Environmental asbestos exposure sources in Korea

Dong-Mug Kang1,2, Jong-Eun Kim2, Ju-Young Kim3,2, Hyun-Hee Lee1, Young-Sik Hwang2, Young-Ki Kim1,2, Yong-Jin Lee3

1Occupational and Environmental Medicine, Pusan National University Yangsan Hospital Environmental Health Center for Asbestos, Yangsan-si, South Korea, 2Preventive and Occupational Medicine, School of Medicine, Pusan National University, Yangsan-si, South Korea, 3Asbestos Environmental Health Center, SoonChunhyang University Hospital Cheonan, Cheonan-si, South Korea

Background: Because of the long asbestos-related disease latencies (10–50 years), detection, diagnosis, and epidemiologic studies require asbestos exposure history. However, environmental asbestos exposure source (EAES) data are lacking.

Objectives: To survey the available data for past EAES and supplement these data with interviews.

Methods: We constructed an EAES database using a literature review and interviews of experts, former traders, and workers. Exposure sources by time period and type were visualized using a geographic information system (ArcGIS), web-based mapping (Google Maps), and OpenWeatherMap. The data were mounted in the GIS to show the exposure source location and trend.

Results: The majority of asbestos mines, factories, and consumption was located in Chungnam; Gyeonggi, Busan, and Gyeongnam; and Gyeonggi, Daejeon, and Busan, respectively. Shipbuilding and repair companies were mostly located in Busan and Gyeongnam.

Conclusions: These tools might help evaluate past exposure from EAES and estimate the future asbestos burden in Korea.

Keywords: Modeling, Spatial, Temporal, GIS, Mapping, Reconstruction, Past

Introduction

Asbestos is designated as a Group 1 carcinogen by the International Agency for Research on Cancer.1 Asbestos causes asbestos-related diseases (ARDs) including malignant diseases such as malignant mesothelioma (MM), lung cancer, laryngeal cancer, and ovarian cancer as well as benign diseases such as asbestosis, pleural plaque, and pleural thickening.1 The number of MM cases in Korea has risen since 2001,2 and environmentally compensated cases of MM have rapidly increased since 2011 after the Asbestos Damage Relief Act (ADRA), which compensates environmental asbestos victims in Korea.3

Because ARDs have long latencies (10–50 years), recent health problems might be caused by past asbestos exposure.4 ARDs caused by environmental asbestos exposure sources (EAES) have a longer latency period than those caused by occupational asbestos exposure.5 Therefore, individuals, mainly those older than 60 years, who have been compensated by the ADRA might have been exposed to asbestos in their childhood.6 To determine the cause, health specialists involved with ARDs need to be aware of past EAES. Data regarding past EAES can provide not only epidemiological causal relationships at a national level, but also helpful information for individual treatment plans for patients at the clinical level.

EAEs data in Korea are very limited.7 Because the main time period of asbestos use was 1970 through the early 1990s, when asbestos was used for national industrialization and roof renovation, it is difficult to find data. Furthermore, the majority of asbestos-producing companies are small and do not have accurate records of production data. The purpose of this study was to survey the available data for past EAES and supplement these data with interviews.

Materials and methods

Study scope

The territory of North Korea was excluded. Asbestos source data were collected for the years 1935, which is suspected as the beginning of asbestos production in asbestos mines,7 to 2010, just after the asbestos ban in 2009. The study period was 2007–2014.

Literature review

We conducted a broad literature review, from publications of the Japanese Government-General of Choson to recent
academic publications, reports, newspaper articles, and Internet-based advertisements. The inclusion criterion for the literature review was asbestos source data (factory, mine, shipyard, ship breaking and/or repair, steel mill, petrochemical plant, electric power plant, and town redevelopment area) that had an address, production amount, and/or operational period.

The search for international journals published up to 31 December 2013 was conducted using PubMed with the terms “asbestos and Korea.” Of the 73 papers retrieved, one article was excluded because it lacked information regarding the name, address, and operational period of the asbestos factories.8

For the systematic literature review of Korean journals, books, and scientific publications, the search was conducted using the search term which was “asbestos” in the Korean language in the Research Information Sharing Service (www.riss.kr) provided by the Korea Education and Research Information Service. The 2,655 results included 273 theses, 609 journal publications, 1,700 books, and 73 reports. Of the theses and journal papers, one publication was retrieved that initiated this study.7 We searched for governmental reports in the national library of Korea (www.nl.go.kr/). The web pages of each industrial association were searched for member status information for shipyards, ship repairs, steel mills, chemical complexes, and power plants. The major literature sources are listed in Table 1.

Interviews
Because accurate and complete records do not exist in Korea, we conducted interviews of former asbestos import and distribution dealers, former asbestos workers, and patients with ARD to verify the company name, location, production amount, and operational period in the author-gathered EAES data, which were provided to the interviewees. In addition, we attempted to find information that was missing from the literature review. As a result, the interviews primarily collected information regarding operational period and production amount. Furthermore, information regarding asbestos shipping and cargo handling was collected through interviews of former workers and residents in the relevant areas.

The two major dealers who managed almost all of the imported raw asbestos material were interviewed twice. In addition, because the ADRA has compensated patients with ARDs caused by environmental exposure since 2011, the authors reviewed the 525 cases of compensated asbestos victims from 2011.3 There are two environmental health centers for asbestos (EHCA) designated by the Ministry of Environment of Korea: SoonChunHyang EHCA, which focuses on asbestos mines in central and western Korea (Seoul, Gyeonggi, Incheon, Daejeon, Chungbuk, and Chungnam), and Pusan National University Yangsan EHCA, which focuses on asbestos factories in southern and Eastern Korea (Daegu, Gyeongbuk, Busan, Ulsan, Gyeongnam, Gwangju, Jeonbuk, Jeonnam, and Jesu). Since 2011, two EHCAs have conducted health impact assessments of asbestos by each annually surveying approximately 2,000 people who had lived near former asbestos mines or factories; occupational and environmental asbestos exposure history was collected to detect ARDs. The authors analyzed the questionnaires from 2011 to 2013, resulting in data for approximately 12,000 people.

Interviews were conducted with 25 patients with ARD who visited the Yangsan EHCA for the purpose of compensation. Also, approximately 20 former asbestos miners were interviewed by the SoonChunHyang EHCA, and approximately 70 former asbestos workers were interviewed by the Yangsan EHCA. To correct the EAES information and geocode the EHCA location on the geographic information system (GIS) map, two experts who were chief executives of the Korea Land & Housing Corporation were interviewed.

Spatiotemporal visualization
Exposure sources by period and type were visualized using ArcGIS (ESRI, Redlands, CA, U.S.A). Web-based mapping was conducted using Google Maps (Google, Inc., Mountain View, CA, U.S.A) and the open application programming interface OpenWeatherMap (Mountain View, CA, U.S.A).

Results
EAES data by information source
Of the 1,483 EAES, 42 were asbestos mines, 199 were asbestos factories, and 17 were asbestos processing plants. The majority of the data for mines was gathered from the Ministry of Environment (n = 38), the majority of the data for factories was from the Ministry of Labor (n = 81), and the majority of data for shipbuilding, ship repairs, and steel mills were collected from membership information of the related industrial associations (Table 2). All of the data for town redevelopment were obtained from the literature.

Spatiotemporal distribution
Table 3 shows the regional distribution of the EAES according to source type: asbestos mines, mills, factories (including textile, construction material, and other factory types), shipbuilding and repair companies, steel mills, chemical complexes, power plants, shipping areas, and town redevelopment areas. The number of asbestos mines was highest in Chungnam (n = 29). Asbestos factories were located in Gyeonggi (n = 40), Busan (n = 39), and Gyeongnam (n = 24). Shipbuilding and repair companies were concentrated in Busan (n = 370), Gyeongnam (n = 68), and Jeonnam (n = 43). Town redevelopment areas were distributed in Seoul (n = 248), Daegu (n = 48), and Busan (n = 46) (Table 3).

Regional asbestos consumption is shown in Table 3. Of 2,719,241 tons in total, approximately 417,824 tons (15.2% of total consumption) of asbestos were mined, and
approximately 2,324,439 tons (84.8% of total consumption) were used in factories (Table 4).

Asbestos was mined by 42 mines (mean 9,949 tons) and used by 199 factories (mean 11,686 tons) (Table 4). The two asbestos mines with the greatest output were Gwangcheon mine located in Hongseong-gun Gwangcheon-eup Sangjung-ri (190,379 tons) and Hongseong mine located in Hongseong-gun Guhang-myeon Cheonggwang-ri (83,617 tons). The two asbestos factories with the greatest output were KCC in Suwon City Seodun-dong (1,035,742 tons) and Byucksan in Daejeon City Taepyeong-dong (568,933 tons). Detailed data are listed on the homepage of the Environmental Health Center on Asbestos.

EAES are mapped in Figures 1 and 2. Asbestos mines and mills were concentrated in Chungnam, located in direction from west to east. Asbestos factories were concentrated in the capital areas and Busan, Gyeongnam, and Daegu, located in the direction of the Gyeong-Bu line. Shipbuilding and repair companies were concentrated in Ulsan, Busan, Jinhae, and Geoje in the Dongnam industrial belt.

Figure 2 shows the EAES according to time period. Asbestos has been mined since the 1930s, peaked in the 1970s, and then rapidly decreased until 2006 owing to the exhaustion of asbestos veins and the increase in labor costs, which resulted in increased importing of asbestos. Asbestos textile factories were operated in the Busan and Gyeongnam area from 1969 until the late 1990s. Friction materials were produced in Daegu-Gyeongbuk and new industrial cities in the capital area. Production of construction materials such as asbestos slate began in Yongsan (Seoul) in 1929 and later expanded to Suwon and Daejeon. Asbestos was also used in shipbuilding (Figure 2).

**Discussion**

Evaluation of past asbestos exposure is crucial for ARDs because of their long latencies. However, there are limited data regarding past exposure in Korea. In the present
Table 2  Information sources, research methods, and exposure data by industry

| Source                                                                 | Method                  | Mine | Factory |
|-----------------------------------------------------------------------|-------------------------|------|---------|
| Status of asbestos mines (Ministry of Environment)                    | Literature review       | 38   |         |
| Status of asbestos mines (SoonChunHyang Environmental Health Center for Asbestos) | Literature review       | 2    | 1       |
| Asbestos mines (Ministry of Commerce and Industry)                    | Literature review       | 2    | 3       |
| Company lists of asbestos manufacturing licenses (Ministry of Labor)  | Literature review       | 81   |         |
| Handbook of industrial complex (Korea Industrial Complex Corporation) | Literature review       | 57   |         |
| Survey and database implementation for asbestos-contained materials (Korea Occupational Safety & Health Agency) | Literature review       | 26   |         |
| Status of the national urban renewal redevelopment (Korea Land & Housing Corporation) | Literature review       | 236  |         |
| Fact sheet of redevelopment and reconstruction (Minister of Land, Infrastructure and Transport) | Literature review       | 176  |         |
| Environmental status report around national asbestos mines (Ban Asbestos Network Korea) | Literature review       | 2    |         |
| Dealers                                                               | Interview               | 13   |         |
| Patients                                                              | Interview               | 2    | 15      |
| Asbestos Damage Relief Act                                            | Questionnaire           | 11   | 16      |
| Health impact assessment                                              | Questionnaire           | 4    | 3       |
| Related industry association                                          | Search of homepages     |      |         |
| Total                                                                 |                         | 42   | 199     | 17      | 23      | 540     | 75      | 94      | 77      | 4       | 412     | 1483    |
Asbestos import statistics are available from 1975, when 74,206 tons were reportedly consumed, suggesting that the amount of imports before 1975 could be considerable. We attempted to gather all possible data and validate those data by interviewing individuals who could recall the situation in the past, which might have reduced the estimation errors that occurred in previous studies. However, it is possible that all of the literature, and formal and informal data were not included. The mined asbestos data in this study had been validated by government officials from the Ministry of Environment and municipal governments through field surveys, which provided additional previous data. Furthermore, more recent factory data had been added to the literature review through the study, in addition to gathering available EAES by literature review and interviews, the database was mounted in GIS for use by clinicians, epidemiologists, and environmental health experts. The total asbestos consumption in this study was 2,719,241 tons, including 417,842 tons of mined asbestos and 2,324,439 tons of asbestos used in factories. In comparison, a previous study in Korea estimated a total of 2.0–2.2 million tons, including 145,000 tons of mined asbestos and 1,698,188 tons of imported asbestos.7,9 There are several possible explanations for the higher estimate in the present study. First, raw materials from mines and imports that undergo an initial production process might be used again to make a second product, which could result in double counting. However, underestimation is also possible. Asbestos import statistics are available from 1975, when 74,206 tons were reportedly consumed, suggesting that the amount of imports before 1975 could be considerable. We attempted to gather all possible data and validate those data by interviewing individuals who could recall the situation in the past, which might have reduced the estimation errors that occurred in previous studies. However, it is possible that all of the literature, and formal and informal data were not included. The mined asbestos data in this study had been validated by government officials from the Ministry of Environment and municipal governments through field surveys, which provided additional previous data. Furthermore, more recent factory data had been added to the literature review through the...
Kang et al. Environmental asbestos exposure sources in Korea

The incidence of MM in Korea is very low, approximately two cases per million people per year (approximately 100 cases among a population of 50 million), compared with that in industrialized countries (14–35 cases per million people per year). Whereas Korea used asbestos at a rate of 4.0–5.6 kg per capita per year according to this study, industrialized countries used asbestos at 2.0–5.5 kg per capita per year approximately 25 years before the increase in the MM incidence. Hence, we could expect a trend of increasing MM in Korea until it is 5–10 times higher than the present level. In other words, assuming at least one MM for every 170 tons of asbestos consumption and considering the 2.0–2.8 million tons of asbestos consumed in Korea, we could expect 11,765–16,471 total MM cases. Because asbestos causes at least a two-fold higher incidence of lung cancer than MM, the ARD incidence will be much higher when all ARDs are considered.

It is estimated that more than 107,000 people die each year from ARDs resulting from exposure at work. Although this estimate is focused on occupational exposure, the actual incidence of ARDs, including those caused by environmental exposure, might be higher. ARDs caused by asbestos from various environmental sources including mines, factories, shipyards, and power plants have been studied in other countries. The validation process. Despite these efforts to reduce errors, this study depended on limited data and memory, limiting the accuracy and validity and potentially either under or overestimating the results. For example, if the majority of the records and recall was restricted to relatively large facilities, this study could underestimate the real situation. However, the potential double counting already described could result in overestimation. Hence, the possible asbestos consumption in Korea, including mined and imported asbestos, might be 2.0–2.8 million tons.

It is estimated that more than 107,000 people die each year from ARDs resulting from exposure at work. Although this estimate is focused on occupational exposure, the actual incidence of ARDs, including those caused by environmental exposure, might be higher. ARDs caused by asbestos from various environmental sources including mines, factories, shipyards, and power plants have been studied in other countries. The incidence of MM in Korea is very low, approximately two cases per million people per year (approximately 100 cases among a population of 50 million), compared with that in industrialized countries (14–35 cases per million people per year). Whereas Korea used asbestos at a rate of 4.0–5.6 kg per capita per year according to this study, industrialized countries used asbestos at 2.0–5.5 kg per capita per year approximately 25 years before the increase in the MM incidence. Hence, we could expect a trend of increasing MM in Korea until it is 5–10 times higher than the present level. In other words, assuming at least one MM for every 170 tons of asbestos consumption and considering the 2.0–2.8 million tons of asbestos consumed in Korea, we could expect 11,765–16,471 total MM cases. Because asbestos causes at least a two-fold higher incidence of lung cancer than MM, the ARD incidence will be much higher when all ARDs are considered.
A lack of data regarding EAES in Korea has made it difficult to determine exposure sources for epidemiologic studies or clinical purposes for individual patients. The results of this study might be helpful for researchers and clinicians. Because the basic information we evaluated, such as location, operational period, and amounts, is insufficient to estimate past exposure, further studies on emission rates from exposure sources and ambient air concentrations are necessary. This study and further studies on environmental asbestos exposure might be helpful for both evaluating past asbestos exposure and estimating future asbestos burden.

**Disclosure statement**
No potential conflict of interest was reported by the authors.
References

1 International Agency for Research on Cancer (IARC) [Internet]. IARC monographs volume 100C asbestos (chrysotile, amosite, crocidolite, tremolite, actinolite, and anthophyllite) [cited 2015 Feb 5]. Available from: mono-graphs.iarc.fr/ENG/Monographs/vol100C/ mono100C-11.pdf
2 Jung SH, Kim HR, Koh SB, Yong SI, Chung MJ, Lee CH, et al. A decade of malignant mesothelioma surveillance in Korea. Am J Ind Med. 2012;55(10):869–75.
3 Kang DM, Kim YK, Kim JE. Asbestos and environmental diseases. J Korea Med Assoc. 2012;55(3):214–22.
4 Kang DM. Health effects of environmental asbestos exposure. J Environ Health Sci. 2009;35(2):71–7.

5 Metintas M, Ozdemir N, Hillerdal G, Ucgun I, Metintas S, Baykul C, et al. Environmental asbestos exposure and malignant pleural mesothelioma. Respir Med. 1999;93(5):349–55.
6 Kang D, Myung MS, Kim YK, Kim JE. Systematic review of the effects of asbestos exposure on the risk of cancer between children and adults. Ann Occup Environ Med. 2013;25(1):10.
7 Choi JK, Paek DM, Paik NW. The production, the use, the number of workers and exposure level of asbestos in Korea. Korean Ind Hyg Assoc J. 1998;8(2):242–53.
8 Park D, Choi S, Ryu K, Park J, Paik N. Trends in occupational asbestos exposure and asbestos consumption over recent decades in Korea. Int J Occup Environ Health. 2008;14(1):18–24.
9 Ki YH, Kim JM, Roh YM, Chung L, Kim YS, Sim SH. A survey for some asbestos containing products in Korea. Korean J Environ Health. 2008;34(1):108–15.
10 World Health Organization (WHO) [Internet]. Asbestos: elimination of asbestos-related diseases. Fact sheet No. 343 [cited 2015 Feb 5]. Available from: http://www.who.int/mediacentre/factsheets/fs343/en/index.html
11 Magnani C, Agudo A, González CA, Andrion A, Calleja A, Chellini E, et al. Multicentric study on malignant pleural mesothelioma and non-occupational exposure to asbestos. Br J Cancer. 2000;83(1):104–11.
12 Tossavainen A. Global use of asbestos and the incidence of mesothelioma. Int J Occup Environ Health. 2004;10(1):22–5.
13 McCormack V, Peto J, Byrnes G, Straif K, Boffetta P. Estimating the asbestos-related lung cancer burden from mesothelioma mortality. Br J Cancer. 2012;106(3):575–84.