Estimates of the Number of Workers Exposed to Diesel Engine Exhaust in South Korea from 1993 to 2013

Sangjun Choi, Donguk Park, Seung Won Kim, Kwonchul Ha, Hyejung Jung, Gwangyong Yi, Dong-Hee Koh, Oknam Sun, Sanni Uuksulainen

1 Department of Occupational Health, Catholic University of Daegu, Gyeongsangbukdo, Republic of Korea
2 Department of Environmental Health, Korea National Open University, Seoul, Republic of Korea
3 Department of Public Health, Keimyung University, Daegu, Republic of Korea
4 Department of Biohealth Science, Changwon National University, Changwon, Republic of Korea
5 Department of Occupational and Environmental Medicine, Catholic Kwandong University, Incheon, Republic of Korea
6 Occupational Safety and Health Research Institute, Korea Occupational Safety and Health Agency, Ulsan, Republic of Korea
7 Ministry of Employment and Labor, Republic of Korea
8 Finnish Institute of Occupational Health Work Environment, Helsinki, Finland

ABSTRACT

Background: The aim of this study was to estimate the number of workers exposed to diesel engine exhaust (DEE) by industry and year in the Republic of Korea.

Method: The estimates of workers potentially exposed to DEE in the Republic of Korea were calculated by industry on the basis of the carcinogen exposure (CAREX) surveillance system. The data on the labor force employed in DEE exposure industries were obtained from the Census on Establishments conducted by the Korea National Statistical Office from 1993 to 2013. The mean values of prevalence rates adopted by EU15 countries were used as the primary exposure prevalence rates. We also investigated the exposure prevalence rates and exposure characteristics of DEE in 359 workplaces representing 11 industries.

Results: The total number of workers exposed to DEE were estimated as 270,014 in 1993 and 417,034 in 2013 (2.2% of the total labor force). As of 2013, the industry categorized as "Land transport" showed the highest number of workers exposed to DEE with 174,359, followed by "Personal and household services" with 70,298, "Construction" with 45,555, "Wholesale and retail trade and restaurants and hotels" with 44,005, and "Sanitation and similar services" with 12,584. These five industries, with more than 10,000 workers exposed to DEE, accounted for 83% of the total DEE-exposed workers. Comparing primary prevalence rates used for preliminary estimation among 49 industries, "Metal ore mining" had the highest rate at 52.6%, followed by "Other mining" with 50.0%, and "Land transport" with 23.6%.

Conclusion: The DEE prevalence rates we surveyed (1.3–19.8%) were higher than the primary exposure prevalence rates. The most common emission sources of DEE were diesel engine vehicles such as forklifts, trucks, and vans. Our estimated numbers of workers exposed to DEE can be used to identify industries with workers requiring protection from potential exposure to DEE in the Republic of Korea.

Copyright © 2016, Occupational Safety and Health Research Institute. Published by Elsevier. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
reclassified by the International Agency for Research on Cancer (IARC) from probably carcinogenic to humans (Group 2A) to carcinogenic to humans (Group 1) [2]. IARC also noted that DEE has a positive association (based on limited evidence) with an increased risk of bladder cancer.

One of the major challenges in occupational cancer prevention is a lack of knowledge regarding precisely where carcinogenic exposures are occurring and the number of workers affected. To create an exposure surveillance system supporting the effective prevention of occupational cancer, it is necessary for a country to build a basic database to perform surveillance on the number of workers exposed to carcinogens and their distribution according to type of industry, occupation, and other exposure variables. The carcinogen exposure (CAREX) system is an international information system for estimating the numbers of workers exposed to known (Group 1) and suspected (Group 2A) carcinogens as classified by the IARC. Estimates on occupational exposure to carcinogens in the European Union (EU) in the 1990s, including DEE, have been published [3,4]. CAREX was subsequently adapted to serve as a carcinogen exposure surveillance system in several countries [5–7]. No estimates have as yet been produced for Asia, including for the Republic of Korea.

The aims of this study were to estimate the number of workers exposed to DEE by industry and by year in the Republic of Korea using the CAREX method, to compare our estimates with results from other countries in which the CAREX method has been applied, and to investigate the DEE prevalence rate for several industries.

2. Materials and methods

The CAREX surveillance system has already been fully explained elsewhere [3–6]. A brief description of the assessment procedures used to estimate the number of workers exposed to DEE in this study is presented here as Fig. 1.

Firstly, all industries projected by the CAREX results from the 15 EU countries were listed. The 49 industries with an exposure prevalence rate were first referred to as “industries with the possibility of DEE exposure” (hereafter referred to as DEE exposure industry). Industries with an International Standard Industrial Code (ISIC) revision 2 were reclassified according to the three-digit level of the Korea Standard Industrial Classification (KSIC) revisions 8 and 9. Some nonmanufacturing sectors were classified at the one- or two-digit levels.

Secondly, data on the labor force employed in DEE exposure industries were obtained from the “Census on Establishments” (a nationwide annual census on the characteristics of enterprises with one or more employees doing business in Korea) conducted by the Korea National Statistical Office from 1993 to 2013 [8]. The industrial classes of the labor force from 1993 to 2005 and from 2006 to 2013 were coded at the three-digit level of KSIC revisions 8 and 9, respectively. These labor force figures cover all workers, including self-employed workers, working family members, and part-time workers.

Thirdly, the estimates of workers potentially exposed to DEE were calculated on the basis of the CAREX system, multiplying the labor force by the primary prevalence rate of the industry concerned. In this study, we used the mean value of prevalence rates adopted by the EU15 countries as the primary prevalence rate for estimation of DEE exposure.

Finally, our field investigation of DEE exposure rates from 11 DEE exposure industries were compared with those estimated for EU countries. We investigated 359 workplaces where workers were exposed DEE in order to obtain DEE exposure prevalence rates. Because of the lack of airborne DEE levels or industrial hygiene data to assess DEE exposure, we qualitatively assessed DEE exposure among the overall workforce in terms of the workers involved, how, and what type of job. Workers who drive diesel vehicles or work near the operation of such vehicles or who work in a space where diesel fuel is used by vehicles or mechanical instruments were considered workers exposed to DEE. Exposure to DEE over more than 75% of the working hours was regarded as the minimum DEE exposure duration guideline as indicated by the CAREX system. The surveyed prevalence rates were compared with the primary prevalence rates.

3. Results

3.1. Number of workers exposed to DEE by industry and year

The number of workers exposed to DEE from among the total labor force and in DEE exposure industries has been on the rise from 1993 until 2013 (Fig. 2). The total number of workers exposed
to DEE ranged from 270,014 in 1993 to 417,034 in 2013 (2.2% of the total labor force).

These numbers are also described by industry in a four-year interval in Table 1. Fig. 3 shows the five major industries that make up the DEE exposure estimates from 1993 to 2013. As of 2013, the “Land transport” designation (KSIC revision 9 code: 49) showed the highest number of workers exposed to DEE (174,359), followed by “Personal and household services” (KSIC revision 9 code: 95, 96) with 70,298, “Construction” (KSIC revision 9 code: 41, 42) with 45,555, “Wholesale and retail trade and restaurants and hotels” (KSIC revision 9 code: 45, 46, 47, 55, 56) with 44,005, and “Sanitation and similar services” (KSIC revision 9 code: 37, 38, 39, 742) with 12,584. These five industries showing over 10,000 workers exposed to DEE accounted for 83% of the total DEE-exposed workers. Comparing primary prevalence rates among 49 industries, “Metal ore mining” (KSIC revision 9 code: 06) had the highest rate at 52.6%, followed by “Other mining” (KSIC revision 9 code: 07) with 50.0%, and “Land transport” with 23.6%.

3.2. Comparison of DEE exposure estimates in the Republic of Korea with EU CAREX

The estimated number of workers exposed to DEE and DEE exposure prevalence rates were compared with results from other countries to which the CAREX method had been applied (Table 2). The average DEE exposure prevalence rate in the total work force from 1993 to 2013 (2.2%) was generally similar to those estimated in the 15 EU countries where it ranged from 1.7% to 3.2%.

3.3. Field investigation of exposure prevalence rate and exposure characteristics of DEE

Our DEE exposure prevalence rates as investigated in 11 DEE exposure industries were compared with the EU results (Table 3). They ranged from 1.3% to 19.8%, and were found to be generally higher than the primary prevalence rates estimated in EU countries. The most common tasks in the DEE exposure group were: (1) delivery of materials or persons with diesel-engine vehicles such as forklifts, trucks, vans, and ambulances; (2) the management of facilities with emergency generators; and (3) operation of diesel-engine equipment, including cleaning and metal-working machinery.

4. Discussion

We found that a total of 49 industries were estimated to feature a potential for DEE exposure higher than to the airborne level commonly found in the outdoor environment (Table 1). The industry with the most common DEE exposure was found to be “Land transport”, which accounted for 41.8% of the total DEE exposure estimates in 2013, followed by “Personal and household services” (16.9%), “Construction” (10.9%), “Wholesale and retail trade and restaurants and hotels” (10.9%), and “Sanitation and similar services” (3%; Fig. 3). Our results were generally found to be similar to those estimated in the EU CAREX: “Land transport” (32.8%), “Construction” (21.6%), “Personal and household services” (10.5%), “Other mining” (4.4%), and “Wholesale and retail trade and restaurants and hotels” (3.9%). There appears to be a possibility of underestimating the number of DEE-exposed workers in “Construction” due to the high proportion of temporary workers who are not included in the related workforce. The employment rate of temporary workers in this industry in Korea increased from 16.6% in 2001 to 29.7% in 2004, which were evaluated as the second highest among Organization for Economic Co-operation and Development countries in 2007 [9] and showing the fastest rate of change.

The average number of workers (1993–2013) estimated to be exposed to DEE in the Republic of Korea was identified as lower than those in Italy (552,495), the UK (473,062), Germany (741,443), and France (410,499; Table 2), although the reference year of estimation and total workforce differed among countries. The CAREX project estimated about 3 million workers in the EU15 countries in
Table 1
Number of workers exposed to diesel engine exhaust (DEE) from 1993 to 2013 by industry

| Industry | Industry code | Reference country | Primary prevalence rate* (%) | DEE exposure estimate by y 1993 | 2001 | 2005 | 2009 | 2013 |
|----------|---------------|-------------------|-----------------------------|---------------------------------|------|------|------|------|
| Land transport | 711 60 49 | FIN, USA | 23.6 | 89,162 | 124,061 | 144,185 | 148,672 | 172,773 | 174,359 |
| Personal and household services | 95 92, 93, 95 95, 96 | FIN | 10.0 | 40,258 | 45,441 | 51,216 | 55,876 | 61,544 | 70,298 |
| Construction | 5 45, 46 41, 42 | FIN, USA, FRA | 4.4 | 28,661 | 42,407 | 27,692 | 34,153 | 39,174 | 45,555 |
| Wholesale and retail trade and restaurants and hotels | 6 50, 51, 52, 55 45, 46, 47, 55, 56 | FIN, FRA | 0.90 | 30,485 | 34,886 | 37,367 | 37,369 | 39,603 | 44,005 |
| Sanitation and similar services | 92 90, 759 37, 38, 39, 742 | FIN, USA, ITA | 6.7 | 5,898 | 8,094 | 10,794 | 16,569 | 9,735 | 12,584 |
| Services allied to transport | 719 631, 632, 633 | FIN, USA | 8.2 | 5,382 | 6,077 | 6,620 | 8,124 | 6,712 | 7,914 |
| Other mining | 29 12 07 | FIN | 50.0 | 11,894 | 9,427 | 6,887 | 6,661 | 6,581 | 6,096 |
| Manufacture of fabricated metal products, except machinery and equipment | 381 28 251, 259 | FIN, USA | 1.3 | 3,289 | 3,295 | 3,602 | 4,366 | 4,804 | 5,606 |
| Manufacture of other nonmetallic mineral products | 369 263, 269 | USA, FRA | 8.6 | 8,261 | 7,419 | 6,001 | 5,279 | 5,032 | 5,299 |
| Manufacture of plastic products not elsewhere classified | 356 252 222 | USA, FRA | 2.3 | 2,416 | 2,374 | 2,527 | 4,000 | 4,074 | 4,948 |
| Water transport | 712 61 50 | FIN, USA | 19.1 | 3,389 | 3,160 | 3,181 | 3,030 | 4,446 | 3,678 |
| Public administration and defense | 91 76 84 | FIN, ITA | 0.48 | 2,417 | 2,800 | 2,524 | 2,570 | 3,143 | 3,075 |
| Manufacture of transport equipment | 384 34, 35 30, 31 | FIN, USA | 0.56 | 2,088 | 1,974 | 1,902 | 2,098 | 2,362 | 2,889 |
| Iron and steel basic industries | 371 271, 273 241, 243 | FIN, USA | 2.0 | 2,591 | 1,771 | 1,835 | 1,882 | 1,995 | 2,370 |
| Food manufacturing | 311, 312 151, 152, 153, 154 | USA, FRA | 1.0 | 2,314 | 2,822 | 2,240 | 2,215 | 2,101 | 2,288 |
| Manufacture of machinery except electrical | 382 291, 292, 293, 300 | USA | 0.5 | 1,510 | 1,369 | 1,605 | 1,668 | 1,626 | 1,980 |
| Air transport | 713 62 51 | USA | 7.1 | 2,120 | 455 | 970 | 1,037 | 1,234 | 1,939 |
| Manufacture of electrical machinery apparatus, appliances, and supplies | 383 295, 31, 32 26, 28 | USA, FRA | 0.25 | 1,230 | 1,174 | 1,305 | 1,537 | 1,422 | 1,671 |
| Forestry and logging | 12 02 02 | DEN, FRA | 23.5 | 122 | 309 | 453 | 751 | 876 | 1,478 |
| Water works and supply | 42 41 36 | USA | 9.1 | 395 | 835 | 1,194 | 1,378 | 1,334 | 1,436 |
| Communication | 72 64 61 | USA | 1.4 | 1,028 | 1,229 | 2,019 | 1,892 | 1,353 | 1,337 |
| Nonferrous metal basic industries | 372 272, 273 242, 243 | USA | 3.4 | 1,255 | 1,132 | 1,142 | 1,062 | 1,105 | 1,332 |
| Agriculture and hunting | 11 01 01 | DEN, FRA | 5.5 | 356 | 1,303 | 1,294 | 1,257 | 1,149 | 1,268 |
| Manufacture of pottery, china, and earthenware | 361 262 232 | FRA, ITA | 7.1 | 2,899 | 1,959 | 1,657 | 1,305 | 1,140 | 1,184 |
| Fishing | 13 05 03 | FRA, ITA | 21.4 | 4,104 | 7,509 | 2,164 | 1,343 | 1,023 | 1,118 |
| Manufacture of wood and wood and cork products, except furniture | 331 20 16 | FIN, USA | 3.0 | 1,871 | 1,436 | 1,325 | 1,232 | 1,028 | 1,066 |
| Electricity, gas, and steam | 41 40 35 | USA, FRA | 1.8 | 624 | 735 | 830 | 929 | 961 | 952 |
| Manufacture of industrial chemicals | 351 241, 244 201, 202, 203, 205 | USA | 1.2 | 1,117 | 1,027 | 945 | 854 | 769 | 932 |
| Manufacture of other chemical products | 352 242, 243, 294 204, 21, 252 | USA | 0.8 | 955 | 911 | 912 | 845 | 750 | 894 |
| Beverage industries | 313 155 11 | FIN, USA | 5.3 | 1,968 | 1,183 | 1,278 | 1,041 | 843 | 872 |
| Manufacture of rubber products | 355 251 221 | FRA, ITA, NET | 1.6 | 826 | 622 | 661 | 733 | 688 | 849 |
| Manufacture of textiles | 321 17 13 | USA | 0.6 | 2,237 | 1,508 | 1,480 | 1,050 | 772 | 833 |
| Medical, dental, other health and veterinary services | 933 85 86, 76, 731 | USA, ITA | 0.1 | 234 | 309 | 385 | 487 | 624 | 768 |
| Manufacture of paper and paper products | 341 21 17 | FIN, USA | 1.0 | 777 | 709 | 702 | 675 | 615 | 708 |
| Education services | 921 80 15 | FRA | 0.04 | 282 | 347 | 437 | 519 | 591 | 649 |
| Printing, publishing, and allied industries | 342 22 18, 58 | USA | 0.17 | 255 | 234 | 239 | 231 | 419 | 484 |
| Petroleum refineries | 353 232 192 | USA | 4.6 | 661 | 738 | 462 | 445 | 482 | 455 |
| Manufacture of wearing apparel, except footwear | 322 18 14 | FIN, USA | 0.29 | 979 | 609 | 563 | 434 | 418 | 418 |
| Other manufacturing industries | 39 369 33 | USA | 0.55 | 614 | 483 | 465 | 394 | 323 | 352 |

(continued on next page)
TABLE 1

| Industry code | Industry | ISIC revision 2 | ISIC revision 8 | ISIC revision 9 | 1993 | 1997 | 2001 | 2005 | 2009 | 2013 |
|---------------|----------|----------------|----------------|----------------|------|------|------|------|------|------|
| 354           | Manufacture of footwear, except vulcanized or molded rubber or plastic footwear | 231 | RRA, ITA | 3.4 | 1.0 | 4.0 | 2.0 | 0.0 | 8.0 | 6.0 | 3.0 |
| 305           | Manufacture of nonferrous metal basic industries | 372 | FIN, USA | 8.4 | 4.0 | 10.0 | 4.0 | 2.0 | 1.0 | 6.0 | 8.0 |
| 273           | Manufacture of other chemical products | 373 | RRA, ITA | 13.0 | 7.0 | 12.0 | 7.0 | 4.0 | 2.0 | 6.0 | 8.0 |
| 243           | Manufacture of iron and steel basic industries | 371 | FIN, USA | 12.0 | 6.0 | 12.0 | 6.0 | 4.0 | 2.0 | 6.0 | 8.0 |
| 311           | Manufacture of basic iron and steel products | 370 | RRA, ITA | 18.0 | 10.0 | 14.0 | 10.0 | 4.0 | 2.0 | 6.0 | 8.0 |
| 261           | Manufacture of coke, petroleum coke, and certain coking materials | 369 | RRA, ITA | 22.0 | 12.0 | 20.0 | 12.0 | 4.0 | 2.0 | 6.0 | 8.0 |
| 253           | Manufacture of basic iron and steel products | 368 | FIN, USA | 18.0 | 10.0 | 14.0 | 10.0 | 4.0 | 2.0 | 6.0 | 8.0 |
| 243           | Manufacture of iron and steel basic industries | 367 | RRA, ITA | 22.0 | 12.0 | 20.0 | 12.0 | 4.0 | 2.0 | 6.0 | 8.0 |
| 231           | Manufacture of footwear, except vulcanized or molded rubber or plastic footwear | 366 | FIN, USA | 18.0 | 10.0 | 14.0 | 10.0 | 4.0 | 2.0 | 6.0 | 8.0 |

Primary prevalence rate was presented as the mean value of reference countries. DEN, Denmark; FIN, Finland; FRA, France; ISIC, International Standard Industrial Classification; ITA, Italy; KSIC, Korea Standard Industry Code; NET, Netherland; USA, The United States of America.
industries. For example, with the “Personal and household services” industry, which had the highest prevalence rate at 19.8%, 77% of the workplaces (10/13) investigated were in the category of “General repair services of motor vehicles” (KSIC revision 9 code: 95211). Although “Personal and household services” consisted of 31 fields classified at the five-digit level, we were able to collect information from only three of them. In order to acquire a more accurate exposure prevalence, it is necessary to conduct more systematic surveillance covering all industries. Our field investigation results indicated that DEE prevalence rates estimated

| Country        | Total workforce | Total employees in DE exposure industry | No. of workers exposed to DEE | Prevalence rate within total workforce (%) | Prevalence rate within DE exposure industry (%) | Year estimated |
|----------------|-----------------|----------------------------------------|------------------------------|-------------------------------------------|-----------------------------------------------|----------------|
| Austria        | 3,086,425       | 2,126,450                              | 79,300                       | 2.6                                       | 3.7                                           | 1990–1993      |
| Belgium        | 3,506,842       | 2,294,407                              | 67,051                       | 1.9                                       | 2.9                                           | 1990–1993      |
| Denmark        | 2,812,902       | 1,807,507                              | 71,331                       | 2.5                                       | 3.9                                           | 1990–1993      |
| Finland        | 2,138,381       | 1,024,335                              | 38,490                       | 1.8                                       | 3.8                                           | 1990–1993      |
| France         | 21,786,228      | 18,319,703                             | 410,499                      | 1.9                                       | 2.2                                           | 1990–1993      |
| Germany        | 34,035,522      | 23,759,879                             | 741,443                      | 2.2                                       | 3.1                                           | 1990–1993      |
| Greece         | 3,332,580       | 1,908,777                              | 78,546                       | 2.4                                       | 4.1                                           | 1990–1993      |
| Ireland        | 1,088,450       | 636,626                                | 21,075                       | 1.9                                       | 3.3                                           | 1990–1993      |
| Italy          | 17,073,393      | 13,800,125                             | 552,495                      | 3.2                                       | 4.0                                           | 1990–1993      |
| Luxembourg     | 186,493         | 131,913                                | 4,394                        | 2.4                                       | 3.3                                           | 1990–1993      |
| Netherlands    | 6,463,694       | 3,977,161                              | 108,934                      | 1.7                                       | 2.7                                           | 1990–1993      |
| Portugal       | 4,019,845       | 2,538,389                              | 73,176                       | 1.8                                       | 2.9                                           | 1990–1993      |
| Spain          | 12,162,830      | 8,021,270                              | 274,321                      | 2.3                                       | 3.4                                           | 1990–1993      |
| Sweden         | 4,003,674       | 2,186,882                              | 80,625                       | 2.0                                       | 3.7                                           | 1990–1993      |
| UK             | 22,821,375      | 14,874,425                             | 473,062                      | 2.1                                       | 3.2                                           | 1990–1993      |
| 15 EU total    | 138,518,634     | 97,407,849                             | 3,074,742                    | 2.2                                       | 3.2                                           | 1990–1993      |
| Republic of Korea | 12,245,073   | 10,479,119                             | 270,014                      | 2.2                                       | 2.6                                           | 1993           |
|                | 13,470,343      | 11,264,620                             | 324,873                      | 2.4                                       | 2.9                                           | 1997           |
|                | 14,109,641      | 11,765,619                             | 334,947                      | 2.4                                       | 2.8                                           | 2001           |
|                | 15,147,471      | 12,413,643                             | 356,947                      | 2.4                                       | 2.9                                           | 2005           |
|                | 16,818,015      | 13,232,999                             | 386,522                      | 2.3                                       | 2.9                                           | 2009           |
|                | 19,173,474      | 14,863,105                             | 417,034                      | 2.2                                       | 2.8                                           | 2013           |

* Prevalence rate within total workforce was calculated as the number of workers exposed to DEE divided by the total workforce.

** Prevalence rate within DE exposure industry was calculated as the number of workers exposed to DEE divided by the total employees in DE exposure industries.

EU, European Union.
Table 3
Summary of the prevalence rates and exposure characteristics of diesel engine exhaust (DEE) in 11 industries as identified through field investigation

| Industry                                      | No. of workplaces surveyed | No. of workers surveyed | No. of workers exposed to DEE | DEE prevalence rate (%) | Source of DEE | Major tasks using DEE powered vehicles or machinery |
|-----------------------------------------------|----------------------------|-------------------------|-------------------------------|-------------------------|---------------|---------------------------------------------------|
| Manufacture of fabricated metal products, except machinery and equipment | 57                        | 9,294                   | 536                           | 5.77                    | Material delivery | Forklift, truck                                    |
| Manufacture of transport equipment            | 47                        | 5,138                   | 67                            | 1.30                    | Facilities management | Emergency generator of transport vehicles          |
| Manufacture of plastic products               | 37                        | 1,297                   | 68                            | 5.24                    | Material delivery | Cleaning in car repair shop                        |
| Wholesale and retail trade                   | 26                        | 1,755                   | 68                            | 5.13                    | Material delivery | Cleaning in car repair shop                        |
| Iron and steel basic industries               | 12                        | 334                     | 19                            | 1.34                    | Emergency generator | Forklift, truck, van                               |
| Food manufacturing                           | 10                        | 294                     | 10                            | 3.35                    | Material delivery | Cleaning equipment                                |
| Total                                         | 359                       | 22,364                  | 1,145                         | 5.12                    | Material delivery |                                                    |

DEE exposure prevalence was estimated based on the CAREX method in 11 industries as identified through field investigation. The level of DEE exposure was determined through the CAREX method, which is based on the structure and employment characteristics of the country applying the method.

In accordance with the following considerations, DEE exposure prevalence as estimated based on the CAREX method in the 15 EU countries was directly applied to national circumstances in the Republic of Korea without updating DEE prevalence rates. To our knowledge, there has been no substantial change in legislation that may lead to considerable variations in the prevalence rate or in the probability of DEE exposure by industry in the Republic of Korea from 1990s to date. Furthermore, no literature to date has reported on either DEE occupational exposure or health effects related to DEE in the Republic of Korea. Despite the carcinogenicity of DEE, there have been no proportionately strict measures to control DEE exposure in occupational settings.

There are specific factors able to substantially influence the DEE exposure prevalence rate in an occupational setting. The main factor for determining the probability of DEE exposure is the indoor or outdoor use and repair and/or testing of diesel-powered vehicles or diesel mechanical instruments, although the airborne level of DEE exposure involved is associated with the size, number, and duration of use of diesel engines and the degree of ventilation. It has become widely known that the major source of occupational exposure to DEE is from vehicles using diesel fuel, such as buses, trains, ferries, trucks, tractors, and forklift trucks. According to European vehicle market statistics, the average market share of diesel passenger cars in 27 European countries has risen from 36% in 2001 to 55% in 2012. In the Republic of Korea, the proportion of diesel vehicles among all newly registered cars has also been increasing, from 28% in 1997 to 38.1% in 2012, although it remains lower than that in European countries.

DEE is also generated from stationary power sources which may be used in tunnels, alongside railway lines during maintenance work and on construction sites. Enclosure of the work site and type of diesel equipment used are the most important determinants affecting occupational DEE exposure.

Studies of indoor diesel contributions have focused on occupational exposure, such as in mines or warehouses, and on jobs or tasks using diesel-powered vehicles or diesel mechanical instruments. Metal ore mining and other mining industries have been estimated to have the highest DEE exposure prevalence rate. In order to investigate DEE exposure prevalence rates, it is important to determine where diesel engine-powered vehicles and machinery have been used and when they were either introduced or abolished. They may have been replaced with new technologies at a certain point, such as hybrids, fuel cells, or electronic vehicles, which can substantially influence the probability of DEE exposure. The use of diesel forklifts for lifting and transporting materials or products over short distances either within or between operations causes not only their drivers, but also all the workers within the same operation to be exposed to DEE. For example, our investigation into the prevalence rate at one large-vehicle tire manufacturing plant employing 2,652 workers found that a total of 46 forklift trucks were used to transport products or material either between or within operations, resulting in direct exposure to DEE on the part of 60 drivers, and indirect exposure among workers working near the operation of these trucks (data not shown here).
During the 1990s, exhaust emissions from forklift operations began to be addressed, which led to emission standards for forklift manufacturers being implemented in various countries [1]. Due to the lack of any official data on the size of diesel vehicles by industry, it cannot be generalized into a prevalence rate. The introduction of electric forklifts and fuel cell technology can result in zero local emissions. There has been no legislation or guidelines enforced in Korea regarding banning or limiting the use of diesel-powered vehicles or diesel mechanical instruments in industry. In addition, the number of diesel-powered vehicles used in workplaces has not been reported. In particular, many off-road applications, such as in ships, trains, bulldozers, locomotives, forklift trucks, construction, distribution, farming, and the military, as well as diesel generators, are still largely uncontrolled worldwide [1]. Off-road vehicle turnover is low and older engines are generally used longer in off-road than in on-road vehicles [12]. In order to examine DEE prevalence rates, further study should be conducted to investigate the number and size of diesel-powered vehicles or diesel mechanical instruments used by industry.

The strengths and limitations of CAREX have been described elsewhere [4,6]. Briefly, the CAREX assessment method as applied shows a number of advantages, such as its systematic approach, wide coverage of industries and countries, ease of use, use of national experts, comprehensive documentation, and generalizability of the estimation process [4]. A single harmonized assessment method can be applied to respective countries, which improves the comparability of the estimates across countries. The reliability of the estimates should be improved by incorporating field investigation into DEE exposure prevalence in DEE exposure industries. Some of the differences between estimates are likely to result from not only methodological factors, but also differences in industry structure among countries.

Several factors should be considered when the CAREX system is used to estimate DEE exposure industries and the number of workers exposed to DEE in the Republic of Korea. Firstly, the CAREX approach may neglect a portion of the exposure stemming from miscellaneous operations in many industries. The CAREX data on DEE may also be considered rather crude, since DEE was only one out of the 85 carcinogens assessed initially by CAREX and the method used was less detailed and data-based than the present procedures. Comparisons across countries could be partly hampered by the lack of detailed estimation procedures by specific carcinogen. It is unclear for DEE exposure industries whether to include the exposures of scattered self-employed workers who either drive diesel engine vehicles or possess on-road or off-road diesel vehicles, as well as whether to include several jobs with the possibility of potential high exposure to DEE. There remains the question of whether workers such as police officers, traffic wardens, and toll booth operators who are occupationally exposed to DEE should be included in DEE exposure industries. Workers in toll booths can be exposed to diesel and gasoline engine exhaust emissions. The total number of toll booth workers in Korea is 4,958 as of 2013. Jobs with exposure to trafficked streets, such as those found in a significant proportion of bars, restaurants, shops, stands, and street-side vending, were not included. It is also unclear whether to consider occupational exposure among those in direct contact with diesel vehicles in operations where manufactured products are loaded in diesel vehicles either outdoors or indoors in manufacturing and nonmanufacturing industries.

Secondly, the numbers of workers exposed to carcinogens estimated through the CAREX method feature basic limitations on their application to exposure assessment within epidemiology. The CAREX surveillance system lacks information concerning the use of occupational and job classifications for industries in which DEE is generated, as well as on levels of exposure, which could be used to associate the risk of health effect. Further standardization of classifications based on occupation and exposure level is recommended for an epidemiologic study when the CAREX surveillance system is further refined in respective countries. The number of workers exposed to occupational carcinogens in Canada was estimated based on CAREX projects in the EU. CAREX Canada’s exposure estimates were presented for every available dimension, including industry, occupation, province, sex, and exposure level, which is a key enhancement compared with previous CAREX projects [6]. Priority was given to common occupations and industries with high DEE exposures, which contribute significantly to the results of epidemiological studies. Further refinements are possible as new exposure measurement data become available [11].

Thirdly, differences in industry structure or scale among countries should be considered when adapting the CAREX method. The industrial substructure of the Republic of Korea—one of the most industrialized countries in the world—may differ considerably from the 15 EU countries depending on the type of products or manufacturing processes used. For example, automobile, ship, and electronics manufacturing in the Republic of Korea are leading industries that are either limited or do not exist in other countries, including some countries in the EU. Exposure to DEE in automobile and ship manufacturing workplaces particularly occurs during repair or testing procedures when the operators work adjacent to or underneath an engine and where engines are running as part of the operation. With the considerable number of workers exposed to DEE, the present results warrant greater attention and further study.

In conclusion, in spite of the apparent limitations, our estimation of occupational exposure to DEE based on the CAREX method can potentially be used to assess exposure to DEE by industry, to identify high-risk groups by industry, and to set priorities for prevention-related activities. When combined with data on exposure levels and other specific exposure characteristics such as job and occupation, they can also contribute to a decrease in carcinogen exposures and thereby to the prevention of occupational cancer among exposed workers.

Conflicts of interest

No potential conflicts of interest related to this article were reported.

References

[1] Lloyd AC, Cackette TA. Diesel engines: environmental impact and control. J Air Waste Manag Assoc 2001;51:809–47.
[2] International Agency for Research on Cancer (IARC). Agents classified by the IARC monographs [Internet]. IARC: 2012. Available from: http://monographs.iarc.fr/ENG/Classification/.
[3] Kauppinen T, Pajarskiene B, Podnieczie Z, Rajzanow V, Smerhovsky Z, Veidebaum T, Leino T. Occupational exposure to carcinogens in Estonia, Latvia, Lithuania and the Czech Republic in 1997. Scand J Work Environ Health 2001;27:343–5.
[4] Kauppinen T, Toikkonen J, Pedersen D, Young R, Ahrens W, Boffetta P, Hansen J, Kromhout H, Maqueda Blasco J, Mirabelli D, de la Orden-Rivera V, Panett B, Plato N, Savela A, Vincent R, Kogevinas M. Occupational exposure to carcinogens in the European Union. Occup Environ Med 2000;57:10–8.
[5] Blanco-Romero LE, Vega LE. Lozano-Chavarria LM, Partanen TJ. CAREX Nicaragua and Panama: Worker exposures to carcinogenic substances and pesticides. Int J Occup Environ Health 2011;17:251–7.
[6] Peters CE, Calvin BG, Hall AL, Davies HW, Demers PA. CAREX Canada: An enhanced model for assessing occupational carcinogen exposure. Occup Environ Med 2015;72:64–71.
[7] Mannanje AT, Pearce N, McLean D, Douwes J, Dryson E, Walls C, Ellison-Loshmann L, Blair A, Kromhout H, Slater T, Boffetta P. Workplace exposure to carcinogens in New Zealand (HRC 08/569). Centre for Public Health Research, Massey University; 2013.
[8] KOSTAT. Korea Standard Industrial Classification (KSIC) [Internet]. Statistics Korea; 2007 [cited 2016 Jan 16]. Available from: http://kosis.kr/ups/ups_01List.jsp?pubcode=ZY. [in Korean].

[9] Jones RS, Tsutsumi M. Sustaining growth in Korea by reforming the labour market and improving the education system. OECD Economics Department Working Papers. Paris (France): OECD Publishing; 2009.

[10] Partanen T, Chaves J, Wesseling C, Chaverri F, Monge P, Ruepert C, Aragón A, Kogevinas M, Hogstedt C, Kauppinen T. Workplace carcinogen and pesticide exposures in Costa Rica. Int J Occup Environ Health 2003;9:104–11.

[11] Kauppinen T, Uuksulainen S, Saalo A, Mäkinen I, Pukkala E. Use of the Finnish information system on occupational exposure (FINJEM) in epidemiologic, surveillance, and other applications. Ann Occup Hyg 2014;58:380–96.

[12] International Council on Clean Transportation (ICCT). European vehicle market statistic—pocketbook 2013 [Internet]. 2013 [cited 2016 May 30]. Available from: http://www.theicct.org/sites/default/files/publications/EU_vehiclemarket_pocketbook_2013_Web.pdf. [in Korean].

[13] Ministry of Environment. White papers on environment 2002 [Internet]. 2003 [cited 2016 May 30]. Available from: http://library.me.go.kr.

[14] Ministry of Environment. White papers on environment 2013 [Internet]. 2013 [cited 2016 May 30]. Available from: http://library.me.go.kr. [in Korean].

[15] Pronk A, Coble J, Stewart PA. Occupational exposure to diesel engine exhaust: A literature review. J Expo Sci Environ Epidemiol 2009;19:443–57.