforce whereas persons with health problems are more inclined to quit prematurely. We restrict further analysis to the active population in 1991.

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Table 3 Mesothelioma and all-cause mortality in 2001-2009 by activity status for men aged 18-65 year in 1991*†

Characteristics		N	Mesothelioma		Overall	
			O	SMR (CI)	O	SMR (CI)
Active population	Asbestos workers	2056	21	2890 (1789-4417)	139	116 (97-136)
	Potentially exposed workers	385046	169	141 (121-164)	18097	88 (87-90)
	All other workers	1010597	249	68 (60-78)	53838	85 (84-86)
	Missing information	30922	12	103 (53-180)	2460	118 (114-123)
Non-active population	Pre-retirement	190090	265	115 (101-130)	52575	108 (108-109)
	Unemployed	86131	45	130 (95-175)	9012	148 (145-151)
	Disabled	25046	25	140 (91-207)	6220	194 (189-198)
	Students	119742	0	0 (0-1678)	642	65 (59-69)
	Other	30734	2	59 (7-214)	1241	152 (143-160)
	Missing information	58938	14	71 (39-119)	4912	136 (132-139)

* Abbreviations: Number of men (N); Observed number of deaths (O); Standardised mortality ratio (SMR); 95% confidence interval (CI) † Reference population: Flemish and Brussels men (18-65 years)

The results on asbestos-related mortality among asbestos workers and potentially exposed workers are presented in table 4, with the SMRs and 95% confidence intervals by occupational type for the period 2001-2009.

Asbestos-related mortality

Asbestos workers

Mesothelioma mortality is over 40 times higher among manual workers in the asbestos industry than among all other workers (SMR 4 071; CI 2 327-6 611). Manual workers also experience 75% more lung cancer deaths than expected (SMR 175; CI 108-268). Results on laryngeal cancer mortality are inconclusive as the ratio is based on only one observed death. No asbestosis deaths occurred among manual workers during the period 2001-2009.

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We also find significant excess in asbestos-related mortality for jobs that do not involve direct contact with asbestos fibres. Non-manual workers in the asbestos industry have 45 times higher mesothelioma mortality than expected (SMR 4 489; CI 1 458-10 476). Laryngeal cancer mortality is almost 15 times higher than expected (SMR 1 425; CI 173-5 148). Contrary to their colleagues in manual labour jobs, non-manual workers do not seem to experience higher lung cancer mortality (SMR 29; CI 1-161)

Potentially exposed workers

Workers from the automotive industry, the electrical products manufacturing industry or the textile industry do not seem to experience significant excess in mortality due to asbestos-related diseases (not shown in table 4).

Mesothelioma mortality is significantly higher among manual workers in the electrical generation and distribution industry (SMR 863; CI 317-1 878), shipping industry (SMR 475; CI 266-784), the railroad industry (SMR 352; CI 141-725), the chemical industry (SMR 293; CI 160-492), the basic metals manufacturing industry (SMR 291; CI 145-520) and the construction industry (SMR 227; CI 168-302). Manual workers in the metal products manufacturing industry have a SMR of 187 (CI 85-354).

Lung cancer deaths are significantly higher than expected among construction workers (SMR 153; CI 144-163), shipping workers (SMR 141; CI 119-167) and metal products manufacturing workers (SMR 138; CI 119-158) in manual labour jobs.

With regard to laryngeal cancer mortality, observed deaths among manual workers in the construction industry are twice as large as expected (SMR 203; CI 155-260).

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Among all potentially exposed workers in manual labour, four cases of asbestosis deaths have been recorded. Three deaths occurred among construction workers, resulting in an elevated SMR for asbestosis (SMR 401; CI 83-1 171). One worker in metal products manufacturing died due to asbestosis.

The results for non-manual workers show significant excess in asbestos-related mortality in two industries with potential asbestos exposure. We find significant excess in mesothelioma mortality and asbestosis mortality in the construction industry with SMRs of 260 (CI 149-422) and 843 (CI 102-3 043), respectively. Mesothelioma mortality is more than four times higher among non-manual workers in the electricity generation and distribution industry (SMR 430; CI 173-885).

Electricity generation and distribution is also one of three industries with a significant deficit in lung cancer mortality for non-manual workers (SMR 66; CI 46-93). The SMRs for lung cancer in the chemical industry and the basic metal manufacturing industry are 67 (CI 55-81) and 57 (CI 38-82), respectively.

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Table 4 Overall and asbestos-related mortality in selected industries for manual and non-manual workers[††]

	Asbestos industry						Chemical industry						Construction industry						Electrical generation and distribution industry					
	Manual			Non-manual			Manual			Non-manual			Manual			Non-manual			Manual			Non-manual		
	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI
All deaths	121	150	125-180	18	80	47-126	957	97	91-103	882	80	75-86	5341	119	116-122	1333	100	95-106	133	98	82-116	277	87	77-98
All neoplasms	61	174	133-223	13	129	68-220	416	97	88-107	416	86	78-95	2399	125	120-130	602	105	97-114	75	122	96-153	131	91	76-108
Laryngeal cancer	1	182	5-1015	2	1425	173-5148	4	60	16-155	11	153	76-274	61	203	155-260	8	95	41-187	0	0	0-326	2	95	12-344
Lung cancer	21	175	108-268	1	29	1-161	151	103	88-121	110	67	55-81	995	153	144-163	200	104	90-119	25	118	76-174	33	66	46-93
Mesothelioma	16	4071	2327-6611	5	4489	1458-10476	14	293	160-492	4	75	21-193	48	227	168-302	16	260	149-422	6	863	317-1878	7	430	173-885
Asbestosis	0	0	0-21850	0	0	0-59137	0	0	0-1809	0	0	0-1487	3	401	83-1171	2	843	102-3043	0	0	0-11166	0	0	0-4692

Table 4 Overall and asbestos-related mortality in selected industries for manual and non-manual workers (continued)

	Manufacture of basic metals						Metal products manufacturing						Railroad industry						Shipping industry					
	Manual			Non-manual			Manual			Non-manual			Manual			Non-manual			Manual			Non-manual		
	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI
All deaths	748	101	94-109	263	81	72-92	1211	114	108-121	298	84	75-94	467	112	102-122	547	99	91-108	784	124	116-133	204	94	82-108
All neoplasms	328	100	90-112	127	87	72-103	498	113	103-123	134	87	73-103	226	126	110-143	223	93	81-105	338	121	108-134	95	100	81-122
Laryngeal cancer	3	54	11-158	3	133	27-388	12	163	84-285	1	42	1-235	7	206	83-424	4	93	25-238	5	113	37-264	0	0	0-216
Lung cancer	127	112	94-134	29	57	38-82	203	138	119-158	47	90	66-119	74	122	96-153	78	95	75-118	136	141	119-167	34	106	73-147
Mesothelioma	11	291	145-520	3	178	37-522	9	187	85-354	2	118	14-425	7	352	141-725	3	112	23-327	15	475	266-784	1	97	2-540
Asbestosis	0	0	0-3205	0	0	0-5046	1	710	18-3957	1	1654	42-9217	0	0	0-6301	0	0	0-4079	0	0	0-2773	0	0	0-7192

[†] Abbreviations: Observed number of deaths (O); Standardised mortality ratio (SMR); 95% confidence interval (CI) † Reference population: manual and non-manual workers in all other industries

Other causes of death

Table 5 presents the number of deaths from other causes by industry and occupational type, with the corresponding SMRs and 95% confidence intervals. Results indicate significantly more oral cancer deaths among manual workers in the asbestos industry, the railroad industry, the shipping industry, and the construction industry. When examining more closely, high oral cancer mortality is driven by excess deaths due to cancers of the mouth (ICD-10 C01-C06) in all four industries. Mouth cancer mortality is nine times higher among asbestos workers (SMR 938; CI 305-2 189). Railroad workers experience about four times more mouth cancer deaths (SMR 390; CI 213-655). Shipping workers have an elevated SMR of 211 (CI 96-400). Construction workers experience 40% more mouth cancer deaths than expected (SMR 140; CI 101-189). For construction workers, we also find significant excess in pharyngeal cancer mortality (SMR 151; CI 104-212).

Significant excess in mortality is found for two other types of malignancies. The SMR for oesophageal cancer mortality among construction workers in manual labour jobs equals 131 (CI 108-158). Prostate cancer deaths are two times higher among manual workers in shipping (SMR 203; CI 135-293).

Findings also indicate elevated mortality due to diseases of the circulatory system for manual workers in six industries: the asbestos industry, the construction industry, the basic metals manufacturing industry, the metal products manufacturing industry, the railroad industry, and the shipping industry. Looking at the circulatory diseases separately, we find asbestos workers experience a higher number of deaths caused by cerebrovascular disease (SMR 200; CI 80-411) (not shown in table 5). Mortality due to

ischemic heart disease is significantly higher among construction workers (SMR 118; CI 109-127), shipping workers (SMR 124; CI 100-151), and railroad workers (SMR 132; CI 102-169) (not shown in table 5).

For mortality due to respiratory diseases, we find elevated SMRs for manual workers in the asbestos industry, the construction industry, the basic metals manufacture industry, the metal products manufacture industry, the railroad industry, and the shipping industry. This is due to relatively high numbers of deaths from chronic obstructive pulmonary diseases (COPD). Mortality due to COPD is significantly higher for construction workers (SMR 127; CI 109-147), basic metals manufacturing workers (SMR 166; CI 116-230), metal products manufacturing workers (SMR 172; CI 128-226), and shipping workers (SMR 176; CI 124-243) (not shown in table 5). In addition to elevated mortality due to COPD (SMR 228; CI 84-496), results for asbestos workers indicate higher pneumonia mortality (SMR 336; CI 91-859) (not shown in table 5).

Construction workers in manual labour jobs experience excess mortality due to other diseases, because of a significantly higher number of deaths from alcoholic liver disease (SMR 138; CI 115-164, not shown in table 5).

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Table 5 Overall and cause-specific mortality in selected industries for manual and non-manual workers‡†

	Asbestos industry						Chemical industry						Construction industry						Electrical generation and distribution industry					
	Manual			Non-manual			Manual			Non-manual			Manual			Non-manual			Manual			Non-manual		
	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI
All deaths	121	150	125-180	18	80	47-126	957	97	91-103	882	80	75-86	5341	119	116-122	1333	100	95-106	133	98	82-116	277	87	77-98
All neoplasms	61	174	133-223	13	129	68-220	416	97	88-107	416	86	78-95	2399	125	120-130	602	105	97-114	75	122	96-153	131	91	76-108
Malign. head and neck	6	315	115-685	2	436	53-1576	19	82	50-129	18	74	44-117	155	148	126-173	32	114	78-160	2	64	8-233	6	86	32-187
Oral cancer	5	383	124-894	0	0	0-985	15	95	53-157	7	43	17-88	89	125	100-153	22	116	73-176	2	95	12-344	4	86	23-219
Mouth	5	938	305-2189	0	0	0-2351	5	77	25-180	3	44	9-129	42	140	101-189	9	114	52-216	0	0	0-352	1	52	1-287
Pharynx	0	0	0-751	0	0	0-2993	3	62	13-181	4	73	20-187	33	151	104-212	7	110	44-227	1	164	4-912	2	128	15-462
Other head and neck	0	0	0-5637	0	0	0-21873	0	0	0-469	0	0	0-431	5	168	55-393	2	244	30-883	0	0	0-3440	0	0	0-1516
Malign. digestive system	7	76	31-157	1	38	1-209	110	98	80-118	119	94	78-112	561	111	102-121	140	93	78-109	17	105	61-169	36	95	67-132
Oesophageal cancer	2	128	16-463	0	0	0-739	18	95	56-150	22	107	67-162	112	131	108-158	18	75	44-118	2	76	9-275	9	149	68-284
Stomach cancer	1	84	2-471	0	0	0-899	17	117	68-188	10	63	30-115	77	118	93-148	24	127	81-189	4	197	54-504	1	21	1-118
Colon cancer	1	38	1-214	0	0	0-380	33	104	71-146	32	87	59-123	152	106	90-125	33	75	51-105	2	43	5-156	13	118	63-202
Rectal cancer	2	226	27-818	0	0	0-1168	13	121	64-206	12	99	51-173	58	121	92-157	19	133	80-208	3	192	40-562	2	55	7-197
Liver cancer	0	0	0-290	0	0	0-984	9	72	33-136	14	98	54-165	53	94	70-123	13	77	41-131	2	109	13-393	3	70	41-203
Pancreas cancer	1	54	1-298	1	183	5-1020	18	79	47-125	28	108	72-156	101	99	80-120	31	100	68-142	4	122	33-312	8	104	45-204
Other digestive	0	0	0-3427	0	0	0-10249	2	186	23-673	1	72	2-402	8	160	69-314	2	114	14-411	0	0	0-1864	0	0	0-763
Malign. urogenital system	6	159	58-346	2	163	20-590	38	82	58-113	48	86	63-113	216	103	90-118	65	94	73-120	10	144	69-264	19	113	68-177
Prostate cancer	3	175	36-511	0	0	0-498	18	85	51-135	27	99	66-145	98	101	82-123	28	82	55-119	5	153	50-357	8	100	43-196
Testicular cancer	0	0	0-13840	0	0	0-92164	0	0	0-1140	0	0	0-1726	3	203	42-594	2	683	83-2469	0	0	0-13444	0	0	0-7289
Bladder cancer	1	103	3-573	1	322	8-1792	10	85	41-156	10	70	34-129	64	120	92-153	17	99	57-158	2	111	13-402	4	92	25-237
Kidney cancer	2	188	23-680	1	324	8-1806	10	77	37-142	11	76	38-135	51	88	66-116	18	105	62-166	3	160	33-468	7	160	64-329
Non-neoplasms	48	130	96-173	4	36	10-93	430	95	86-105	401	76	69-84	2313	112	107-116	607	94	87-102	51	80	59-105	127	84	70-100
Circulatory system	27	131	86-191	2	32	4-117	238	94	83-107	230	78	68-89	1298	113	107-119	360	100	90-110	31	86	58-122	74	87	68-109
Respiratory system	10	238	114-437	1	70	2-391	46	89	65-119	36	56	39-77	279	118	104-132	74	91	72-114	4	51	14-131	18	95	56-150
Other diseases	11	91	46-163	1	30	1-166	146	99	83-116	135	81	68-96	736	108	101-116	173	85	73-99	16	80	45-129	35	75	52-104
External cod	12	141	73-247	1	64	2-357	111	104	86-125	65	71	55-91	629	127	118-138	124	111	93-133	7	66	27-137	19	87	52-135

‡ Abbreviations: Observed number of deaths (O); Standardised mortality ratio (SMR); 95% confidence interval (CI) † Reference population: manual and non-manual workers in all other industries

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Table 5 Overall and cause-specific mortality in selected industries for manual and non-manual workers (continued) §†

	Manufacture of basic metals						Metal products manufacturing						Railroad industry						Shipping industry					
	Manual			Non-manual			Manual			Non-manual			Manual			Non-manual			Manual			Non-manual		
	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI	O	SMR	CI
All deaths	748	101	94-109	263	81	72-92	1211	114	108-121	298	84	75-94	467	112	102-122	547	99	91-108	784	124	116-133	204	94	82-108
All neoplasms	328	100	90-112	127	87	72-103	498	113	103-123	134	87	73-103	226	126	110-143	223	93	81-105	338	121	108-134	95	100	81-122
Malign. head and neck	9	46	21-87	8	104	45-206	37	141	99-194	3	37	8-109	25	199	128-293	16	102	59-166	23	150	95-225	2	43	5-156
Oral cancer	6	44	16-96	5	96	31-225	24	132	85-196	2	37	4-132	17	192	112-308	12	110	57-192	18	172	102-271	1	32	1-179
Mouth	3	54	11-158	3	139	29-407	11	148	74-264	2	88	11-317	14	390	213-655	5	111	36-258	9	211	96-400	1	77	2-429
Pharynx	2	51	6-184	1	57	1-317	9	155	71-295	0	0	0-162	2	71	9-255	1	27	1-150	5	157	51-367	0	0	0-288
Other head and neck	0	0	0-588	0	0	0-1410	1	137	3-766	0	0	0-1302	1	285	7-1589	0	0	0-700	0	0	0-706	1	741	19-4131
Malign. digestive system	87	102	81-125	39	101	72-138	100	87	71-106	40	99	70-134	46	98	72-131	58	92	70-119	74	101	79-126	19	76	46-119
Oesophageal cancer	16	103	59-168	5	78	25-183	22	107	67-162	5	74	24-174	10	106	51-196	11	91	45-163	14	112	61-187	2	50	6-181
Stomach cancer	12	109	56-191	3	62	13-182	22	145	91-220	4	78	21-201	6	98	36-213	5	61	20-143	12	128	66-223	3	96	20-280
Colon cancer	20	86	52-132	15	136	76-225	25	79	51-117	14	121	66-202	10	82	39-151	21	124	77-190	24	116	74-172	7	96	39-198
Rectal cancer	13	158	84-270	1	27	1-148	6	55	20-120	5	129	42-301	5	117	38-273	3	52	11-151	6	85	31-186	1	42	1-235
Liver cancer	7	74	30-152	4	91	25-234	10	79	38-145	1	22	1-122	5	96	31-225	6	85	31-186	5	60	20-141	3	106	22-311
Pancreas cancer	18	105	62-165	11	140	70-250	15	65	36-107	11	133	66-238	10	106	51-196	11	87	43-156	13	87	46-149	3	59	12-172
Other digestive	1	134	3-744	0	0	0-778	0	0	0-281	0	0	0-693	0	0	0-757	1	179	5-999	0	0	0-425	0	0	0-1074
Malign. urogenital system	26	80	52-117	19	116	70-181	48	108	80-143	16	91	52-148	24	147	94-218	23	97	62-146	40	132	94-180	13	115	61-197
Prostate cancer	14	100	55-169	5	65	21-153	19	98	59-152	9	108	49-205	6	90	33-195	10	98	47-181	28	203	135-293	8	145	63-285
Testicular cancer	0	0	0-1621	0	0	0-7102	0	0	0-604	0	0	0-4339	0	0	0-3023	0	0	0-2645	0	0	0-2329	0	0	0-8691
Bladder cancer	6	70	26-152	5	117	38-273	10	88	42-162	4	89	24-229	9	210	96-398	2	32	4-117	7	90	36-185	3	105	22-308
Kidney cancer	6	61	22-132	9	202	92-383	19	145	88-227	3	65	13-190	9	171	78-325	11	153	77-274	5	59	19-137	2	70	8-253
Non-neoplasms	325	99	88-110	111	73	60-88	528	112	103-122	139	83	70-98	195	104	90-120	260	103	91-117	354	121	109-134	92	88	71-108
Circulatory system	184	100	86-115	68	79	62-100	290	112	99-125	84	90	71-111	120	116	96-139	155	111	94-129	195	119	103-137	53	90	68-118
Respiratory system	52	150	112-197	12	66	34-115	68	139	108-176	14	70	38-117	27	154	101-224	24	93	59-138	45	134	97-179	8	61	26-120
Other diseases	89	80	65-99	31	65	44-92	170	105	90-122	41	76	55-104	48	73	54-97	81	94	75-117	114	120	99-144	31	95	64-135
External cod	95	115	93-141	25	100	64-147	185	126	108-145	25	77	50-114	46	89	65-119	64	108	84-139	92	155	125-190	17	102	59-163

§ Abbreviations: Observed number of deaths (O); Standardised mortality ratio (SMR); 95% confidence level (CL) † Reference population: manual and non-manual workers in all other industries

Discussion

Cause-specific mortality among high-risk workers and all other workers is compared to determine the current impact of asbestos exposure on Belgian workers' mortality. In addition to asbestos workers, 10 types of industrial workers are identified as potentially exposed. Results indicate significant excess in asbestos-related mortality in the asbestos industry and in seven of the selected industries, i.e. the chemical industry, the construction industry, the electrical generation and distribution industry, the basic metals manufacturing industry, the metal products manufacturing industry, the railroad industry, and the shipping industry. Contrary to other reports,[15–21] we did not find significant excess risks for asbestos-related mortality in the automotive industry, the textile industry and the electro-technical industry.

Results clearly show a very high impact of asbestos exposure on asbestos workers. Mesothelioma mortality is 41 times higher among manual workers and 45 times higher among non-manual workers than in the reference population. Significant excess in laryngeal cancer and lung cancer mortality is found for non-manual workers and manual workers, respectively. Working in the asbestos industry seems to entail serious asbestos-related health risks, regardless of the occupational type. It is likely that asbestos exposure in this industry is not confined to specific work-related tasks, but also includes site-related environmental exposure.

Among potentially exposed workers, significant excess in mesothelioma mortality is found for manual work in the chemical industry, the basic metal manufacturing industry, and the railroad industry. Surprisingly, both manual and non-manual

workers in the electricity generation and distribution industry have a significantly higher number of mesothelioma deaths. This may indicate more widespread asbestos exposure in this industry than expected.

Shipping workers in manual labour jobs experience significantly higher mesothelioma and lung cancer mortality. Results also show increased mortality risks for mesothelioma and lung cancer among manual workers in metal products manufacturing, with significant excess in lung cancer deaths.

The construction industry is the only industry with elevated SMRs for all four established asbestos-related diseases. In addition to manual workers, non-manual workers in the construction industry experience significantly higher numbers of mesothelioma and asbestosis deaths. An underestimation of asbestosis mortality is possible because asbestosis is frequently coded as a contributing cause of death and this study is based on underlying causes of death.

Cause-specific mortality is further scrutinised to identify additional excess in mortality among high-risk workers and evaluate a potential association with asbestos exposure. The results for four industries corroborate a possible association between asbestos exposure and the development of oral cancer. Manual workers in the asbestos industry, the construction industry, the shipping industry, and the railroad industry have significantly higher oral cancer mortality. Tobacco and alcohol consumption are considered to be major risk factors.[22] However, occupational asbestos exposure has also been reported as a possible causal factor for oral cancer types,[23–25] and for pharyngeal cancer.[26] Historical exposure circumstances should be

explored further in order to answer why specifically these workers experience high oral cancer mortality.

Reports of elevated prostate cancer risks related to occupational asbestos exposure are scarce.[27,28] Krstev and colleagues find significant excess prostate cancer mortality among unexposed shipping workers.[29] Therefore, a causal effect of asbestos exposure is doubtful.

Potential confounding factors for laryngeal cancer are smoking and alcohol use. Tobacco consumption, a major risk factor for lung cancer, could even have a multiplicative effect combined with asbestos.[30,31] Considering the use of various carcinogens such as nickel, cadmium or PAHs in the selected industries, concomitant occupational exposure is highly likely. Because of insufficient data, potential confounders could not be considered in our analyses. Results do show that manual workers in construction, in basic metal manufacturing, in metal products manufacturing and in shipping have significantly higher mortality due to COPD, which is known to be caused predominantly by smoking. Occupational exposure to dusts, fumes, and gases have been associated with increased incidence of COPD.[32] Construction workers also experience significant excess in mortality due to alcoholic liver disease, oesophageal cancer, mouth cancer, and pharyngeal cancer suggesting high alcohol use. Although mesothelioma and asbestosis mortality provide clear indications of considerable asbestos-related health effects in these industries, further research is needed to estimate the effect of asbestos exposure on lung cancer and laryngeal cancer mortality.

The main advantage of this study is the availability of census-linked cause-specific mortality data. The anonymous linkage at individual level minimises the nominator-denominator bias. Furthermore, even industries with relatively small working populations could be included in this study due to the large number of persons in the dataset.

The study design has some limitations. Occupational information is only available for a specific time period. Our findings may be confounded by exposure during previous jobs. Persons who have already quit asbestos-related industries at the time of the 1991 census cannot be identified. The most heavily exposed workers may have already left the workforce due to health reasons. As only actively employed workers are studied, healthy worker effects may bias our results. Based on the number of mesothelioma deaths among pre-retired men in the non-active population, we believe that a considerable proportion of occupational asbestos victims remain unnoticed.

As a result of job changes prior to the census date, it is also possible that occupationally exposed workers are included in the reference population. Although workers in the reference population are at least partially exposed to asbestos in the environment or through indirect contact, the number of mesothelioma deaths is larger than anticipated. As recent studies estimate that 8.3% to 11% of all mesothelioma deaths are attributable to non-occupational asbestos exposure,[33,34] our results may still underestimate the true influence of occupational asbestos exposure.

Occupational information after the 1991 census is not available. Hence, potential confounders related to the last job have not been taken into account. Due to the long period between asbestos exposure and onset of related diseases, we believe this does not alter the interpretation of our results.

Assumptions on asbestos exposure are industry-based. Although occupational type is considered, individual exposure information is not available and the number of workers at risk is surely overestimated. It is possible that asbestos exposure occurs in some industries only among specific groups of workers in specific workstations and the effect of occupational asbestos exposure remains unnoticed. This may explain why no significant effects were found for asbestos-related mortality in the automotive industry, the textile industry and the electro-technical industry.

The distinction between manual and non-manual workers is based on the physical or intellectual nature of the work as stated in the labour agreement between employer and employee. This criterion is highly subject to interpretation. Reports have been made of workers doing the same job, but with different statuses (blue-collar vs. white-collar status).[35,36]

In conclusion, cause-specific mortality reveals the repercussions of historical asbestos use on Belgian workers. Not only asbestos workers experience increased asbestos-related mortality. The study also identifies eight industries with significantly elevated asbestos-related mortality, which have been previously overlooked in Belgian asbestos research. Furthermore, observations in four industries indicate a possible association between occupational asbestos exposure and the development of oral cancer. This study contributes to the large amount of international evidence

on the adverse health effects of occupational asbestos exposure. Workers should be informed about the risks of past exposure and all forms of asbestos use should be banned.

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Conflict of interest

The authors declare no conflicts of interest.

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