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Malignant mesothelioma in Australia 2015: Current incidence and asbestos exposure trends

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ABSTRACT
Australia is known to have had the highest per-capita asbestos consumption level of any nation, reaching a peak in the 1970s. Although crocidolite was effectively banned in the late 1960s, and amosite use ceased in the mid 1980s, a complete asbestos ban was not implemented until 2003. This resulted in an epidemic of asbestos-related disease, which has only now reached its peak. Between 1982 and 2011, 13,036 individuals were newly diagnosed with malignant mesothelioma, with 690 diagnosed in 2011. A further 778 cases were identified between 1945 and 1981 from retrospective searches and the first 2 years of the Australian Mesothelioma Program. The age-standardized malignant mesothelioma incidence rate has leveled off in the last 10 years (2.8 per 100,000 in 2011). There has been a marked increase over time in the age-specific incidence rates for individuals aged 75 years or older. Data from the current Australian Mesothelioma Registry on asbestos exposure history in Australia is available for 449 subjects diagnosed between July 1, 2010, and April 1, 2015. This asbestos exposure history data show that 60% (n = 268) of cases had probable or possible occupational asbestos exposure, with trade-based jobs being the most frequent sources of occupational asbestos exposure. In addition, out of the 449 cases, 377 were recorded as having probable or possible nonoccupational asbestos exposure. Continuous vigilance toward changes over time in the settings in which people are exposed to asbestos and in the descriptive epidemiology of malignant mesothelioma is recommended to enable a comprehensive understanding of the current and future impact of asbestos-related diseases in Australia.

Australia is one of a number of high-income countries considered to be a sentinel site for observing over time the adverse human health, environmental, economic, and social effects associated with high levels of prior asbestos consumption. This is due to the fact that Australia had the world's highest per-capita asbestos consumption rate in the 1950s, primarily from mining, use of asbestos in construction materials, and also importation of asbestos-containing products (Henderson and Leigh 2011; Leigh and Driscoll 2003). Asbestos consumption in Australia peaked in the 1970s at 704,425 metric tonnes (1970–1979 aggregate) (Leigh et al. 2002). Between 1880 and 1889 approximately 47 tonnes of amphiboles was mined at Jones' Creek, near Gundagai, New South Wales, and between 1890 and 1899 about 35 tonnes of chrysotile was mined at Anderson's Creek, Tasmania. South Australia was the first state to mine crocidolite, at Robertstown in 1916.

Over the 20th century there was a gradual rise in asbestos production, with more chrysotile than amphiboles mined until 1939. With the commencement of mining at Wittenoom, Western Australia, in 1937, crocidolite dominated production, until final closure in 1966. New South Wales, the first state to mine asbestos, also produced the largest tonnages of chrysotile (until 1983), as well as smaller quantities of amphiboles (until 1949). With the closing of the crocidolite mine at Wittenoom in 1966, Australian asbestos production declined to a pre-1952 level. Australian asbestos (crocidolite and chrysotile) was exported to the USA, Japan, UK and Europe. In particular, Wittenoom crocidolite was exported to the United States and Europe. The export process itself, bagging, transport, and wharf labor, enhanced exposure. Exports declined from 1967. Imports of chrysotile also started to decline. The earliest records of asbestos imports date from 1929. The main

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Table 1. Trade-specific exposure assessment for people diagnosed with malignant mesothelioma, Australia, July 1, 2010, to April 1, 2015, according to the probability of asbestos exposure. *Note*. Data extracted from the Australian Mesothelioma Registry report published in 2015.

	Assessed probability of exposure				
	Probable asbestos exposure				
Job title	High	Medium	Low	Possible asbestos exposure	Unlikely asbestos exposure
Construction (carpenter, joiner, builder, bricklayers, etc.)	88			3	10
Other metal and mechanical trades (including fitters, turners, machinists)	48	2		6	11
Other (not specified)	27	1		4	20
Electrician	25			4	7
Boilermaker, welder	21				
Plumber	18		1	1	2
Engineer	5			2	3
Telecommunications technician	2			2	5

sources of raw asbestos imports were Canada (chrysotile) and South Africa (crocidolite and amosite). Approximately twice as much chrysotile was imported as was mined and half as much crocidolite was imported as was mined. After Wittenoom was closed, 122 tonnes of crocidolite were mined in South Australia. In New South Wales, the chrysotile mine at Baryulgil continued production. In 1971 the chrysotile deposits at Woodsreef near Barraba, New South Wales, began to be exploited and exports of asbestos fiber expanded as production was elevated. This operation was open-cast with dry milling. Australian production of asbestos fiber decreased in 1981 because of the fall in world demand for asbestos and increased operating costs at the Woodsreef mine. This mine ceased production in 1983 when the dry milling plant could not meet dust control regulations.

In addition to imports of asbestos fiber, Australia also imported many manufactured asbestos products, including asbestos cement articles, asbestos yarn, cord and fabric, asbestos joint and millboard, asbestos friction materials, and gaskets. The main sources of supply were the United Kingdom, the United States, the Federal Republic of Germany, and Japan. In Australia more than 60% of all production and 90% of all consumption of asbestos fiber was by the asbestos cement manufacturing industry. From about 1940 to the late 1960s all three types of asbestos were used in this industry, with crocidolite then being phased out. Amosite use in this industry continued until about 1983. Chrysotile was used until about 1987. Much of this industry output remains in service today in the form of "fibro" houses and water and sewerage piping. By 1954 Australia was number 4 in the world in gross consumption of asbestos cement products, after the United States, the Uited Kingdom and France, and clearly first on a per-capita basis. After World War II to 1954, 70,000 asbestos cement houses were built in the state of New South Wales alone (52% of all houses built). In Australia, as a whole, until the 1960s, 25% of all new housing was clad in asbestos cement.

Chrysotile use continued in friction products, sealing gaskets, and adhesives until 2003, with a complete ban on all importation and use of asbestos across Australia occurring in 2003 (Jamrozik, de Klerk, and Musk 2011; Leigh et al. 2002). However, due to the long latency period between asbestos exposure and asbestos-related disease, ranging between 10 and 50 or more years (Linton et al. 2012), these deleterious human health effects are still present.

There are nonmalignant and malignant asbestos-related diseases. The first group includes pleural plaques, diffuse pleural thickening, and asbestosis. Asbestos-related lung cancer and malignant mesothelioma are the two most important malignant conditions elicited by asbestos (Jamrozik, de Klerk, and Musk 2011). Malignant mesothelioma is the most commonly measured epidemiological marker of asbestos-related disease burden in Australia due to its strong epidemiological associations with exposure to airborne asbestos fibers, as noted by International Agency for Research on Cancer (IARC 2012) as well as the ability to monitor disease trends using high-quality population-level data. Malignant mesothelioma, most frequently located in the pleura (more than 90%), has a rapid onset of mortality in the first year following diagnosis. Median survival for malignant mesothelioma has been estimated to range between 9 and 12 mo from the time of diagnosis to death from any cause (Kao et al. 2010; Linton et al. 2012; 2014).

High-quality international data on age-standardized cancer incidence rates, using an international age distribution, demonstrated that Australia and the United Kingdom have significantly higher incidence rates of malignant mesothelioma compared to other parts of the world (Forman et al. 2014). For example during 2003–2007, Australia's male age-standardized malignant mesothelioma incidence rates ranged between 2.5 and 3.1 per 100,000 person-years. In almost all other countries, the male age-standardized incidence rates were approximately 1 per 100,000 or below. Across all countries, female age-standardized incidence rates were generally below 1 per 100,000, reflecting gender differences in asbestos exposure.

At the population level, information regarding the disease burden of malignant mesothelioma in Australia—and all other malignant disease—is recorded through cancer registration at the subnational level, where these records are then aggregated into a national cancer database referred to as the Australian Cancer Database. Australia has also made significant investment in developing a malignant mesothelioma surveillance system that records incident cases of malignant mesothelioma and, where possible, asbestos exposure histories. These surveillance systems included integration of high-quality population-based cancer registration data with the collection of asbestos exposure histories from those newly diagnosed with malignant mesothelioma. While these surveillance systems have not been continuous over time, they provide useful data for identifying particular subpopulation groups who are more at risk of developing malignant mesothelioma.

In this paper, we aim to present up-to-date information regarding the descriptive epidemiology of malignant mesothelioma in Australia and an overview of asbestos exposure data collected through the current and previous Australian Mesothelioma Registry. In particular, the incidence (occurrence of new cases of malignant mesothelioma), measured as both a count and a rate measure by age group, gender, and jurisdiction, will be examined. These data have been extracted from routine reporting from both the Australian Cancer Database and the Australian Mesothelioma Registry, where aggregate data on incidence are available. A summary of malignant mesothelioma data published by the Australian Institute of Health and Welfare of relative survival, a population-based measured that accounts for all causes of death, is also presented. The most recently available data on asbestos exposure for individuals diagnosed after July 1, 2010, from the Australian Mesothelioma Registry are provided and these data are supplemented with other asbestos exposure reports in Australia.

Population-based data sources to measure malignant mesothelioma

Incidence

There are two primary data sources for measuring malignant mesothelioma incidence in Australia. The first data source is the Australian Cancer Database. The Australian Cancer Database is a data collection of all primary, malignant cancers diagnosed in Australia since 1982, where data are compiled at the Australian Institute of Health and Welfare from cancer data provided by the eight Australian statutory population-based state and territory cancer registries. Information about a cancer diagnosis in Australia is received from various sources, including hospitals, pathology labs, radiotherapy centers, and birth, death, and marriage registries. Currently, the Australian Cancer Database is considered complete for all incident cancers diagnosed during 1982–2009, although preliminary data up to 2011 are available. The second data source—where more recent cancer registration data are available—is the Australian Mesothelioma Registry. A unique feature of this data collection is that pathologically confirmed cases of malignant mesothelioma recorded at the state or territory level are fast-tracked to this registry, in order to collect, if possible, information regarding an individual's asbestos exposure. The Australian Mesothelioma Registry regularly reports on its data collection. The most recent report includes data for the period July 1, 2010, to December 31, 2014, and current as of May 31, 2015.

Australia is made up of eight states and territories, most commonly referred to as jurisdictions. Asbestos consumption is known to have varied in Australia by jurisdiction. Although malignant mesothelioma incidence rates are published by each of the eight subnational cancer registries in Australia, there may be differences in the way data are analyzed and presented. Drawing upon high-quality global cancer incidence data published by IARC (Curado et al. 2007; Forman et al. 2013; Parkin et al. 2002), it is possible to describe Australian malignant mesothelioma incidence rate differences by jurisdiction where equivalent data collection, quality control, and analytic procedures were used.

Survival

Malignant mesothelioma is almost invariably a fatal disease with a rapid force of cause-specific mortality in the first year following diagnosis. Survival estimates may be measured at the population level using cancer-mortality data linkage methods. The Australian Institute of Health and Welfare regularly performs a probabilistic data linkage of records held within the Australian Cancer Database with records held in the National Death Index. This enables variables such as cause of death, fact of death, and date of death to be calculated. If a person is not recorded as having died, that person is assumed to be alive at the end of follow-up. The Australian Institute of Health and Welfare published population-based estimates of survival following a malignant mesothelioma diagnosis, expressed as relative survival (Australian Institute of Health and Welfare [AIHW] 2012). Relative survival, a method of comparing of survival in the cancer population compared to their expected survival using background mortality data, can be interpreted as survival experienced by individuals diagnosed with malignant mesothelioma after their diagnosis and accounting for all causes of death. Regression modeling of relative survival is also possible with results reported recently for Australian trends over time in malignant mesothelioma survival (Dickman et al. 2004; Soeberg et al. 2016).

Asbestos exposure

National data collections

Since the mid 1980s, Australia has made significant investment in collecting asbestos exposure data from subjects newly diagnosed with malignant mesothelioma. Three different iterations of this system were implemented—the Australian Mesothelioma Surveillance Program, the Australia Mesothelioma Register, and the recently reestablished Australia Mesothelioma Registry operating for the last 5 years. Detailed information regarding the first two data collections are published elsewhere (Driscoll et al. 1993; Leigh 1995; Leigh and Driscoll 2003; Leigh et al. 1991a; 1991b; 2002; Rogers et al. 1991). Briefly, the Australian Mesothelioma Surveillance Program was active between 1980 and 1985 and collected voluntary notifications of malignant mesothelioma at the subnational level from clinicians, hospitals, occupational health divisions, and pathologists. Notified cases of malignant mesothelioma were confirmed with relevant cancer registries in each jurisdiction. During 1980–1985, 854 cases of malignant mesothelioma were notified to the Australian Mesothelioma Surveillance Program, with tissue for histological examination available for 777 of those cases (Leigh et al. 1991b). One of the primary reasons the Australian Mesothelioma Surveillance Program was disestablished was the high burden of collecting comprehensive asbestos exposure data. The Australian Mesothelioma Register was then established in 1986 and collected information regarding incident malignant mesothelioma cases, as well as a reduced level of asbestos exposure histories. Sixty percent of cases had detailed histories from the Western Australian Mesothelioma Register or the New South Wales Dust Diseases Board. The remainder of data were gathered from responses to a short mailed exposure questionnaire assessing the occupation, industry, or circumstances of asbestos exposure, with the questionnaire followed up on four occasions if necessary.

Patterns of asbestos exposure were also previously noted using national and subnational data from the Australian Mesothelioma Program (national) (Ferguson et al. 1987; Leigh and Driscoll 2003), the Australian Mesothelioma Register (national) (Leigh and Driscoll 2003), the Western Australian Mesothelioma Register (Driscoll and Leigh 2008), and the New South Wales Dust Diseases Board (Driscoll and Leigh 2008). From these previous data collections, the most notable consistent trends nationally are the increase in proportion of cases exposed in building construction workers from 4 to 30%, power station workers, electrical workers, and boilermaker or welder workers. There was also a marked rise in individuals being exposed in multiple settings, as well as in home renovation (from 5 to 8% in males; from 4 to 36% in females). Conversely, there was a significant decrease in the proportion of cases exposed in waterside and transport work, shipbuilding, and railway work. There was also a marked reduction in the proportion of cases assessed as having no exposure to asbestos (from 28 to 4%). The occupations having the highest lifetime risk, that is, of 5% or greater, are Wittenoom mine or mill workers (16.6%), power station workers (11.8%), railway labor workers (6.4%), and navy/merchant navy workers (5.1%), as illustrated in Figure 1. Occupations with elevated lifetime risks of between 3.1 and 0.7% in order of magnitude include Wittenoom residents, carpenters or joiners, waterside workers, plasters, boilermakers or welders, bricklayers, plumbers, painters or decorators, electrical fitters or electricians, and vehicle mechanics. The dose-response relationship between asbestos exposure and mesothelioma has no threshold, and exposures as short as 1 day were found. Chrysotile-only exposures were noted in 4% of cases where the main types of exposure were through occupational exposure in automotive mechanic work, as well as individuals exposed to asbestos products known to contain only chrysotile and persons involved in production of chrysotile-only products.

The registry stopped publicly reporting in 2004 and it was disestablished in 2007, due to, among other things, underascertainment of malignant mesothelioma incident cases because of changes in privacy legislation (Macfarlane et al. 2012). A national forum was held in 2009 to discuss options for Australian's mesothelioma surveillance system, including collection of asbestos exposure data for people newly diagnosed with malignant mesothelioma. In July 2010, the Australian Mesothelioma Registry was reestablished

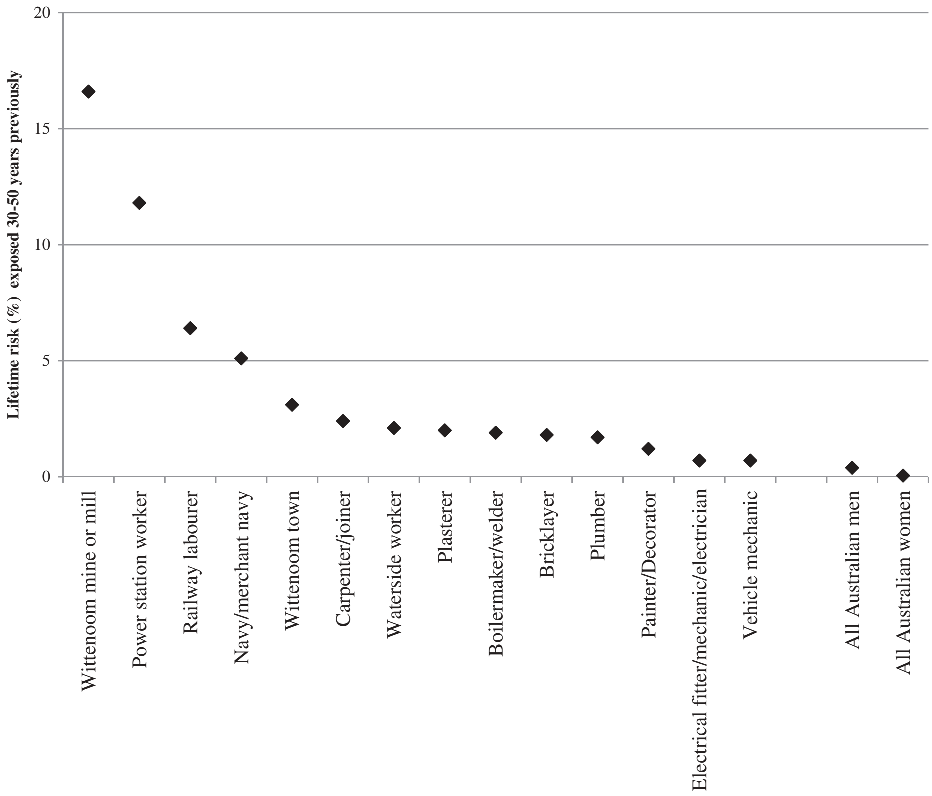

Figure 1. Lifetime risk of malignant mesothelioma in occupational groups exposed 30–50 years previously as approximated by Leigh and Driscoll (2003).

as a consortium arrangement based at the Cancer Institute NSW with Safe Work Australia and academic, cancer registration, and other occupational health and safety groups. The registry was fully in operation by January 1, 2011. The main aims of the Australian Mesothelioma Registry include (1) accurately tracking malignant mesothelioma incidence and survival over time, (2) better understanding the relationship between asbestos exposure and malignant mesothelioma, and (3) identifying changes over time of asbestos exposure patterns in occupational and nonoccupational settings.

Collecting newly diagnosed malignant mesothelioma cases

Through the reestablishment of the Australian Mesothelioma Registry, notification of malignant mesothelioma to state and territory cancer registries is mandatory in Australia. However, there is often a delay of several years in obtaining complete ascertainment of cancer incident cases from state- and territory-based cancer registries. A special arrangement is in place for the Australian Mesothelioma Registry to receive "fast-tracked" notifications of any new confirmed cases of malignant mesothelioma from a state or territory on a regular basis. Individuals diagnosed with malignant mesothelioma are also able to self-notify to the registry, with a self-notification not fully recorded until the relevant cancer registry confirms the case.

Collecting and assigning asbestos exposure data in the Australian Mesothelioma Registry

Detailed methods for the manner in which asbestos exposure data was assigned are published elsewhere (Australian Mesothelioma Registry 2015). Briefly, following the receipt of a confirmed malignant mesothelioma case, each cancer registry contacts the relevant clinician in order to obtain consent to contact the person with malignant mesothelioma. Consent is provided if the subject was diagnosed with malignant mesothelioma from July 1, 2010, is living at the time of the consent being given and is well enough to participate. Once consent is granted, the person with malignant mesothelioma is contacted by the cancer registry to ask for his or her consent to participate in the collection of asbestos exposure data. Each consenting individual is provided with a postal questionnaire relating to his or her asbestos exposure history. Based upon data collected from the postal questionnaire, a tailored telephone interview is then conducted using a Web-based application called OccIDEAS (Fritschi et al. 2009; Macfarlane et al. 2012). All participants, regardless of their occupational history, are asked about asbestos exposure in occupational and nonoccupational environments, including their home renovation activity. Exposure assessment algorithms available in OccIDEAS then determine the likelihood of asbestos exposure in occupational and nonoccupational settings.

For the purpose of the Australian Mesothelioma Registry's public reporting, each person is assigned as having probable, possible, or unlikely asbestos exposure above background exposure levels, with probable exposure further defined into high, medium, and low likelihoods for asbestos exposure. The assessment of asbestos exposure does not account for duration, frequency, or intensity of asbestos exposure. A sequential process is used such that occupational asbestos exposure is first assessed. If it is considered that a subject's occupational asbestos exposure was unlikely, questions regarding that person's nonoccupational asbestos exposure are then initiated. If an individual completed a number of job-specific questions in the same field, then the highest probability of exposure is recorded.

A limitation of the current consent system in the Australian Mesothelioma Registry is the potential for time lags in the process of collecting asbestos exposure data from people newly diagnosed with malignant mesothelioma (Champion De Crespigny et al. 2014). The Australian Mesothelioma Registry is working with cancer registries and clinicians to reduce these time lags.

Overall patterns in incidence and survival

Number of incident cases

During 1982–2011, 13,036 individuals were newly diagnosed with malignant mesothelioma in Australia. A further 778 cases were identified between 1945 and 1981 from retrospective searches and the first 2 years of the Australian Mesothelioma Program. Data reported by the Australian Institute for Health and Welfare of 2009–2011 and the

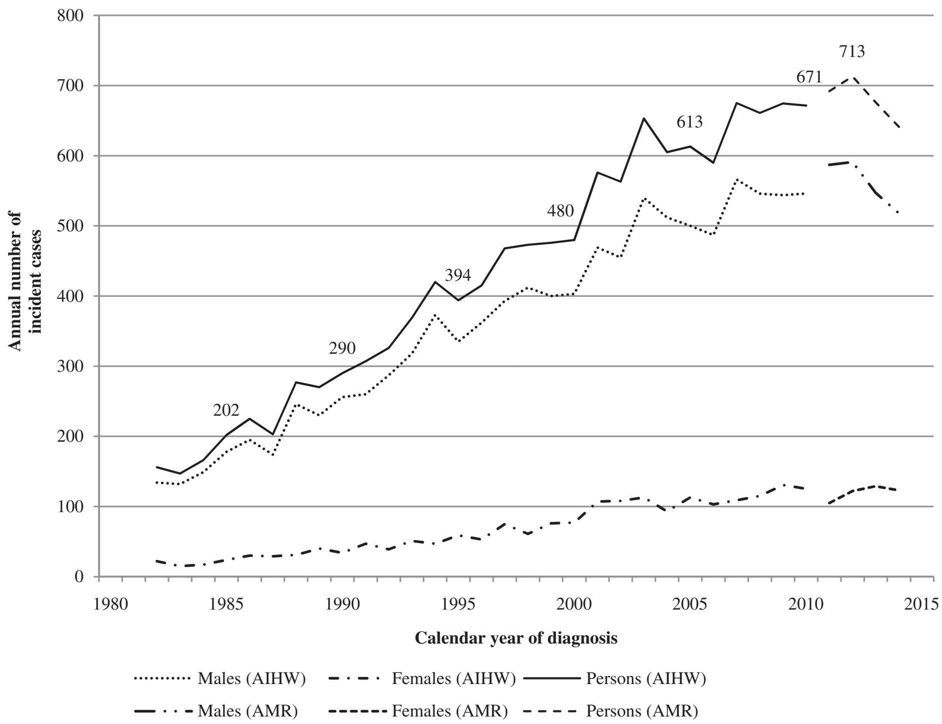

Figure 2. Number of people newly diagnosed with malignant mesothelioma, Australia, 1982–2014, by calendar year of diagnosis. Data for 1982–2010 were extracted from aggregate data published by the Australian Institute of Health and Welfare (AIHW) in 2015. Data for 2011–2014 were extracted from aggregate data published by the Australian Mesothelioma Registry (AMR) in 2015.

Australian Mesothelioma Registry for 2012–2013 are yet to be finalized (Australian Institute of Health and Welfare (AIHW) 2015); however, the number of incident malignant mesothelioma cases appears to have reached a maximum (Figure 2). In 2011, 692 new cases of malignant mesothelioma occurred—a 20% increase in the number of cases recorded in 2001 (n = 576). However, the numbers in 2012 and 2013 were 713 and 676, respectively, suggesting the maximum was attained, even if some late notifications for 2013 are allowed for. The number of incident cases is a useful measure for understanding the burden on health care and occupational compensation systems. However, age-standardized incidence rates are a more useful measure to assess population-level disease burden, as these incidence rates account for changes over time in the composition of the general population.

Incidence rate patterns

Up-to-date data on malignant mesothelioma age-standardized incidence rates, calculated using different age weights, are regularly published by the Australian Institute of Health and Welfare (Australian Institute of Health and Welfare [AIHW] 2015). The most recent data available are for the 1982–2011 period. The age-standardization weights include a national age distribution weight and two international age distribution weights. To assist with interpretation of data, this section presents data using all three weights with the remaining results presented using the Australian Standard Population only. Further, age-standardized mortality rates for malignant mesothelioma are similar in magnitude to incidence rates. This is due to the fact that the majority of individuals with malignant mesothelioma who died in a particular year would have been diagnosed in the preceding 12–24 mo. For this reason, incidence rates are the focus here.

Regardless of the weights used, there was a significant elevation in the age-standardized incidence rate for malignant mesothelioma in Australia from 1982 up to the early 2000s (Figure 3). The highest age-standardized incidence rate during 1982–2011 occurred in 2003, with rates of 3.2, 2.2, and 1.9 per 100,000 using the Australian, WHO, and Segi World standard

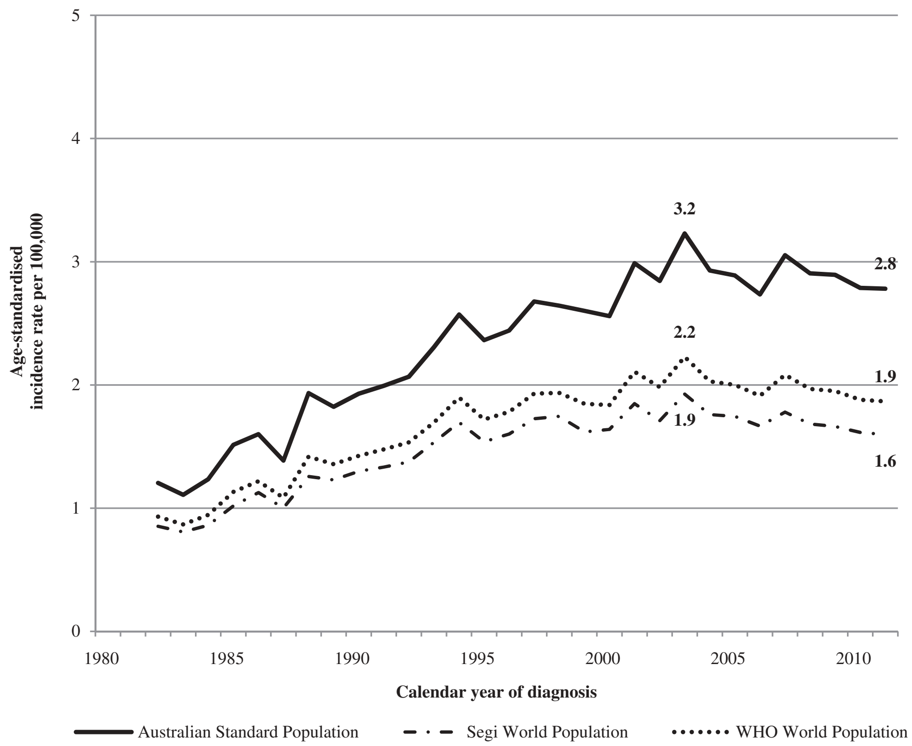

Figure 3. Age-standardized incidence rates per 100,000 person-years for people diagnosed with malignant mesothelioma, Australia, 1982–2011, by calendar year of diagnosis and population standard. Data were extracted from aggregate data published by the Australian Institute of Health and Welfare in 2015.

populations, respectively. The corresponding figures for 2011 are 2.8, 1.9, and 1.6 per 100,000. There appears to be a plateau in the age-standardized incidence rates during 2003–2011.

As of May 2015, the age-standardized malignant mesothelioma incidence rate for 2012 and 2013 reported by the Australian Mesothelioma Registry was 2.8 and 2.6 per 100,000, respectively. However, these data need to be interpreted with some caution as the 2012 and 2013 incidence rates are marginally underestimated due to the length of time between a possible case of malignant mesothelioma being pathologically confirmed in population-based cancer registration systems.

Differences by age group

There are differences in the trajectory of malignant mesothelioma over time by age group (Figure 4). There has been little change over time for the youngest age group, those of age 15–44 years, with an age-specific incidence rate in 2011 of 0.3 per 100,000. The age-specific incidence rate for subjects 55–64 years of age peaked in 1998, a rate of 7 per 100,000, with a slow, steady decline with a rate of 4 per 100,000 in 2011. For individuals of age 65–74 years, incidence leveled off since 1997, where the age-specific incidence rate remained between 13 and 14 per 100,000. The steep increase in the age-specific incidence rates for the oldest two age groups is such that there has been a convergence in the age-specific incidence rates for people of age 75–84 years and those 85 years and older. In 2011, the age-specific incidence rate for subjects of age 75–84 years was 22.2 per 100,000 with a similar figure (22.4 per 100,000) for individuals 85 years or older. Notably, the age-specific incidence rate for people age 85 years or older doubled since 1997 (9.9 per 100,000).

Differences by gender

There have also been different trajectories of malignant mesothelioma incidence rates in Australia by gender (Figure 5). There was a marked increase in the male age-standardized incidence from 1982 up to the early 2000s. During 1982–2011, the highest age-standardized incidence

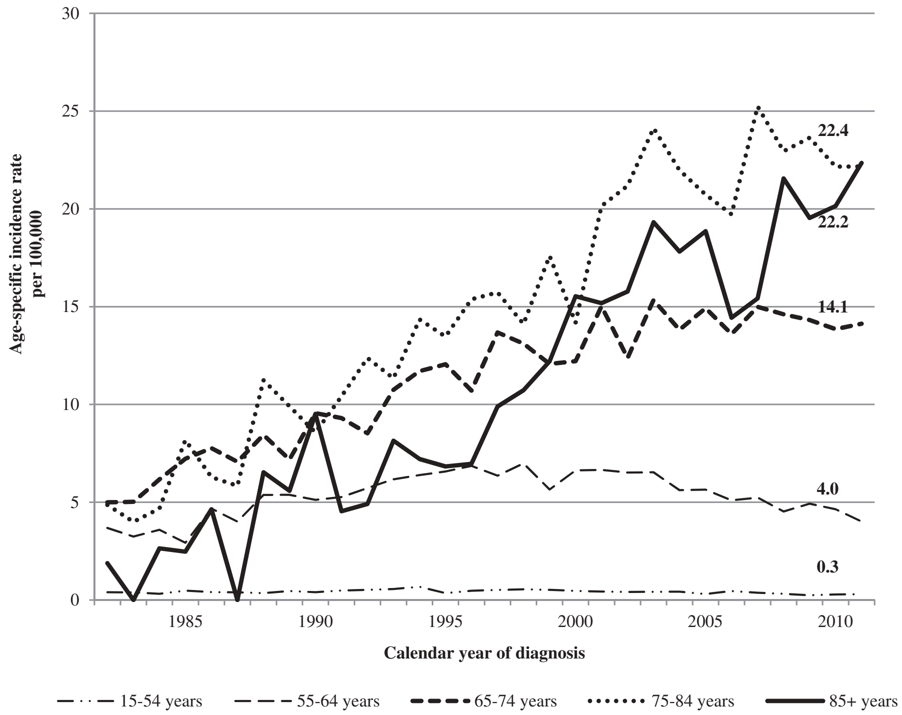

Figure 4. Age-specific incidence rates per 100,000 for people ages 15–99 years who were diagnosed with malignant mesothelioma in Australia, 1982–2011, by calendar year of diangosis. Age-specific incidence rates were calculated using aggregate data published by the Australian Institute of Health and Welfare in 2015.

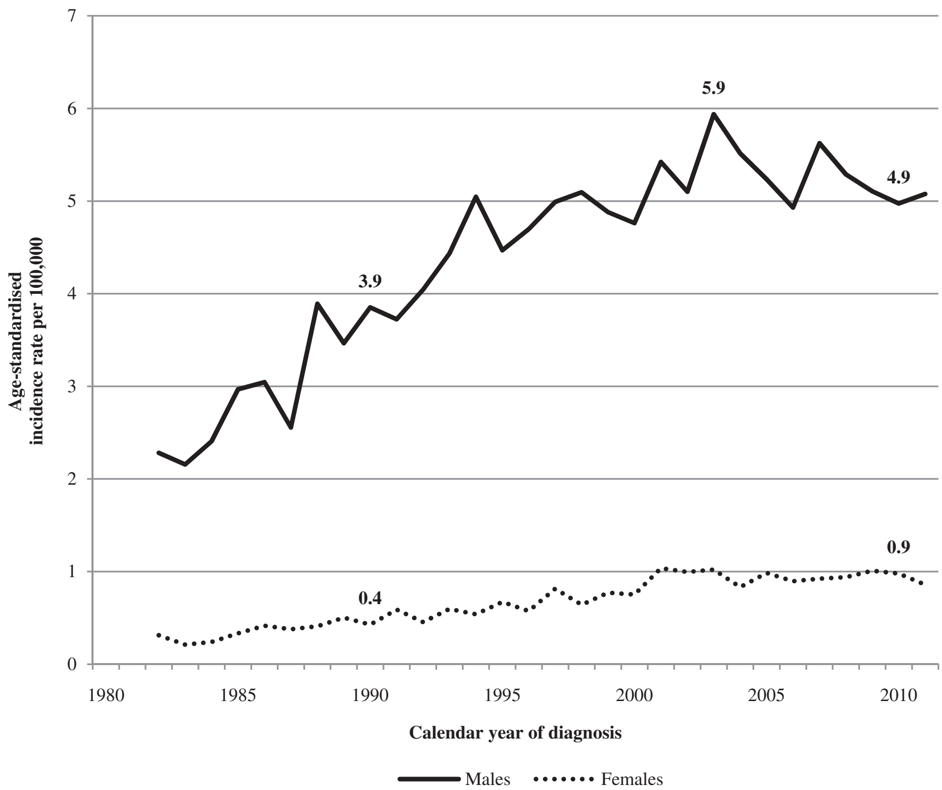

Figure 5. Age-standardized incidence rates per 100,000 for men and women who were diagnosed with malignant mesothelioma in Australia, 1982–2011, by calendar year of diagnosis. Age-specific incidence rates were calculated using aggregate data published by the Australian Institute of Health and Welfare in 2015.

rate for men was in 2003, a rate of 5.9 per 100,000, with the rate stabilizing around 5 per 100,000 since that time point. Although the burden of malignant mesothelioma in Australia primarily affects men, a slow, steady rise in female age-standardized incidence rate was also observed. In 1990, the rate for females was 0.43 per 100,000 with a doubling of the rate in 2010, a rate of 0.98 per 100,000. One way of describing the different disease trajectories by gender is to examine absolute and relative differences between male and female rates. Between 1990 and 2010, absolute difference between the two rates remained stable with an absolute difference between male and female rates of between 3 and 4. A simple calculation of relative differences comparing male to female incidence rate, a ratio of the two rates, shows a narrowing of the relative difference during 1990–2010. This ratio was 9 in 1990 (the relative difference between 3.9 per 100,000 rate for men and 0.4 per 100,000 rate for women) and reduced to 5 in 2010 (4.9 per 100,000 for men and 0.98 per 100,000 for women).

Differences in incidence by jurisdiction

During 2003–2007 (Figure 6), incidence rates were highest in Western Australia (4.5 per 100,000), with New South Wales, Queensland and South Australia displaying rates of approximately 3 per 100,000 and rates of between 2 and 2.9 per 100,000 in the remaining states and territories (Australian Capital Territory, Northern Territory, Tasmania, and Victoria).

The highest age-standardized malignant mesothelioma incidence rates occurred in Western Australia (Figure 6). However, a consistent pattern is emerging of these rates declining over time. The age-standardized incidence rate for Western Australia during 1993–1997 was 5.2 per 100,000, compared to 4.7 per 100,000 during 1998–2002 and 4.5 per 100,000 in 2003–2007. The finite nature of Western Australia's malignant mesothelioma incidence was also described by Musk and colleagues (2015). The incidence rates have been stable over time in New South Wales and Victoria. A recent study published using individual unit record malignant mesothelioma data from the NSW Central Cancer Registry during 1972–2009 also demonstrated stabilization in age-standardized rates but an increase in the annual number of malignant pleural mesothelioma cases (Soeberg et al. 2015). Notably, there was little change over time in the incidence of malignant peritoneal mesothelioma over the 38-yr period, with age-standardized incidence rates ranging between 0.1 and 0.2 per 100,000 person-years. The point estimates for Tasmania appear to have increased over time but with wide confidence intervals. Incidence rates for Queensland and South Australia rose in 1998–2002 with a small decline in the most recent period (2003–2007). Smaller case numbers in the Australian Capital Territory and the Northern Territory make meaningful interpretation of these data more difficult. Continuous monitoring of these geographic differences in the age-standardized incidence rates, particularly the fall in incidence in Western Australia, might provide important information for understanding the future trajectory of malignant mesothelioma in Australia.

Changes over time in survival

There have been small improvements in survival 1 yr following a malignant mesothelioma diagnosis, particularly in the most recent calendar period (Figure 7). One-year relative survival in 2006–2010 was 44.3, compared to 36.9% in 1994–1999. However, there has been little change over time in 5-yr relative survival (Figure 7). During 1982–1987, 5-yr relative survival was 5.5%, similar to the estimate for 2006–2010, 6.2%.

Small improvements in 1-yr relative survival are most likely explained by earlier and more accurate diagnosis, including greater ability to detect histological subtypes, as well as potentially the role of radical surgical treatment recommended for a number of patients based upon age, gender, patient performance, histological subtype, and presence of other comorbidities (Cao et al. 2011a; 2011b; Linton et al. 2014). Improvements in chemotherapy may also explain changes over time in 1-yr relative survival shown here. Pemetrexed, in combination with cisplatin, was found to increase survival rates (Fennell et al. 2008). However in Australia, pemetrexed for patients with malignant pleural mesothelioma was not widely available until 2008. This investigation presents case data only up to the end of 2010 and capturing only

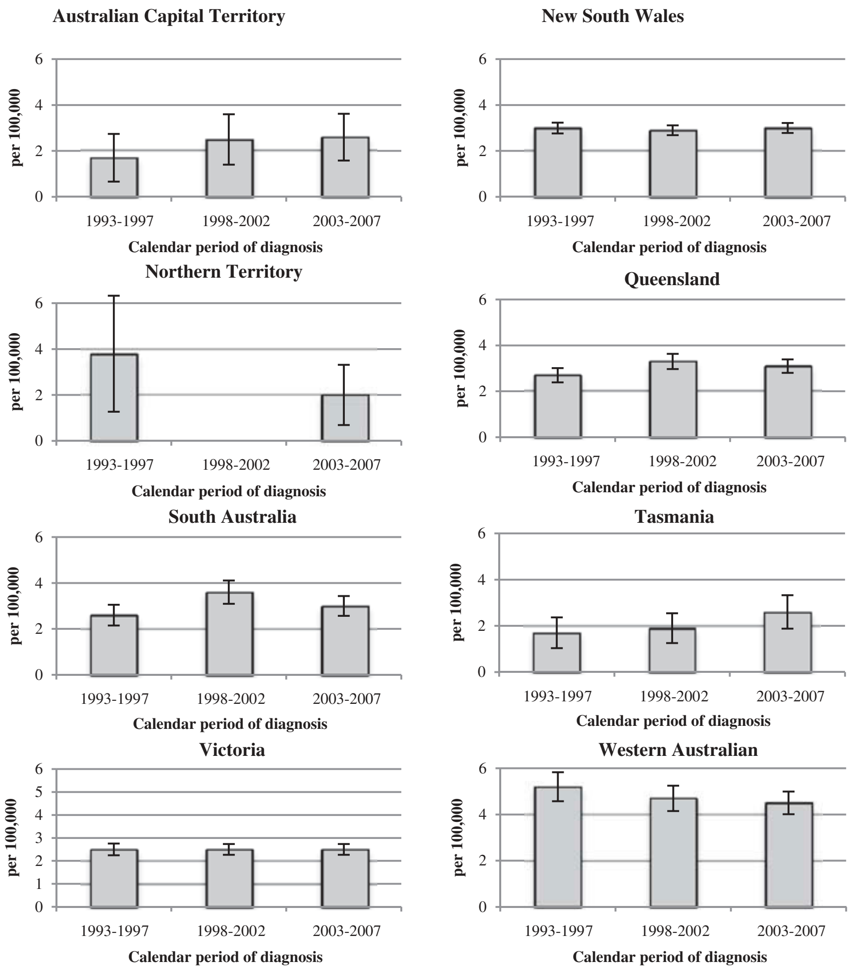

Figure 6. Age-standardized incidence rates for men diagnosed with malignant mesothelioma, Australia 1993–2007, by jurisdiction and calendar period of diagnosis. Data were extracted from aggregate data published by the International Agency for Research on Cancer in volumes 8–10 of the *Cancer Incidence in Five Continents* reports.

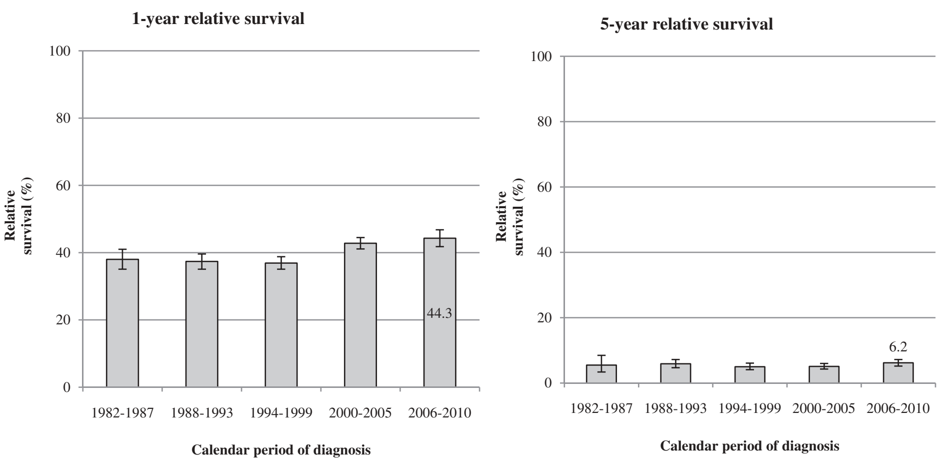

Figure 7. One-year and five-year relative survival ratios with 95% confidence intervals for people diagnosed with malignant mesothelioma, Australia, 1982–2010, by calendar period of diagnosis. Data were extracted from aggregate data published by the Australian Institute of Health and Welfare in 2012.

2 yr of data since the time when pemetrexed was made widely available. More recent data (with completed mortality follow-up data) would be required to test whether survival improvements are noted following introduction of pemetrexed, as investigated, for instance, in the Netherlands (Damhuis, Schroten, and Burgers 2012).

Use of aggregate compared to individual unit record data

These aggregate incidence and survival data provide an important basis for understanding overall patterns of malignant mesothelioma. However, deidentified individual unit records are a more valuable data source for quantifying temporal trends and survival by various patient and tumor factors. Data suggest that the magnitude in changes over time in incidence of malignant mesothelioma varies by age group and tumor location. A descriptive epidemiology study from the United States by Moolgavkar, Meza, and Turim (2009) depicted a significant increase over time in the age-standardized incidence rate for men diagnosed with malignant pleural mesothelioma during 1973–2005, with little alterations over time in the female incidence rate. Moolgavkar, Meza, and Turim (2009) reported no marked change in incidence of malignant peritoneal mesothelioma during the same calendar period of diagnosis. It is worthwhile noting that these data presented by Moolgavkar, Meza, and Turim (2009) were extracted from cancer registration data sources that represent approximately 14% of the total cancer cases recorded in the United States. In Australia, however, the male peritoneal mesothelioma rate was elevated approximately fivefold between 1982–1988 and 2002, and female peritoneal mesothelioma rate rose approximately twofold. Overall the peritoneal mesothelioma rate increased approximately 4-fold (National Occupational Health and Safety Commission (National Institute of Occupational Health and Safety) 1989–2004). Diagnostic accuracy is an important source of potential bias in ascertaining malignant peritoneal mesothelioma cases from registry data, as they may be misdiagnosed as malignancies in other abdominal organs, for example, the ovary (Nielsen et al. 1994). It is also possible that malignant peritoneal mesothelioma is diagnosed more commonly among subjects with known prior asbestos exposure (Boffetta 2007). Further, the best available evidence to date suggests that exposure to asbestos has a causal association with malignant peritoneal mesothelioma but that this relationship is weaker than for malignant pleural mesothelioma (Cocco and Dosemeci 1999; Coggon et al. 1995; Hodgson and Darnton 2000). Other etiological factors also cannot be excluded for their association with malignant peritoneal mesothelioma, including exposure to erionite (Baris et al. 1981; 1987), ionizing radiation (Andersson et al. 1995), simian virus 40 (Shivapurkar et al. 2000), and chronic pancreatitis (Peterson, Greenberg, and Buffler 1984). The strength of the evidence for these other factors is more limited. Further, symptoms of malignant peritoneal mesothelioma are generally nonspecific and might include increased abdominal girth, pain, and weight loss (Sugarbaker et al. 2002; Turner, Varghese, and Alexander 2012).

Recently individual-level data were obtained from the Australian Institute of Health and Welfare and the Australian Mesothelioma Registry for people diagnosed with malignant mesothelioma in Australia during 1982–2012. Data were analyzed on 10,930 individuals with malignant pleural mesothelioma and 640 subjects with malignant peritoneal mesothelioma diagnosed in Australia during 1982–2009 (Soeberg et al. 2016). Trends over time were measured in age-standardized incidence rates, and a rapid decline was found in these rates among men diagnosed with malignant pleural mesothelioma of ages 0–64 years during 2003–2009, an average annual change of −5.1%. This was in contrast to the increase over time in the age-standardized incidence rate among men aged 75 years or more with malignant pleural mesothelioma. Age-specific incidence rates were also projected for malignant mesothelioma in Australia up to 2030 using age-period-cohort modeling. Overall, it was concluded that Australia's malignant mesothelioma incidence rates appears to have reached maximal levels but with differences over time by age, gender, and tumor location. In particular, a rise up to 2020 is projected for malignant pleural mesothelioma in men of age 75 years or older. In addition, there may be an increase in age-specific incidence rates up to 2025 among men of age 65 years or older diagnosed with malignant peritoneal mesothelioma. Large survival differences were also observed by histological subtype among individuals diagnosed with malignant mesothelioma. Continuous tracking of these population-level malignant mesothelioma data may contribute to the understanding of the curve of the asbestos-related disease epidemic in Australia, as well as assisting in the evaluation of the implementation of recently published Australian guidelines for diagnosis and treatment of malignant pleural mesothelioma (van Zandwijk et al. 2013).

Overall patterns in asbestos exposure

Between July 1, 2010, and April 1, 2015, in total, 449 people were recorded on the current Australian Mesothelioma Registry as having completed both postal questionnaires and telephone interviews (Table 1). The majority of subjects were assessed as having probable or possible occupational asbestos exposure (n = 268, 60%). Of the occupational asbestos categories, 88 individuals were assessed as having a high probability that their asbestos exposure occurred in construction jobs, for example, as a carpenter, joiner, builder, or bricklayer. The next largest job category where asbestos exposure was highly probable was metal and mechanical trades (n = 48), including jobs such as fitters, turners, and machinists. This was followed by other job types (not specified, n = 27) and electricians (n = 25). It is noteworthy that all boilermaker and welding cases (n = 21) were considered to have had probable asbestos exposure, with all cases categorized as high likelihood. A similar pattern occurred for plumbers, with all but one case being categorized as having highly probable asbestos exposure in this job (n = 18). Sparse data for engineers and telecommunication technicians make meaningful interpretation more difficult.

All of the 449 participants in the Australian Mesothelioma Registry received an asbestos exposure module to assess their nonoccupational asbestos exposure, including those individuals who were assessed for occupational asbestos exposure. From these data, 377 participants were reported as having possible or probable asbestos exposure in nonoccupational settings, with the remaining 72 cases assessed as not having possible or probable asbestos exposure above background levels. Fifty-five subjects reported ever living in a house made mainly of asbestos cement sheeting (referred to in Australia as "fibro") that was built between 1947 and 1987. Further information regarding occupational and nonoccupational asbestos exposure categories may be found at https://www.mesothelioma-australia.com. While these data are informative, an important consideration when interpreting these data is the extent to which they are considered representative of the entire malignant mesothelioma case series as recorded by the current Australian Mesothelioma Registry (n = 2,722). A comprehensive interpretation of the Australian Mesothelioma Registry asbestos exposure data needs to include consideration of asbestos exposure data collected through the Australia Mesothelioma Register and the Australian Mesothelioma Surveillance Program, as well as state-based data collections including the Western Australian Mesothelioma Registry and malignant mesothelioma data from the NSW Dust Diseases Board (recently renamed to the Dust Diseases Authority).

Subnational data collections

In addition to national data collections, there are also state-based data collections that contain important information regarding asbestos exposure and its role as an etiological factor and as a prognostic factor (de Klerk et al. 2013; Kao et al. 2013a; 2013b; Olsen et al. 2011; Park et al. 2013; Robinson et al. 2014; van Oyen et al. 2015). These data collections are primarily held in Western Australia and New South Wales—states with known high levels of asbestos mining and production of asbestos-containing products. An important advantage of use of these state-based data sets is that clinical data are also often collected, making data more amendable to comprehensively investigating various prognostic factors additional to data fields more traditionally collected in population-based cancer registries. Linton et al. (2014) utilized comprehensive data on participants who developed malignant pleural mesothelioma as a result of asbestos exposure during their employment in New South Wales collected by the Workers' Compensation Dust Diseases Board (DDB). The investigators were able to incorporate asbestos exposure data, namely, age at first asbestos exposure, into univariate and multivariate analyses to investigate prognostic factors for longer term malignant pleural mesothelioma survival. These compensation-based data also contained additional data regarding asbestos exposure that may be used in the future in conjunction with recently published job–exposure matrices developed in Australia (van Oyen et al. 2015). This job–exposure matrix identified that the highest exposures occurred in shipyard, wharf, navy, marine, carpentry, joinery, boiler making or welding, power, railway, and insulation workers, and were classified corresponding to the highest lifetime risks calculated from mesothelioma register data (Leigh and Driscoll 2003).

Conclusions

In this paper, descriptive epidemiological data were presented from two high-quality national cancer registration data sources—the Australian Cancer Database and the Australian Mesothelioma Registry. From these data, it can be determined that the annual number of malignant mesothelioma cases and the age-standardized malignant mesothelioma incidence rate reached a maximum, as predicted in 1997 by Leigh, Hull, and Davidson (1997). In addition, subnational variations were found in the incidence of malignant mesothelioma with declines in Western Australia's age-standardized incident rate occurring over time but little change for other states, including New South Wales, Queensland, and Victoria. Marked increases were noted over time in age-specific incidence rates for people aged 75 years or greater and a decline in the age-specific incidence rate in the last 10–15 years for younger age groups. Using population-based survival analyses, little change was found over time in survival 5 years following a malignant mesothelioma diagnosis. While these data provide important information, more granular investigation of patterns is warranted. For instance, it is likely that there are different disease trajectories by tumor location, namely, pleural and peritoneal mesothelioma, and that survival outcomes are likely to differ by age group, gender, and histological subtype.

Using data from the Australian Mesothelioma Registry, it was demonstrated that the majority (60%) of individuals who had asbestos exposure data recorded between July 1, 2010, and April 1, 2015, were exposed in occupational settings. Of the 449 cases where asbestos exposure was recorded, 377 people were classified as having probable or possible nonoccupational asbestos exposure. However, this figure is inclusive of those participants who were also classified as having occupational asbestos exposure ($n = 268$). Collecting accurate and timely information with respect to prior asbestos exposure for people newly diagnosed with malignant mesothelioma is an essential task of the Australian Mesothelioma Registry and may help answer important public health research questions regarding the subpopulation groups most affected by asbestos-related disease and the targeting of current and future prevention interventions. An important challenge for the Australian Mesothelioma Registry, and its consortium partners, is how to elevate the proportion of newly diagnosed malignant mesothelioma cases whose asbestos exposure histories are documented.

The epidemic of malignant mesothelioma continues to remain an important public health and clinical challenge in Australia. Simultaneous consideration of descriptive epidemiological data, including patterns by tumor location, age, gender, and histological subtype, as well as occupational and nonoccupational asbestos exposure data, has the potential to provide meaningful interpretation of the trends in asbestos-related diseases in Australia.

Conflict of interest

None.

Notes on contributor

M.S. was the primary author of the article, with J.L. and N.v. Z. contributing content on epidemiological exposure data and clinical and treatment aspects, respectively. All authors revised the article for intellectual content.

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