Risk of cancer associated with residential exposure to asbestos insulation: a whole-population cohort study

Rosemary J Korda, Mark S Clements, Bruce K Armstrong, Hsei Di Law, Tenniel Guiver, Philip R Anderson, Susan M Trevenar, Martyn D Kirk

Summary

Background The health risks associated with living in houses insulated with asbestos are unknown. Loose-fill asbestos was used to insulate some houses in the Australian Capital Territory (ACT). We compared the incidence of mesothelioma and other cancers in residents of the ACT who did and did not live in these houses.

Methods Our cohort study included all ACT residents identified using Medicare enrolment data. These data were linked to addresses of affected residential properties in the ACT to ascertain exposure. We followed up residents by linking data to the Australian Cancer Database and National Death Index. Outcomes were diagnosis of mesothelioma and selected other cancers. Effects were estimated for males and females separately using standardised incidence ratios (SIRs), adjusting for age and calendar time of diagnosis.

Findings Between Nov 1, 1983, and Dec 31, 2013, 1 035 578 ACT residents were identified from the Medicare database. Of these, 17 248 (2%) had lived in an affected property, including seven (2%) of 285 people diagnosed with mesothelioma. The adjusted incidence of mesothelioma in males who had lived at an affected property was 2·5 times that of unexposed males (SIR 2·54, 95% CI 1·02–5·24). No mesotheliomas were reported among females who had lived at an affected property. Among individuals who had lived at an affected property, there was an elevated incidence of colorectal cancer in women (SIR 1·73, 95% CI 1·29–2·26) and prostate cancer in men (1·29, 1·07–1·54); colorectal cancer was increased, although not significantly, in males (SIR 1·32, 95% CI 0·99–1·72), with no significant increase in the other cancers studied.

Interpretation Residential asbestos insulation is likely to be unsafe. Our findings have important health, social, financial, and legal implications for governments and communities in which asbestos has been used to insulate houses.

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National Centre for Epidemiology and Population Health, Research School of Population Health, Australian National University, Canberra, ACT, Australia (R J Korda PhD, S M Trevenar BSc, M D Kirk PhD); **Department of Medical Epidemiology and Biostatistics, Karolinska Institutet, Stockholm, Sweden** (M S Clements PhD); **Sydney School of Public Health, University of Sydney, Sydney, NSW, and School of Population and Global Health, University of Western Australia, Perth, WA, Australia** (Prof B K Armstrong DPhil); **Data Linkage Unit, Australian Institute of Health and Welfare, Canberra, ACT, Australia** (H Di Law MPH, T Guiver BMath, P R Anderson PhD) ; **and Faculty of Health, University of Canberra, Canberra, ACT, Australia** (P R Anderson)

Correspondence to:
Dr Rosemary J Korda, National Centre for Epidemiology and Population Health, Research School of Population Health, Australian National University, Acton, ACT 2601, Australia
Rosemary.Korda@anu.edu.au

Introduction

Asbestos insulation has been used in residences in Australia[1] and other countries including the USA, where use of asbestos-contaminated vermiculite insulation was widespread until the 1990s.[2] Asbestos causes mesothelioma, and causal associations have been established for cancers of the lung, ovary, and larynx; epidemiological evidence for other cancers is scant.[3] The risk of cancer increases with intensity, duration, and frequency of exposure to asbestos, with the predominant exposure route being inhalation and, to a lesser extent, ingestion.[3,4] Because asbestos fibres are a health hazard when airborne, loose-fill asbestos insulation is of particular concern.

Estimates of cancer risk associated with asbestos exposure have been based largely on high exposure in occupational settings, including mining, manufacturing, and construction industries.[3] Elevated risks have also been seen in family members of occupationally exposed workers[5] and in communities living near asbestos-related industries.[6,7] Far less is known about the risk of primarily domestic exposure.[5,8–10] In particular, there is no scientific evidence on the risk of cancer associated with living in a house containing loose-fill asbestos insulation.

In Australia, between 1968 and 1979, some houses in the Australian Capital Territory (ACT) and southern New South Wales (NSW) were insulated by blowing crushed, loose-fill asbestos (largely amosite with some crocidolite) into roof spaces. Over time, asbestos fibres migrated to other areas such as wall cavities, subfloor spaces, cupboards, heating and cooling ducts and vents, living areas, and bedrooms.[1] In 1989–93, the ACT Government surveyed the approximately 65 000 houses then in existence for the presence of loose-fill asbestos insulation, identifying around 1000 affected houses across suburbs, without obvious clustering in areas of high or low socioeconomic status. A programme was undertaken to remove visible and accessible loose-fill asbestos insulation from these houses. In 2013, attention was drawn to some houses that had been missed by this programme and, coincidentally, asbestos fibres were found in the living areas of many remediated houses.[1] The ACT Government established the Asbestos Response Taskforce to manage the issue.[11] Furthermore, they commissioned an

Research in context

Evidence before this study

We searched PubMed up to June 1, 2017, with the terms "asbestos", "insulation", "domestic", and "cancer". We restricted our search to English language publications. We also did hand searches of the reference lists of relevant papers. We identified no scientific reports on the risk of cancer associated with living in a house containing loose-fill asbestos insulation. Estimates of cancer risk associated with asbestos exposure have largely been based on high-level exposure in occupational settings. Far less is known about the risk of domestic exposure to asbestos and, in particular, to asbestos insulation.

Added value of this study

To the best of our knowledge, our study is the first to report empirical evidence on cancer risks associated with living in a house with asbestos insulation. In our cohort of 1 million people, the incidence of mesothelioma in men who had lived in a house insulated with loose-fill asbestos was two and a half times that of men who had not lived in these houses. No mesotheliomas were noted among women who had lived at an affected property. Incidence of colorectal cancer in men and women and prostate cancer in men also appeared to be raised in people who had lived in houses insulated with loose-fill asbestos.

Implications of all the available evidence

Residential asbestos insulation is likely to be unsafe. Our findings have important health, social, financial, and legal implications for governments and communities in which asbestos has been used to insulate houses.

independent study to investigate the health effects of living in a home insulated with loose-fill asbestos.

Our whole-population cohort study set in the ACT aimed to ascertain whether incidence of mesothelioma and other asbestos-associated cancers was higher in people who had lived in a house insulated with loose-fill asbestos than in people who had never lived in an affected residence.

Methods

Study population and data sources

The study population for our cohort study was drawn from the enrolment file of Medicare, the Australian universal health insurance provider, which covers almost the entire population of Australia. We included all people enrolled in Medicare with an ACT address at any time between Nov 1, 1983, when Medicare registrations began, and Dec 31, 2013, the last year of available cancer data at the time of this study. The Australian Institute of Health and Welfare—an accredited data integration authority—linked the Medicare enrolment file to three databases: the ACT Asbestos Response Taskforce register of all houses in which loose-fill insulation had been installed (referred to as affected residential properties); the Australian Cancer Database (from Jan 1, 1982, to Dec 31, 2013);[12] and the National Death Index (from Jan 1, 1980, to June 30, 2016).[13] For linkage of Medicare enrolments to the Australian Cancer Database and National Death Index, data records were matched probabilistically using full name, sex, date of birth, and postcode of residence. Linkage to the National Death Index also included all historical addresses for each person. More detail on data sources is provided in the appendix.

See Online for appendix

We obtained ethics approval for the study from the seven relevant Australian state and territory health departments and institutional human research ethics committees.

Procedures

We selected cancer outcomes for this study on the basis of the International Agency for Research on Cancer (IARC) review of evidence on cancer risks associated with asbestos exposure.[3] We classified cancer diagnoses for the study cohort according to International Classification of Diseases version 10 (ICD-10) codes. Mesothelioma (ICD-10 code C45) was the primary cancer of interest, in view of its unique relation with asbestos exposure. Other asbestos-associated cancers included in the study were lung (C33 and C34, which includes bronchus, lung, and trachea), ovarian (C56), laryngeal (C32), pharyngeal (C09–C14), stomach (C16), and colorectal (C18–C20). We also examined four other common cancers with very weak or no evidence for association with asbestos: bladder cancer (C67), kidney cancer (C64), melanoma (C43), and prostate cancer (C50).

We classified exposed individuals as those who had ever lived at an affected residential property during the study period and unexposed individuals as those not known to have ever lived at an affected residential property. Any Medicare address matching an address on the Asbestos Response Taskforce list was flagged as an affected residential property. We reclassified affected residential properties that had been demolished as non-affected residences after the date of demolition. Post office boxes—constituting 12% of ACT addresses—were classified as non-affected residential properties.

Statistical analysis

We defined an individual's entry into the study as the start date of their first Medicare registration, regardless of the Australian state or territory in which they were registered. For every cancer outcome, we calculated total person-years from entry into the study until the date of diagnosis, death from any cause, age 100 years, or Dec 31, 2013, whichever came first. We excluded participants who did not have a date of birth recorded, had a recorded birth

date that was after entry into the study, or had a recorded death date that was before entry into the study. For every cancer outcome, we also excluded individuals who had a diagnosis for that cancer registered before entry into the study.

Because of the known delay (lag) between first exposure to asbestos and diagnosis of asbestos-related disease, we decided a priori to apply a lag of 10 years between first exposure and diagnosis of a cancer that could be attributable to exposure in an affected residential property. Cancers diagnosed and person-years during this lag period were considered to be unexposed. We did not apply this lag to people resident at an affected residential property at the start of the study period, as we assumed previous residence of at least 10 years. We deemed all person-time and cancer diagnoses for cohort members having only non-affected residential property addresses to be unexposed.

We decided a priori to estimate incidence separately for males and females, because of potentially different levels of asbestos exposure within the household and from occupational sources. For each cancer, we calculated crude incidence for males and females among those exposed and unexposed to an affected residential property. For mesothelioma, which was the key outcome of interest, we also described incidence in relation to calendar period (5-year intervals), directly age-standardised to the 2001 Australian population (age groups <35 years, 35–44 years, 45–54 years, 55–64 years, 65–74 years, 75–84 years, and ≥85 years).

We used indirect standardisation to generate standardised incidence ratios (SIRs) and exact Poisson 95% CIs separately for males and females and adjusted for age group and calendar period of diagnosis. Analyses were done using Stata version 12.1 and SAS version 7.1.

We did sensitivity analyses to investigate the effect of our assumptions on our findings. First, we varied lag periods to 5 years and 15 years. Second, we applied the 10-year lag to people living at an affected residential property at the start of the study period. Third, we excluded participants who had a post office box as their mailing address during the study period, unless they had previously been classified as exposed at an affected residential property. Finally, we censored all participants at age 85 years.

Role of the funding source

The funder had no role in study design, data collection, data analysis, data interpretation, or writing of the report. RJK, HDL, and MDK had access to raw data. The corresponding author had full access to all data in the study and had final responsibility for the decision to submit for publication.

Results

Between Nov 1, 1983, and Dec 31, 2013, a total of 1035 578 individuals were identified who had at least one ACT address (figure 1). We linked 1087 (>99%) of the 1089 affected residential property addresses to one or more addresses in the Medicare enrolment file; 17 248 (2%) participants had an affected residential property address and were classified as exposed. In total, 54 771 (5%) of 1035 578 individuals had at least one link to the Australian Cancer Database, with 59 962 cancers diagnosed in total during the study period; 64 866 (6%) of 1035 578 individuals had their death recorded in the National Death Index. After excluding individuals who had no date of birth (n=268), were born after study entry (n=124), or who died before study entry (n=1122), and a further five people diagnosed with mesothelioma before study entry, 1034 059 (>99%) ACT registrants were included in the main mesothelioma analysis.

285 cases of mesothelioma were recorded during the study period, of which 152 (53%) were registered by cancer registries outside the ACT. Nine (3%) of 285 cases were diagnosed in people who had ever lived at an affected residential property. Two people were diagnosed with mesothelioma before they lived at an affected residential property (0·45 years and 5·7 years before) so the cancer was not attributed to exposure in an affected residential property. Seven individuals diagnosed with mesothelioma had lived at an affected residential property before their diagnosis. All seven exposed individuals, and 239 (86%) of 278 people diagnosed with mesothelioma who had not lived in an affected residential property, were men (table), and all cases were diagnosed

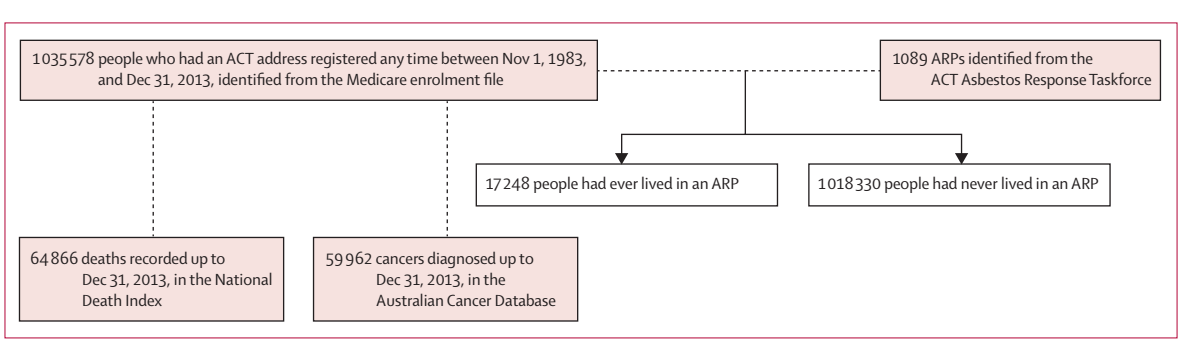

Figure 1: **Data sources and linkage results for the study population**
ACT=Australian Capital Territory. ARP=affected residential property.

	Sample size	ARP			Non-ARP		
		n	Person-years ×100 000	Crude rate* (95% CI)	n	Person-years ×100 000	Crude rate* (95% CI)
Males							
Mesothelioma	504 850	7	0·848	8·26 (3·32–17·0)	239	106	2·25 (1·97–2·56)
Other asbestos-associated cancers							
Lung	504 778	25	0·847	29·5 (19·1–43·6)	2430	106	22·9 (22·0–23·8)
Laryngeal	504 840	4	0·848	4·72 (1·29–12·1)	250	106	2·36 (2·07–2·67)
Pharyngeal	504 846	6	0·848	7·08 (2·60–15·4)	286	106	2·69 (2·39–3·03)
Stomach	504 818	5	0·848	5·90 (1·92–13·8)	649	106	6·12 (5·65–6·60)
Colorectal	504 668	54	0·845	63·9 (48·0–83·4)	3734	106	35·3 (34·1–36·4)
Other cancers							
Bladder	504 805	9	0·847	10·6 (4·86–20·2)	822	106	7·75 (7·23–8·30)
Kidney	504 833	11	0·847	13·0 (6·48–23·2)	849	106	8·00 (7·47–8·56)
Melanoma	504 696	46	0·844	54·5 (39·9–72·7)	3590	106	33·9 (32·8–35·1)
Prostate	504 660	121	0·839	144 (120–172)	8087	106	76·6 (74·9–78·3)
Females							
Mesothelioma	529 209	0	0·891	0 (0–4·14)†	39	112	0·35 (0·25–0·48)
Other asbestos-associated cancers							
Lung	529 173	21	0·890	23·6 (14·6–36·1)	1556	111	14·0 (13·3–14·7)
Ovarian	529 208	10	0·890	11·2 (5·39–20·7)	752	111	6·75 (6·27–7·25)
Laryngeal	529 169	1	0·891	1·12 (0·03–6·26)	32	112	0·29 (0·20–0·41)
Pharyngeal	529 208	1	0·891	1·12 (0·03–6·26)	84	112	0·75 (0·60–0·93)
Stomach	529 191	2	0·891	2·25 (0·27–8·11)	341	112	3·06 (2·74–3·40)
Colorectal	529 057	53	0·888	59·7 (44·7–78·1)	3133	111	28·2 (27·2–29·2)
Other cancers							
Bladder	529 187	2	0·890	2·25 (0·27–8·12)	239	112	2·14 (1·88–2·43)
Kidney	529 196	5	0·891	5·61 (1·82–13·1)	439	111	3·94 (3·58–4·32)
Melanoma	529 058	37	0·885	41·8 (29·4–57·6)	3012	111	27·1 (26·1–28·1)

Data allow for a 10-year lag. ARP=affected residential property. n=number of people diagnosed with each cancer. *Crude rate is per 100 000 person-years. †One-sided 97·5% CI.

Table: **Person-years at risk and crude rates of selected cancers (1983–2013)**

with pleural mesothelioma. The average age of diagnosis was 58·1 years (SD 15·4; median 57·1 years [IQR 43·6–70·4) for people who had lived at an affected residential property, and 67·4 years (SD 12·1; median 68·0 years [60·7–75·6]) for those who had not lived at an affected property. The time between date of first exposure to an affected residential property and mesothelioma diagnosis ranged from 12·8 years to 24·9 years (median 15·0 years [IQR 14·3–24·0]). The estimated time between exposure and diagnosis is probably a minimum, because five of the seven exposed cases were registered as living at an affected residence at the start of the study period.

The 285 cases of mesothelioma occurred over 21·9 million person-years of follow-up. Crude incidence was 1·30 cases (95% CI 1·15–1·46) per 100 000 person-years, with an incidence of 2·30 cases (2·02–2·60) per 100 000 person-years in males and 0·35 cases (0·25–0·47) per 100 000 person-years in females. Age-standardised incidence increased over time (figure 2). Crude incidence of mesothelioma in unexposed males was 2·25 cases (95% CI 1·97–2·56) per 100 000 person-years compared with 8·26 cases (3·32–17·0) per 100 000 person-years in males exposed to an affected residential property (table). After adjusting for age and calendar time of diagnosis, incidence of mesothelioma in exposed males was two and a half times that in unexposed males (SIR 2·54, 95% CI 1·02–5·24; figure 3). An estimated 4·2 (95% CI 0·06–11·7) excess cases of mesothelioma occurred in male residents of affected residential properties between 1984 and 2013. Among unexposed females, the crude rate of mesothelioma was 0·35 (95% CI 0·25–0·48) per 100 000 person-years, with no cases in exposed females (table).

Among other asbestos-associated cancers, incidence of colorectal cancer was higher in ACT residents who had ever lived in an affected residential property than in people who had never lived in an affected property, for both males (SIR 1·32, 95% CI 0·99–1·72) and females (1·73, 1·29–2·26; figure 3), although the figure for males was not statistically significant. For lung, ovarian, laryngeal, pharyngeal, and stomach cancers, which are also associated with asbestos exposure, no evidence was

noted of an association with affected residential property exposure (table; figure 3). With respect to the other four cancers investigated, incidence of bladder and kidney cancers and melanoma did not differ between exposed and unexposed residents, but the incidence of prostate cancer was higher in men exposed to an affected residential property than in those who were unexposed (SIR 1·29, 95% CI 1·07–1·54; figure 3).

In the three sensitivity analyses, the association between mesothelioma and living in an affected residential property was maintained, although considerable uncertainty was present around estimates (appendix). For colorectal and prostate cancer, excluding participants with post office boxes for mailing addresses had the greatest effect on results, substantially reducing the strength of association.

Discussion

We observed an incidence of mesothelioma around two and a half times higher in males who had ever lived in ACT houses containing loose-fill asbestos insulation (affected residential properties) than in males who had not. Of the other six cancers known to be associated or potentially associated with asbestos exposure, only colorectal cancer incidence was significantly elevated in residents who had lived at an affected property (exposed) compared with those who had not (unexposed). Additionally, we noted higher incidence of prostate cancer in exposed males than in unexposed males.

As far as we are aware, no previous studies have been done to estimate the risks of cancer among people who have lived at properties with loose-fill asbestos insulation. Nor, to our knowledge, have studies been done of the effects of living in houses insulated with asbestos-contaminated vermiculite (ore estimated to be 21–26% asbestos by weight), despite this substance being used extensively and remaining in millions of homes in the USA, Canada, and other countries.[2,14] Rates of death from asbestos-associated diseases—including non-malignant respiratory diseases, chronic obstructive pulmonary disease, and asbestosis—are increased in the community of Libby, MT, USA, although at substantially lower levels than in people exposed occupationally to asbestos-containing vermiculite.[7]

The association we recorded between living in an affected residential property and mesothelioma in men is modest compared with that noted in studies of occupational or para-occupational exposure to asbestos. For example, among amosite asbestos miners in Tyler, TX, USA, peritoneal mesothelioma had a standardised mortality ratio of 21·5 (95% CI 8·62–44·2) and pleural mesothelioma had a standardised mortality ratio of 222 (12·7–361).[15] Furthermore, in asbestos textile workers in Italy, standardised mortality ratios for these two diseases were 29·1 (21·5–38·6) and 33·7 (25·7–43·4), respectively.[16] Similarly, a very high incidence of mesothelioma has been recorded in crocidolite miners in Wittenoom, WA, Australia.[17]

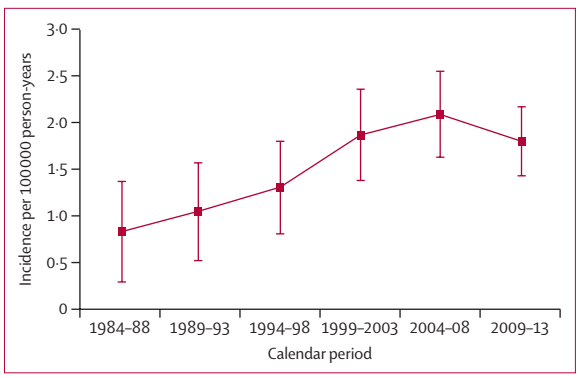

Figure 2: **Age-standardised incidence of mesothelioma, by calendar period (1984–2013)**
Incidence is directly age-standardised to the Australian 2001 population. Vertical bars represent 95% CIs around point estimates for the incidence in every period.

	Total cases	O/E	SIR (95% CI)
Males			
Mesothelioma	246	7/2·75	2·54 (1·02–5·24)
Other asbestos-associated cancers			
Lung	2455	25/26·2	0·96 (0·62–1·41)
Laryngeal	254	4/2·60	1·54 (0·42–3·93)
Pharyngeal	292	6/3·21	1·87 (0·69–4·07)
Stomach	654	5/6·81	0·73 (0·24–1·71)
Colorectal	3788	54/40·9	1·32 (0·99–1·72)
Other cancers			
Bladder	831	9/8·37	1·07 (0·49–2·04)
Kidney	860	11/9·58	1·15 (0·57–2·05)
Melanoma	3636	46/37·6	1·23 (0·90–1·63)
Prostate	8208	121/94·0	1·29 (1·07–1·54)
Females			
Mesothelioma	39	0/0·39	0·0 (0–9·37)*
Other asbestos-associated cancers			
Lung	1577	21/16·0	1·31 (0·81–2·01)
Ovarian	762	10/7·77	1·29 (0·62–2·37)
Laryngeal	33	1/0·31	3·25 (0·08–18·1)
Pharyngeal	85	1/0·94	1·07 (0·03–5·95)
Stomach	343	2/3·04	0·66 (0·08–2·37)
Colorectal	3186	53/30·7	1·73 (1·29–2·26)
Other cancers			
Bladder	241	2/2·13	0·94 (0·11–3·40)
Kidney	444	5/4·48	1·12 (0·36–2·60)
Melanoma	3049	37/29·4	1·26 (0·89–1·74)

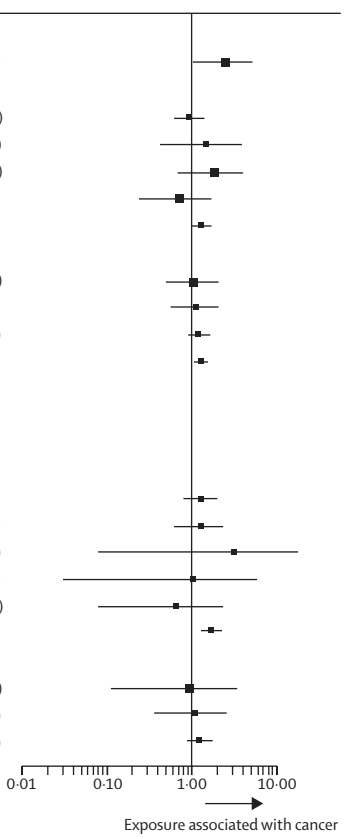

Figure 3: **Cancer outcomes**
SIRs are the incidence of each selected cancer in ARP residents compared with the incidence in non-ARP residents, standardised for age and calendar period. SIRs are plotted on a log scale and are represented with squares, with 95% CIs indicated by horizontal lines. ARP=affected residential property. E=expected. O=observed. SIR=standardised incidence ratio. *One-sided 97·5% CI.

Our observation of an elevated SIR for mesothelioma in men but not women is consistent with previous evidence. This finding could suggest confounding by occupational exposure to asbestos, but it is unlikely that such exposure

would be distributed differentially among residents who had and had not lived at an affected property. The association could indicate higher levels of exposure to loose-fill insulation among men. In a survey of residents of affected residential properties, a higher proportion of men than women reported entering the roof space (85% *vs* 41%), and 15% of men who had reported entering the roof space did so more than 50 times.[18]

The association between living in a house insulated with loose-fill asbestos and colorectal cancer was somewhat unexpected. Previous studies on asbestos exposure and colorectal cancer have produced mixed findings, with elevated risks from prolonged and heavy exposure. The highest risk of colorectal cancer was noted among North American insulation workers and British male insulation workers.[19] Further evidence also supports an association between colorectal cancer and prolonged exposure to high levels of asbestos, but not with lower levels of exposure.[19,20] In our study, it is possible that some exposure to asbestos occurred through ingestion, because asbestos fibres were found on surfaces in living areas of affected residential properties, including kitchen and dining areas.[1] Ingestion of asbestos produces cancerous lesions in rats.[19] However, evidence for an association between ingestion of asbestos and colorectal cancer is weak,[4] making the link between loose-fill asbestos insulation and colorectal cancer in the ACT uncertain.

We did not expect to find a raised risk of prostate cancer in our study. Asbestos fibres have been noted in the prostate,[21] and increased risks of prostate cancer were reported in a study of Finnish construction workers in an asbestos screening programme[22] and in a cohort study of former residents of the crocidolite mining town of Wittenoom, WA, Australia.[23] However, these elevated rates might have been attributable to ascertainment bias, with exposed men perhaps more likely to have been screened for prostate cancer than unexposed men. Thus, although a causal association between affected residential properties and prostate cancer is plausible, further evidence is needed before any conclusions can be drawn about this observation.

A major strength of our study is that we had access to a complete register of affected properties. We also had access to the Medicare database to assemble a population-based cohort. This allowed virtually complete coverage of the ACT population and use of an internal reference population. However, the Medicare database had limitations. Medicare registrations began in November, 1983, and exposure to loose-fill asbestos insulation might have occurred from 1968 onwards; hence, we might have misclassified people who were exposed to asbestos insulation before 1983 but did not live in an affected residential property after this time, or we might have missed them altogether if they moved away from the ACT or died. This possibility would be likely to bias results toward the null. Delays registering changes of address can also happen, which would have non-differentially affected accuracy of our estimates of person-years with respect to the exposure; as a result, estimates of absolute cancer incidence could be inaccurate, but SIRs are unlikely to be biased. Finally, individuals with post office boxes as their address might have been classified incorrectly as unexposed. In our sensitivity analysis, excluding people with post office boxes for their address, relative incidence of mesothelioma remained raised but uncertainty increased.

Another strength of our study was the use of data from an Australia-wide cancer registry to ascertain outcomes. However, we might have missed cases occurring before mandatory reporting began in the ACT in 1994, or residents who did not live in Australia at the time of their diagnosis. Furthermore, linkage to mortality data is subject to quality issues because of incomplete data for date of birth, particularly in earlier years; however, any under-ascertainment of cancers or deaths and linkage errors would be non-differential with respect to exposure to an affected residential property.

We were unable to account for potential confounding other than by age and sex. Potential confounders vary depending on the particular cancer, but include behavioural risk factors such as smoking in addition to occupational exposure to asbestos and prostate cancer screening. Smoking does not increase the risk of mesothelioma, but is a potential confounder (and effect-modifier) in the relation between exposure to an affected residential property and other cancers investigated in this study.[24] In particular, the absence of information on smoking restricted the ability to interpret the findings for lung cancer. Finally, we lacked statistical power to analyse the rarer cancers.

The findings of our study have implications for public health policy about loose-fill asbestos insulation that remains in situ. The ACT Government undertook to purchase affected properties at an estimated cost of AU$1 billion,[11] and identification and buy-back is also now underway in NSW. These localised contamination issues have major implications for communities in terms of health and the social and financial effects.[18,25,26] Internationally, information on the nature and scale of use of residential asbestos insulation is scarce, but it is clear from use of vermiculite in loft insulation in the USA and some other countries that the situation in Australia is not unique.

In conclusion, living in a house insulated with loose-fill asbestos could be associated with some mesotheliomas in men, possibly because of their entry into roof spaces of—and their renovation of—asbestos-insulated houses. The recorded associations between living in these houses and colorectal and prostate cancers were somewhat unexpected and should be regarded as uncertain, although some evidence exists for such associations in other studies of people exposed to asbestos. Future extension of our study to include more years of follow-up will be worthwhile.

Furthermore, studying the health of people exposed occupationally to this asbestos might be useful. Our findings have important health, social, financial, and legal implications for governments and communities in which asbestos has been used to insulate houses.

Contributors

RJK, MSC, BKA, and MDK had the idea for the study and contributed to study design. RJK, MSC, BKA, HDL, TG, PRA, SMT, and MDK contributed to data acquisition and data interpretation. RJK, MDK, and HDL contributed to statistical analysis. RJK, SMT, and MDK did the literature search. RJK and MDK wrote the initial draft of the manuscript and all authors contributed to critical revision for important intellectual content and final approval of the submitted manuscript.

Declaration of interests

We declare no competing interests.

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References

1 ACT Government Asbestos Response Taskforce. Long term management of loose fill asbestos insulation in Canberra homes. August, 2014. http://www.asbestostaskforce.act.gov.au/__data/assets/pdf_file/0009/675189/Longterm-management-review.pdf (accessed Sept 26, 2017).

2 United States Environmental Protection Agency. Protect your family from asbestos-contaminated vermiculite insulation. Dec 28, 2016. https://www.epa.gov/asbestos/protect-your-family-asbestos-contaminated-vermiculite-insulation (accessed Sept 26, 2017).

3 International Agency for Research on Cancer (IARC) Working Group on the Evaluation of Carcinogenic Risks to Humans. Arsenic, metals, fibres, and dusts: volume 100 C—a review of human carcinogens. 2012. http://monographs.iarc.fr/ENG/Monographs/vol100C/mono100C.pdf (accessed Sept 26, 2017).

4 Gamble J. Risk of gastrointestinal cancers from inhalation and ingestion of asbestos. *Regul Toxicol Pharmacol* 2008; **52** (1 suppl)**:** S124–53.

5 Goswami E, Craven V, Dahlstrom DL, Alexander D, Mowat F. Domestic asbestos exposure: a review of epidemiologic and exposure data. *Int J Environ Res Public Health* 2013; **10:** 5629–70.

6 Sullivan PA. Vermiculite, respiratory disease, and asbestos exposure in Libby, Montana: update of a cohort mortality study. *Environ Health Perspect* 2007; **115:** 579–85.

7 Naik SL, Lewin M, Young R, Dearwent SM, Lee R. Mortality from asbestos-associated disease in Libby, Montana 1979–2011. *J Expo Sci Environ Epidemiol* 2017; **27:** 207–13.

8 Lacourt A, Gramond C, Rolland P, et al. Occupational and non-occupational attributable risk of asbestos exposure for malignant pleural mesothelioma. *Thorax* 2014; **69:** 532–39.

9 Liu B, van Gerwen M, Bonassi S, Taioli E. Epidemiology of environmental exposure and malignant mesothelioma. *J Thorac Oncol* 2017; **12:** 1031–45.

10 Noonan CW. Environmental asbestos exposure and risk of mesothelioma. *Ann Transl Med* 2017; **5:** 234.

11 Kirby T. Canberra Government to demolish asbestos-contaminated homes. *Lancet Respir Med* 2014; **2:** 975.

12 Australian Institute of Health and Welfare. Australian Cancer Database (ACD). Aug 30, 2017. https://www.aihw.gov.au/about-our-data/our-data-collections/australian-cancer-database (accessed Sept 26, 2017).

13 Australian Institute of Health and Welfare. National Death Index (NDI). Aug 29, 2017. https://www.aihw.gov.au/about-our-data/our-data-collections/national-death-index (accessed Sept 26, 2017).

14 Spear TM, Hart JF, Spear TE, Loushin MM, Shaw NN, Elashhab MI. The presence of asbestos-contaminated vermiculite attic insulation or other asbestos-containing materials in homes and the potential for living space contamination. *J Environ Health* 2012; **75:** 24–29.

15 Levin JL, Rouk A, Shepherd S, Hurst GA, McLarty JW. Tyler asbestos workers: a mortality update in a cohort exposed to amosite. *J Toxicol Environ Health B Crit Rev* 2016; **19:** 190–200.

16 Pira E, Romano C, Violante FS, et al. Updated mortality study of a cohort of asbestos textile workers. *Cancer Med* 2016; **5:** 2623–28.

17 Berry G, Reid A, Aboagye-Sarfo P, et al. Malignant mesotheliomas in former miners and millers of crocidolite at Wittenoom (Western Australia) after more than 50 years follow-up. *Br J Cancer* 2012; **106:** 1016–20.

18 Kirk MD, Batterham PJ, Clements MS, et al. ACT Asbestos Health Study: cross sectional survey report. December, 2016. http://nceph.anu.edu.au/files/ACTAHS-Component-3-Report_9Feb2017_V2.pdf (accessed Sept 26, 2017).

19 Paris C, Thaon I, Herin F, et al. Occupational asbestos exposure and incidence of colon and rectal cancers in French men: the Asbestos-Related Diseases Cohort (ARDCo-Nut). *Environ Health Perspect* 2017; **125:** 409–15.

20 Offermans NS, Vermeulen R, Burdorf A, et al. Occupational asbestos exposure and risk of esophageal, gastric and colorectal cancer in the prospective Netherlands Cohort Study. *Int J Cancer* 2014; **135:** 1970–77.

21 Auerbach O, Conston AS, Garfinkel L, Parks VR, Kaslow HD, Hammond EC. Presence of asbestos bodies in organs other than the lung. *Chest* 1980; **77:** 133–37.

22 Koskinen K, Pukkala E, Reijula K, Karjalainen A. Incidence of cancer among the participants of the Finnish Asbestos Screening Campaign. *Scand J Work Environ Health* 2003; **29:** 64–70.

23 Reid A, Franklin P, Olsen N, et al. All-cause mortality and cancer incidence among adults exposed to blue asbestos during childhood. *Am J Ind Med* 2013; **56:** 13.

24 US Department of Health and Human Services. The health consequences of smoking: 50 years of progress—a report of the Surgeon General. 2014. https://www.surgeongeneral.gov/library/reports/50-years-of-progress (accessed Sept 26, 2017).

25 van Dorn A. Libby: the long legacy of a public health disaster. *Lancet Respir Med* 2017; **5:** 174–75.

26 Cline RJ, Orom H, Child JT, Hernandez T, Black B. Social support functions during a slowly-evolving environmental disaster: the case of amphibole asbestos exposure in Libby, Montana. *Health Commun* 2015; **30:** 1135–48.