ORIGINAL ARTICLE

Lung cancer in heavy equipment operators and truck drivers with diesel exhaust exposure in the construction industry

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Background: Several studies indicate that truck drivers have an increased risk of lung cancer, but few studies have examined lung cancer risk in heavy equipment operators. Workers in both occupations are exposed to diesel exhaust.
Aims: To examine the incidence and mortality from lung cancer among truck drivers and among drivers of heavy vehicles.
Methods: A computerised register of Swedish construction workers participating in health examinations between 1971 and 1992 was used. Male truck drivers (n = 6364) and drivers of heavy construction vehicles (n = 14 364) were selected as index groups; carpenters/electricians constituted the reference group (n = 119 984).
Results: Operators of heavy construction equipment experienced no increased risk of lung cancer compared to risk among the carpenter/electrician referents (61 cases *v* 70.1 expected). However, a significant inverse trend risk with increasing use of cabins was apparent. Truck drivers had increased risks of cancer of the lung (61 cases *v* 47.3 expected) and prostate (124 cases *v* 99.7 expected), although only mortality for lung cancer was significantly increased. Comparisons with the general population showed similar results.
Conclusion: Results are consistent with those of previous studies suggesting that heavy equipment operators with potential exposure to diesel exhaust may have little or no increased risk of lung cancer, although the use of cabins seemed to decrease the risk of lung cancer. The results for truck drivers are also consistent with previous reports of increased lung cancer risk among truck drivers exposed to diesel exhaust, as well as recent reports linking diesel exhaust exposure to prostate cancer.

The International Agency for Research on Cancer (IARC)[1] and several reviewers[2–4] consider diesel exhaust a probable cause of lung cancer, although others have disputed the causal nature of the relation.[5–7]

Previous studies have focused on occupational groups with increased exposure to diesel exhaust (for example, railroad workers, truck drivers, bus drivers, heavy equipment operators). Studies of truck drivers indicate an increased risk of lung cancer, with a pooled estimate of relative risk about 1.5.[3 4] "Heavy equipment operator" is a diesel exhaust exposed occupation that has been less studied. The pooled estimate of the relative risk is modest, ranging from 1.1 (95% confidence interval (CI) 0.95 to 1.29)[3] to 1.28 (95% CI 0.99 to 1.66).[4] However, a recent study reported a greater increased lung cancer risk for heavy equipment operators than that observed previously (odds ratio (OR) = 2.3, 95% CI 1.4 to 3.7).[8]

The purpose of this study is to estimate lung cancer incidence among heavy construction equipment operators with potential exposure to diesel exhaust in a cohort of construction workers, adjusting for potential confounding from smoking, as well as age at diagnosis, death, and time period. We also examined lung cancer incidence among truck drivers with potential exposure to diesel exhaust within the same cohort of construction workers. Incidence of other types of cancer in both heavy construction equipment operators and truck drivers was also estimated.

Main messages

- Results suggest that heavy equipment operators with potential exposure to diesel exhaust have little or no increased risk of lung cancer.
- Findings are consistent with previous reports of increased lung cancer risk among truck drivers.
- To understand difference in risk between different occupational groups, detailed information about exposure to diesel exhaust is needed, but rarely provided by retrospective studies.

Policy implications

- There seems to be a different risk of lung cancer between heavy equipment operators and truck drivers with potential exposure to diesel exposure. The cause of the difference in risk is not known.

SUBJECTS AND METHODS

All Swedish construction workers were affiliated with a national industrial health service known as Bygghälsan from the mid-1960s until 1 January 1993. All workers were offered a free health examination on a regular basis. The participation rate has been estimated to be about 80% (A Englund, personal communication).

Information from the health examinations conducted between 1971 and early 1993 has been computerised. This file

Abbreviations: CI, confidence interval; OR, odds ratio; PCMR, proportional cancer mortality ratio; RR, relative risk; SIR, standard incidence rate; SMR, standard mortality rate

Table 1 Major type of equipment operated by heavy equipment operators in the construction industry and occurrence of lung cancer

Type of equipment	No. of subjects	Observed/ expected
Paving machine	1125	6/6.9
Earth movers	1017	3/8.6
Dumper	881	0/2.2
Excavator	4754	15/24.6
Tractor	2185	12/12.8
Loading machine	1727	7/6.2
Sweeper	12	0/0.1
Road grader	939	7/11.8
Roller	950	4/4.8
Others (e.g. dredger) or operation of more than one machine	572	7/2.8

The referent group for the expected number cases is the general population.

contains more than 389 000 construction workers and is based on the unique personal identification number for each resident of Sweden. We linked such individuals to the National Cancer Registry and National Death Registry to identify all incident cases and deaths from cancer.

At each health examination, the job title of each worker was recorded. We identified workers in three occupational groups: heavy construction equipment operators (n = 14 364), truck drivers (n = 6364), and carpenters/electricians (referents) (n = 119 984).

Each worker was followed until 31 December 1995. Death or emigration was determined through linkage with national registries of the total population and of emigrants. Because women comprised only 0.1–0.3% of the occupational groups of interest, the analysis was restricted to men. The loss of subjects to follow up was small (one truck driver, 17 heavy construction equipment operators, and 215 carpenters/electricians).

Smoking habits at the time of the first health examination were used to classify each subject as a non-smoker, ex-smoker, or smoker. If smoking status was not reported at the first health examination, the subject's smoking status at a later visit was used.

Occupational subgroups were formed based on whether the equipment had a cabin or not. Cabin was defined as having doors and windows, while some equipment just had a roof. Safety engineers (n = 5) were asked to classify the occurrence of cabins by type of equipment according to table 1. Cabins had always been used on dumpers and road graders, and had been introduced during the 1960s on excavators, tractors, and loading machines, and during the 1970s on earthmovers. Paving machines rarely used cabins in the early years. There was a gradual change to cabins during the 1960s and 1970s. Cabins with filtered air are still uncommon and are mostly used in areas with high exposure to quartz (for example, in stone crushers). One of the safety engineers reported that operators of excavators often complained about exposure to diesel exhaust, but cabins were improved considerably at the beginning of the 1960s, when the excavators were operated through hydraulic systems. Previously excavators used wires, for example, for lifting of the bucket.

Standard incidence rates (SIR) and standard mortality rates (SMR) were calculated according to the person-year method[9] with an in-house Fortran program. Person-years were calculated from the first health examination until death, emigration, or 31 December 1995. In comparisons with carpenters/electricians, age at diagnosis or death was stratified in 10 year age groups, smoking habits in four levels (non-smoker, ex-smoker, smoker, unknown), and calendar year into three time periods (1971–78; 1979–87; 1988–95). In comparisons with the general population, incidence and mortality rates for the general population were used to generate expected numbers stratifying on age (five year groups) and calendar year (one year groups). As the number of cases is substantially higher for the general population, a finer stratification could be used in the external comparison than in the internal comparison with carpenter/electrician referents. A χ^2 test was used to test the trend between the use of cabins. Ninety five per cent confidence intervals were calculated using a Poisson distribution.

RESULTS

Heavy equipment operators within the construction industry operated different types of machines. Table 1 shows the machine operated at the time of the first health examination. A total of 8436 of the men had more than one health examination; about 80% were operating the same machine at the first and last examination, indicating low mobility between different jobs in the construction industry.

The carpenter/electrician referents were younger than heavy construction equipment operators and truck drivers, and a higher proportion of referents were non-smokers (table 2). The year of the first health examination was similar in the three occupational groups as was the total number of health examinations.

There were 61 incident cases of lung cancer among heavy construction equipment operators, 61 lung cancer cases among truck drivers, and 512 lung cancer cases among the carpenter/electrician referents between 1971 and 1995 (1 753 254 person-years).

Heavy construction equipment operators had a lower incidence of lung cancer than both carpenter/electrician referents (SIR = 0.87; 95% CI 0.66 to 1.11) and the general population (SIR = 0.76; 95% CI 0.58 to 0.97) (table 3). Truck drivers, in contrast, had an increased incidence of lung cancer compared to carpenter/electrician referents (SIR = 1.29; 95% CI 0.99 to 1.65) and the general population (relative risk (RR)

Table 2 Year of birth, year of first health examination, total number of health examinations, and smoking habits by occupation

	Heavy construction equipment operators (n=14364)	Truck drivers (n=6364)	Referents* (n=119984)
Year of birth, mean (SD)	1943 (12)	1939 (14)	1947 (16)
Year of first health examination, mean (SD)	1979 (6)	1979 (6)	1980 (6)
Number of visits to controls, median (range)	2 (1–12)	2 (1–8)	2 (1–9)
Smoking habits			
Non-smokers (%)	31.8	29.8	47.8
Ex-smokers (%)	16.1	16.5	13.3
Smokers (%)	44.1	45.1	33.4
Unknown (%)	7.7	8.7	5.5

*Carpenters/electricians.

Table 3 Lung cancer incidence and mortality between 1971 and 1995 in heavy construction equipment operators and truck drivers compared to two referent groups, carpenters/electricians referents (REF1) and the general population (REF2)

	Heavy construction equipment operators	Truck drivers
Number of incident cases of lung cancer	61	61
Number of deaths from lung cancer	49	57
Person-years	217331	97930
SIR* (95% CI)		
REF1	0.87 (0.66 to 1.11)	1.29 (0.99 to 1.65)
REF2	0.76 (0.58 to 0.97)	1.14 (0.87 to 1.46)
SMR† (95% CI)		
REF1	0.83 (0.61 to 1.09)	1.37 (1.04 to 1.78)
REF2	0.70 (0.51 to 0.92)	1.18 (0.89 to 1.53)

*Standardised incidence ratio comparing incidence of lung cancer, 95% confidence interval in parentheses.
†Standardised mortality ratio comparing mortality from lung cancer, 95% confidence interval in parentheses.
SIR and SMR based on the carpenter/electrician referents (REF1) were adjusted for age, time period, and smoking habits.
SIR and SMR based on the general population referents (REF2) were adjusted for age and calendar year.

= 1.14; 95% CI 0.87 to 1.46). Incidence ratios were similar, regardless of whether mortality or incidence data were analysed. The incidence of lung cancer according to the type of equipment of the operator was mostly below expected (table 1). The increased risk for the type "others" was mainly due to an increased risk among operators of pile drivers (5 observed *v* 1.8 expected).

The risk of lung cancer in smokers is strongly dependent on tobacco dose. If the smoking carpenters/electricians are heavier smokers than heavy equipment operators within each smoking stratum, residual confounding by smoking may have occurred. In the comparisons within the group of construction workers, risk estimates were adjusted according to smoking category (current smoker, ex-smoker, non-smoker), as detailed smoking habits were not available. However, for a subgroup of these workers, smoking habits were recorded in greater detail in the data file. The average numbers of pack-years among smoking heavy equipment operators, truck drivers, and carpenters/electricians born before 1940 were very similar (22.5, 22.6, and 22.8 pack-years, respectively). The proportions with known pack-years were rather similar (15%, 12%, and 10%, respectively)

When the heavy equipment operators were categorised by the use of cabins, estimates of the incidence ratio were 0.86 (95% CI 0.4 to 1.6; 10 cases *v* 11.7 expected) for "never" in a cabin, 0.71 (95% CI 0.5 to 1.0; 37 cases *v* 52.2 expected) for "sometimes" in a cabin, and 0.50 (95% CI 0.2 to 1.0; 7 cases *v* 14.0 expected) for "always" in a cabin ($p < 0.001$ for trend). This pattern suggests that subjects who always worked in a cabin had a lower risk of lung cancer than those who worked in the open.

An analysis of other sites of cancer showed no significantly increased risks among the heavy construction equipment operators (table 4). The total incidence of cancer was significantly decreased compared to the general population (SIR = 0.89, 95% CI 0.82 to 0.96), partly because of a decreased risk of respiratory cancer (SIR = 0.78, 95% CI 0.61 to 0.98) (table 4).

Among truck drivers, a significantly increased incidence of prostate cancer was apparent (SIR = 1.24, 95% CI 1.03 to 1.48) when compared to the general population (table 4). The total incidence of cancer among the truck drivers was slightly, but not significantly, increased (SIR = 1.05, 95% CI 0.96 to 1.15), partly because of the increased risk of cancer of the prostate and lung.

DISCUSSION

Our estimates of lung cancer risk among heavy equipment operators (SIR = 0.87; 95% CI 0.66 to 1.11) are consistent with the relative risk estimates for heavy equipment operators by

Table 4 Standard incidence rates (SIR) among heavy construction equipment operators and truck drivers compared to the general population between 1971 and 1995

Site (ICD8*)	Heavy construction equipment operators (number of observed and expected cases in parentheses)	Truck drivers (number of observed and expected cases in parentheses)
All cancers	0.89 (651/732.8)†	1.05 (509/485.8)
Nasopharynx (140–149)	0.75 (18/24.1)	0.82 (12/14.6)
Gastrointestinal (150–158)	0.84 (143/169.2)	0.99 (115/116.6)
Stomach (151)	1.05 (32/30.6)	1.23 (27/21.9)
Colon (153)	0.82 (40/48.7)	0.57 (19/33.4)
Rectum (154)	0.82 (29/35.6)	1.46 (35/24.1)
Liver (155)	0.94 (15/16.0)	0.98 (11/11.3)
Respiratory (160–162)	0.78 (71/91.0)†	1.13 (68/60.3)
Larynx (161)	1.03 (9/8.7)	1.25 (7/5.6)
Lung (162)	0.76 (61/80.6)†	1.14 (61/53.7)
Prostate (177)	0.93 (116/124.5)	1.24 (124/99.7)†
Kidney (180)	0.74 (24/32.4)	1.12 (23/20.5)
Urinary tract (181)	1.15 (61/53.3)	0.72 (26/36.0)
Melanoma (190)	0.81 (31/38.5)	0.70 (14/20.0)
Other skin cancer (191)	1.04 (28/26.9)	0.98 (19/19.4)
Brain (193)	0.97 (32/33.0)	0.92 (16/17.4)
Lymphoma and leukaemia (200–209)	1.08 (78/72.3)	1.21 (53/43.7)

*International Classification of Diseases, 8th revision.
†95% confidence interval excludes 1.0.

meta-analyses of Bhatia *et al* (RR = 1.11; 95% CI 0.95 to 1.29)[3] and Lipsett *et al* (RR = 1.28; 95% CI 0.99 to 1.66).[4] The meta-analyses of heavy equipment operators are mainly based on studies by Wong and colleagues,[10] Hayes and colleagues,[11] and Boffetta and colleagues.[12] Our findings are in agreement with the overall findings of a study of a heavy construction equipment operators union in the United States (SMR = 1.0) by Wong and colleagues.[10] Workers with at least 20 years membership in the union had an SMR of 1.05. In the occupational group with the highest exposure to diesel exhaust in that study (that is, scraper operators, dozer operators, loader operators, and backhoe operators), the observed mortality from lung cancer was equal to the expected mortality (SMR = 1.0). In a pooled analysis of three case-control studies of lung cancer and employment in motor exhaust related occupations by Hayes *et al*, heavy equipment operators with less than 10 years employment had an odds ratio of 1.0, whereas those with more than 10 years employment had an odds ratio of 1.3 (95% CI 0.3 to 3.1) after adjustment for smoking.[11] Boffetta *et al* found five cases of lung cancer among heavy equipment operators in a prospective cohort study (RR = 2.60; 95% test based CI 1.12 to 6.06).[12] The exposure classification was based on occupational title and included no information on duration of exposure. We have found two other studies not included in the meta-analysis. Decoufle *et al* observed an increased risk of lung cancer in construction machinery operators who were members of an operating engineers union and who died in 1967 (proportional mortality ratio = 1.35, $p < 0.05$).[13] In a proportion mortality study of 15 843 deaths among unionised construction operating engineers in the USA by Stern and Haring Sweeney, the proportional cancer mortality ratio (PCMR) for lung cancer was slightly above 1 (PCMR = 1.14; 95% CI 1.09 to 1.19).[14] There was no association with duration of membership in the union (a proxy for duration of exposure). The finding, however, was not adjusted for smoking, and heavy equipment operators in that cohort had an increased risk of emphysema, indicating heavier smoking than that in the referent population.

We observed a significant inverse trend in risk with increasing use of cabins, suggesting that workers who were protected from the exhaust outside their vehicles may have a lower risk of developing lung cancer than workers who were not protected by a cabin. We assumed that the use of a cabin will decrease the exposure to diesel exhaust, but there are no measurements or other data supporting that assumption. Furthermore, the overall incidence of lung cancer was below expected compared to both reference groups, so the finding of the trend should be prudently interpreted. Some operators may have been exposed to other carcinogens (for example, asphalt fumes and silica), but the findings do not indicate an increased risk associated with any special type of equipment (see table 1).

Our finding of an increased risk of lung cancer in truck drivers with a relative risk of about 1.3 compared to the general population is also consistent with several previous studies. Overall, epidemiological studies of truck drivers show a consistent pattern of an increased relative risk with the pooled RR of 1.5.[3 4] In addition, we observed a significantly increased risk of prostate cancer in truck drivers, whereas heavy construction equipment operators experienced no increased prostate cancer risk. Diesel exhaust has been linked to prostate cancer risk in two previous studies. In a case referent study from Germany, an increased risk of prostate cancer was seen for subjects who drove long distances by car.[15] An association between diesel exhaust and prostate cancer was also apparent when a job exposure matrix in the same study determined diesel exposure. In a recent study an increased risk of prostate cancer was observed among farmers exposed to diesel exhaust.[16]

One limitation of our study is that we were unable to quantify duration and intensity of diesel exposure; exposure status was based on occupational title at the time of health examination. A high turnover rate within the industry may lead to short duration of exposure. However, 80% of heavy construction equipment operators had the same job at the first and last health examination, suggesting that this group had a low turnover rate. Furthermore, because we do not have the date of first exposure, we are unable to analyse risk according to latent period. A short latent period or a short duration of exposure may result in underestimation of the risk of lung cancer**.** Lastly, although the internal comparison with the carpenter/electrician referents was adjusted for differences in smoking status, some residual confounding may be operating if the amount of tobacco smoked differed between the heavy equipment operators and carpenters/electricians.

This study included two occupational groups with potential exposure to diesel exhaust—heavy equipment operators and truck drivers. Heavy equipment operators seem to have a lower risk of lung cancer than truck drivers, not only in our study but also in other epidemiological studies. This may be caused by heavier and/or longer exposure to diesel exhaust among truck drivers, confounding by other occupational exposures that increase the risk of lung cancer, residual confounding from tobacco smoking, or chance.

Diesel exhaust is a complex and variable mixture of particles and gases. Recent exposure assessments have usually analysed elemental carbon. A study of US highway construction workers in 1994–95 found a mean concentration of 14 $\mu g/m^3$ elemental carbon (range 0.5–53 $\mu g/m^3$, n = 14) in operating engineers working outdoors, mainly handling cranes, lifters, and earth movers.[17] The exposure was considerably higher for operating engineers during work in tunnels (mean 39 $\mu g/m^3$). The background concentration on the work site was fairly low (mean 3 and 6 $\mu g/m^3$ at two places, range 0.5–7). However, the authors cite earlier measurements in US cities showing averages between 4 and 7 $\mu g/m^3$. These data suggest that operators of heavy equipment at outdoor construction sites may have low exposure to diesel exhaust. Zaebst *et al* studied diesel exhaust exposure among US truck drivers by measuring elemental carbon particles.[18] They found similar levels of diesel exhaust exposure for local and long distance drivers (mean 5.4 and 5.1 $\mu g/m^3$, respectively). The concentrations were slightly higher than highway background (3.4 $\mu g/m^3$) and residential background exposure (1.1 $\mu g/m^3$), suggesting that truck drivers also have low levels of diesel exposure. However, the limited number of measurements and the sampling strategy make it difficult to draw conclusions regarding whether diesel exhaust exposure is higher among heavy equipment operators than among truck drivers. However, the possibility of a longer duration of exposure in truck drivers compared to heavy equipment operators cannot be excluded in our study because we have no information on duration of exposure.

Residual confounding by tobacco smoking may also contribute to the absence of increased lung cancer risk in heavy equipment operators. However, detailed smoking data available for a subgroup did not indicate any large differences in amount of smoking among the smokers. Thus, considerable residual confounding as a result of tobacco smoking seems a rather improbable cause of the absence of an increased lung cancer risk. Smoking in confined spaces, as in a truck cabin, may be more carcinogenic than smoking in open air. However, an earlier study of truck drivers did not indicate that environmental tobacco smoke within the cabin was an important risk factor for smoking truck drivers.[19] It is also unlikely that confounding from other lung cancer risk factors, such as diet, non-malignant respiratory disease, or socioeconomic status occurred, because our primary analysis was based on internal comparisons.

The truck drivers had an increased total incidence of cancer (SIR = 1.05) compared to heavy equipment operators (SIR = 0.89), which could not entirely be explained by differences in risk of lung cancer. This might indicate some other difference in exposure to carcinogens between these occupational groups. The truck drivers had a higher exposure to pollutants from the general traffic while driving, for example, dust from tyres, exhaust from petrol engines.

In conclusion, our results are consistent with those of previous studies indicating that heavy equipment operators with potential exposure to diesel exhaust have little or no increased risk of lung cancer. The risk estimates of truck drivers were also consistent with previous studies indicating an increased risk of lung cancer, although only the mortality of lung cancer was significantly increased in this study. Data on exposure to diesel exhaust from measurements in other studies and smoking habits as recorded in this study do not explain this difference in lung cancer risk among the heavy equipment operators and truck drivers. To understand the differential risk better, more detailed data on diesel exhaust exposure and smoking habits than has been provided by this and previous studies are needed. It seems unlikely that such studies could be based on retrospective data, particularly as diesel exhaust exposure varies over time for most occupational groups.

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