Lung Cancer and Mesothelioma among Male Automobile Mechanics: A Review

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ABSTRACT

BACKGROUND: Extensive, overt asbestos exposure clearly causes lung cancer and mesothelioma. Elevated cancer risk has also been documented for short term or low levels of asbestos exposure. Automobile mechanics are potentially exposed to asbestos through brake repair work. Few studies have specifically examined the risk of lung cancer and mesothelioma associated with exposure to asbestos in brakes, but automobile mechanics are included in many studies of occupation and cancer. METHODS: We critically reviewed all epidemiologic studies of lung cancer and mesothelioma risk among male automobile mechanics identified through a broadly based Medline search and scrutiny of references in primary and review articles. We discuss the studies grouped by study design and control for smoking, the major risk factor for lung cancer. RESULTS/CONCLUSIONS: We reviewed all individual analytical studies meeting our criteria, plus all available case series and case reports. When examined in aggregate, the evidence did not support an increase in risk of either lung cancer or mesothelioma among male automobile mechanics occupationally exposed to asbestos from brake repair.

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KEYWORDS

epidemiologic studies, occupational risk, friction material, brake repair, asbestos

INTRODUCTION

Extensive, overt exposure to asbestos fibers clearly causes lung cancer and mesothelioma. Elevated cancer risk has also been documented for short term or low levels of asbestos exposure /1/. Automobile mechanics are potentially exposed to low levels of asbestos through repair of friction materials. Few studies, however, have specifically examined the risks of lung cancer and mesothelioma associated with work on automobile brakes. In this paper, we summarize and critically review the available epidemiologic studies on the risk of lung cancer and mesothelioma associated with work as an automobile mechanic.

About 50% of the composition of brake linings and brake shoes consists of chrysotile asbestos encapsulated in a phenolic resin. The use of such products in automobiles, buses, and other heavy equipment causes them to wear, releasing a fine dust of amorphous material together with very small fibers /2/. Automobile mechanics are potentially exposed to asbestos fibers when they grind used linings, bevel new linings, or remove the loose dust from the brake drum and back plates using compressed air, brushes, or wet cloths /3/.

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Although total dust counts in the ambient air can reach high levels for short periods of time during these processes, control methods, such as enclosed vacuum systems or exhaust ventilation systems, effectively lower the exposure /4–5/. Furthermore, the availability of asbestos fibers in used brakes is markedly reduced because high temperatures during braking degrade the vast majority of the asbestos into nonfibrous magnesium silicate /6/. Less than one percent of the dust released in work on brakes contains chrysotile fibers that are longer than five microns, the size known to be relevant to respiratory health /7/. Grinding and drilling of friction pads also releases fibers, which have been of concern. Detailed study of this material has revealed, however, that the fibers consistently remained bound to the resin matrix /8/. Thus, grinding and drilling also appear to pose no important exposure to asbestos fibers.

The absolute exposure level is influenced by the distance to the source, the type and duration of activity, as well as by the type of brake. For example, drum brakes used for trucks, buses, and certain passenger cars, require more cleaning than disc brakes used only in passenger cars /9/. Industrial hygiene reports taking measurements of dust and fiber generated during clutch and brake repair work demonstrate that the exposure to asbestos from this work is low, intermittent and brief /9/. In the 1970s, before the current permissible exposure limit of 0.1 f/mL (fibers per milliliter of air) was proposed by the United States (U.S.) Occupational Safety and Health Administration, episodic peak concentrations of up to 16 f/mL were reported during blowing off of loose dust. Practically all measured levels published after 1987, however, were less than 0.2 f/mL, and time-weighted average exposures during passenger vehicle repair in the 1980s were generally less than 0.05 f/mL /10–12/. Nonetheless, the question remains, were these low levels of asbestos exposure associated with carcinogenic risk /3/. Concerns about this possibility led to warnings, from both government agencies and companies, but with little or no epidemiologic evidence. We therefore reviewed the epidemiologic studies that provided data on risk of lung cancer and mesothelioma among automobile mechanics.

METHODS

We identified studies of lung cancer and mesothelioma risk among motor vehicle mechanics through computer searches and scrutiny of references in primary and review articles. In an attempt to capture all published data on potential exposure to asbestos from work with brake linings, we considered general surveys of occupation and cancer risk, as well as studies focusing specifically on cancer among automobile mechanics. Because of the potential for publication bias by both investigators and journals to highlight positive findings, we performed broadly based Medline searches (1966 through August 2003), using as key words *cancer*, *lung cancer*, *occupation*, and *mesothelioma*. We identified many useful studies that might have been overlooked because they did not specifically mention automobile mechanics in the title or abstract. We also contacted authors for supplemental data and tables if it appeared that the relevant results were available but did not meet the criteria described for inclusion in the published paper. We focused specifically on automobile mechanics, as opposed to broad occupational or industrial categories. For completeness, however, we also included papers that discuss the occupation *mechanics, unspecified*. Separately, we considered papers that do not mention automobile mechanics but from their design and results we concluded that automobile mechanics would have been included if the results had been positive. Therefore, we included all studies in which specific occupations were considered. The review is limited to studies of men.

Not all studies in this discussion controlled for cigarette smoking. Because smoking is such a strong risk factor for lung cancer, however, and there is evidence that smoking rates may vary by occupation, we have placed more emphasis on the studies that included smoking information in their analyses. Available occupational survey data on smoking is limited. A survey in the U.S., however, found that automobile mechanics ranked third in smoking prevalence out of 61 occupations surveyed, with twice the average cigarette consumption of many other similarly skilled workers /13/. In The National Center for Health Statistics 2000 National Health Interview Survey, the prevalence of current smoking among repairers and mechanics was 31.5%, among the highest of those occupations presented /14/. Also, some evidence indicates a higher prevalence of smoking-related causes of death, such as chronic obstructive pulmonary disease (COPD), among mechanics. For example, in the 14 year, 28-state National Occupational Mortality Surveillance (NOMS) study, covering 66,150 deaths among male automobile mechanics, the proportional mortality from COPD was statistically significantly elevated at 1.15 /15/. Studies that do not control for smoking are therefore likely to be confounded and to overestimate any association between work as a vehicle mechanic and risk of lung cancer. As an illustration, Carstensen and colleagues /17/ found that accounting for smoking eliminated an apparent excess lung cancer risk in mechanics and repairmen in Sweden.

We discuss separately studies of lung cancer and mesothelioma. The details on study design, including study population, assessment of exposure and outcome, comparison population, and factors adjusted for, and the main results are presented in the tables. We present the risk estimates (standardized mortality ratios [SMR], standardized incidence ratios [SIR], proportional mortality ratios [PMR], odds ratios [OR], relative risk [RR], among others) and their statistical significance as the authors did, including confidence intervals or p values, whichever are available. We made no attempt to calculate additional estimates from the information included in the papers. The tables are organized by study design, and, for lung cancer, by whether the authors controlled for smoking in their analysis.

LUNG CANCER

Studies of Populations of Automobile and Bus Mechanics

We identified five studies that focused specifically on populations of automobile and bus mechanics (Table 1). Jarvholm and Brisman /17/ and Hansen /18/ identified automobile mechanics through population census data, and Schwartz /19/ extracted this information from the 'usual occupation' recorded on death certificates. Rushton et al. /20/ and Gustavsson et al. /21/ constructed their cohorts and determined exposure from employee work history records at bus garages in London and Stockholm, respectively. In all but the Hansen study the cancer risk of the 'exposed' population (automobile mechanics) was compared with the risk in the general population. Hansen instead constructed a comparison group of skilled workers including carpenters, electricians, instrument makers, dairymen, upholsterers, and glaziers. This group was thought to be similar to automobile mechanics in terms of physical demands, life-style habits—including smoking, geographic distribution and socioeconomic status.

With the exception of the Jarvholm and Brisman study (SMR: 1.70, $p < 0.01$) /17/, no significant association of lung cancer risk with occupation as an automobile mechanic emerged from these studies. Gustavsson and colleagues /21/ calculated cumulative exposure to asbestos, as well as diesel

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TABLE 1

Studies of the risk of lung cancer among male automobile mechanics; did not control for smoking

Author	Study population	Outcome Assessment	Exposure definition	Exposure assessment	Comparison population	Results
Jarvholm & Brisman 1988 (17)	Males, age 20-69, employed as mechanic or in car repair in 1960 in Sweden	Death Registry 1961-73 Cancer Registry 1961-79	"Car repair mechanic" n=21,906	Census, occupational and industrial codes	General population	Deaths: n=39, SMR=1.70, p<0.01 Incidence: n=93 SIR=1.27 p<0.05
Hansen 1989 (18)	Occupationally active, skilled male workers, age 15-74 in 1970 in Denmark	Death Registry, DC, 1970-80	"Auto mechanic" or "mechanic, employed at car-repair workshop" n=21,800	Census	Carpenter, electrician, instrument maker, dairyman, upholsterer, glazier n=51,747	n=41, SMR=1.01 (0.72-1.37)
Schwartz 1987(19)	White, male auto mechanics, age ≥20 in New Hampshire, US	DC 1975-85	Auto mechanic n=453	DC	General population	n=38 PMR=1.12 (0.82-1.53)
Rushton et al, 1983 (20)	Employees of 71 London garages and engineering works	Death Registry	Maintenance men employed ≥1 yr from 1967-75 n=8,490	Employment records	General population	n=102, SMR=1.01 p=0.94
Gustavsson et al. 1990 (21)	Males employed at least 6 months in 5 Stockholm bus garages from 1945-1970	Death Registry & other local records 1952-86 Cancer Registry 1958-84	Cumulative exposure to asbestos among mechanics, servicemen, porters n=695	Company records and IH reports (TWA exposure levels)	Stockholm occupationally active population and general population	Mortality: Total: n=17, SMR=1.22 (0.71-1.96)* 1.13 (0.67-1.84)** high exp: n=6, SMR=1.18* med exp: n=6, SMR=1.97* low exp: n=5, SMR=0.86* trend NS Incidence:* Total: n=17, SIR=1.61 (0.94-2.57)

Abbreviations: DC = death certificates, IH=industrial hygiene, n=number, PMR=proportional mortality ratio, SIR=standardized incidence ratio, SMR=standard mortality ratio, TWA=time weighted average
Confidence bounds = 95% confidence intervals (CI) unless otherwise indicated;
*compared to the occupationally active population
** compared to the general population

exhaust, over a 25-year period, extrapolating from work histories and a current industrial hygiene assessment. The authors observed a statistically nonsignificant elevation of lung cancer incidence overall (SIR: 1.61; 95% CI: 0.94–2.57), but no dose-response association with asbestos exposure. Schwartz reported a PMR of 1.12 (95% CI: 0.82–1.53) and the SMRs reported by Rushton et al. /20/ and Hansen /18/ were not elevated. None of these five studies adjusted for smoking.

Survey and Cohort Studies of Occupation and Cancer

These studies were undertaken to understand the relation between a variety of occupations and the risk of lung cancer specifically, or cancer in general in a defined population (Table 2). Most relied on cancer registries or death certificates for outcome and exposure assessment, usually defining exposure as last known or 'usual' occupation. Lung cancer rates among automobile mechanics are compared either to rates in the general population or to rates in the entire cohort under study.

Two large cohort studies controlled for smoking. In the most comprehensive survey of cancer and occupation, Blair and colleagues /22/ evaluated the relation between occupation and specific cancer sites over a 16-year period in 293,958 U.S. veterans /22/. Information on usual occupation was obtained through two interviews administered near the beginning of follow-up in 1954, and outcome information was extracted from death certificates through 1970. The study was updated through 1980 by Hrubec /23/. At the interview, information on smoking habits was also obtained. Risks for each occupation and each cancer site were calculated, within categories defined by smoking habit. No excess of lung cancer was found for automobile mechanics in the original Blair report (SMR=1.03, p>0.05) or of cancer of the respiratory system in the update (SMR=1.10, 90%CI: 0.89-1.36). In contrast, and as expected, risks were elevated for lung cancer in occupations with known asbestos exposure, such as shipyard workers and plumbers.

Carstensen and colleagues /16/ took advantage of Sweden's extensive population records system to evaluate the incidence of lung cancer. The authors focused on 1.6 million men aged 30 to 64 who were employed in 1960. The researchers reviewed national cancer registry files for any occurrence of lung cancer from 1961 through 1979. Occupation was determined from the 1960 census. Carstensen's group did not attempt to evaluate the smoking habits of each worker, but they did estimate the amount of smoking in each occupational group based on surveys, and used those data to adjust for smoking indirectly. After such adjustment, the SIR for mechanics and repairmen taken together was 1.07 (95% CI: 0.92–1.22). No separate, more specific estimate was made for automobile mechanics alone.

The remainder of the cohort studies relied solely on registries or death certificates for information on occupation and disease surveillance in a given geographic area. Therefore, information on potential confounders, including smoking, was not available. The results from these studies were mixed. Enterline and McKiever /24/ observed a statistically significant association of work as an automobile mechanic with lung cancer mortality in the U.S. population in 1950 (SMR = 1.28). Milham and colleagues /25/ surveyed deaths in Washington State, first in 1976, with updates every 10 years through 1999 /26/. In the 1999 publication, the PMR for lung cancer deaths among automobile mechanics was statistically significantly elevated at 1.15. This result is similar to the findings reported in the NOMS study, described above, which included residents in 28 states. In the latter study, the PMR was 1.16 for white and 1.08 for black automobile mechanics /15/. Although the excess mortality for each group was modest, the sample size was large

TABLE 2

General surveys of cancer and occupation, organized by control for smoking: lung cancer results

Author	Study population	Outcomes Included	Sample size	Number of auto mechanics	Outcome/ Exposure assessment	Comparison population	Results for automobile mechanics[1] N=no. Cases
Control for smoking							
Blair et al, 1985 (22)	US Veterans age 31-84 in 1953 n=293,958	All cancer deaths 1954-69	Total deaths – 107,563	NA	DC/usual occupation from questionnaires	Entire cohort	Never smokers: n=2; Ever smokers: n=26, SMR=0.91, p>0.05; All combined: n=33, crude SMR=1.03, p>0.05
Hrubec et al 1992 (23) *updated from Blair 1985*	US Veterans who served fr 1917-40 and held health insurance policies, age 31-84 in 1953 n=248,046	All deaths 1954-80	Total deaths – 164,785	NA	DC/usual occupation from questionnaires	Entire cohort	Nonsmokers: n=2, RR=0.7; Current cigarettes: n=50, RR=1.2 (90%CI: 0.93-1.49); *Total smoking adjusted*: n=63, RR=1.1 (90%CI: 0.89-1.36)
Carstensen et al. 1988[2] (16)	Swedish males employed 1960, age 30-64 n=1,622,647	Lung cancer 1961-79	NA	NA	Cancer Registry/1960 Census/smoking info in 1% sample	General population	Mechanics and repairmen: SIR=0.97 (0.82-1.22)
Did not control for smoking							
Enterline & McKiever 1963 (24)	United States, males, age 20-64	Lung cancer deaths 1950	NA	681,485	DC	General population with work experience	n=119, SMR=1.28, PMR=1.27 p<0.05
Milham & Ossiander 2001 (26)	Washington State, US whites, age ≥20	All deaths Males: 1950-99	Total deaths: Males: 811,528	[illegible]	DC	General population	n=361; PMR=1.15 p<0.01
NIOSH 2002 (15)	National Occupational Mortality Surveillance (NOMS), 28 states; age 15-90; 1984-1998	All deaths	NA	NA	DC	NOMS population	Whites: n=5,743; PMR=1.18, p≤0.01 Blacks: n=769; PMR=1.08, p≤0.05

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General surveys of cancer and occupation, organized by control for smoking: lung cancer results

Author	Study population	Outcomes included	Sample size	Number of auto mechanics	Outcome/ Exposure assessment	Comparison population	Results for automobile mechanics[1] N=no. Cases
Andersen et al. 1999[7] (27)	Denmark 1971-1987, Sweden 1971-1989, Finland 1971-1990, Norway 1971-1991; age 25-64 N=10 mil	All cancer cases	Cancer cases 1 mil	365,717	Cancer Registry/1970 census	General population	Mechanics, iron and metalware workers: n=6,314; SIR=1.2 (1.2-1.4)
Leigh 1996 (13)	California Occupational Mortality Study: age 16-64	Lung cancer 1979-81	All deaths ~ 173,438	NA	DC	General population	n=NA; SMR=1.31 (1.08-1.54)
Menck & Henderson 1976 (28)	Los Angeles County white males, age 20-64 n=1,560,800	Lung cancer: Deaths 1968-70; Incident cases 1972-73	Deaths 2,161; Cases 1,777	12,750	Deaths: DC; Cases: [illegible] Cancer Surveillance Program	General population	Occupation - not mentioned; Industry - n=28, SMR=1.46 p<0.01
Petersen & Milham 1980 (29)	California, US, white males, age ≥20	all deaths 1959-61	Total deaths ~200,000	1,833	DC	General population	n=69, PMR=1.23, p>0.05
Olsen & Jensen 1987 (30)	Denmark	All cancer cases 1970-79	All cases 50,851	NA	Cancer Registry [illegible]	Whole cohort	n=NA; SIR=1.17 [illegible]
Morrison 1957 (31)	Scotland males age ≥15 N=1,795,273	All deaths 1949-53	NA	NA	DC	General population	Not mentioned
Pearce & Howard 1986 (32)	New Zealand males, age 15-64	cancer deaths 1974-78	Cancer deaths 5,355	NA	Death Registry	General population 10% sample 1976 N.Z. Census	Not mentioned

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TABLE 2 (continued)

General surveys of cancer and occupation, organized by control for smoking: lung cancer results

Author	Study population	Outcomes included	Sample size	Number of auto mechanics	Outcome/ Exposure assessment	Comparison population	Results for automobile mechanics[a] N=no. Cases
Minder and Beer-Portzak 1992 (33)	Working population Switzerland, males age ≥30	Cancer deaths 1979-82	Cancer deaths - 4,008	NA	DC	General population	Not mentioned
Howe & Lindsay 1983 (89)	10% Sample, Canadian Labor Force, males N=415,201	cancer deaths 1965-73	Total deaths - 19,974 Cancer deaths - 4,203 Lung ca - 1,370	NA	Death Registry, Unemployment Insurance Commission	Whole cohort	Not mentioned
Lindsay et al. 1993 (34)	10% sample Canadian Labor Force, males n=415,309	Cancer deaths 1965-79	Cancers - 9,739	NA	Death Registry/Census 1961	Whole cohort	Not mentioned
Firth et al. 1996 (35)	New Zealand males, age 15-64	All cancer cases 1972-84	All cases - 26,207	NA	Cancer Registry	General employed population; total employed population of cancer registry	Not mentioned

Abbreviations: DC=death certificate, fr=from, n=number, NA=not available, PMR=proportional mortality ratio, SIR=standardized incidence ratio, SPIR=standardized proportional incidence ratio, SMR=standardized mortality ratio
Confidence intervals are 95% unless otherwise indicated
[a]results are for automobile mechanics unless otherwise specified
[b]mechanics and repairmen, nonspecific
[c]mechanics, iron and metalware workers grouped together, not specifically automobile mechanics

and the PMRs were statistically significant. In another large study, in the Nordic countries, Andersen and colleagues /27/ observed an elevated SIR (1.2; 95% CI: 1.2–1.4) for lung cancer among mechanics and iron and metal workers grouped together /27/. The results for automobile mechanics were not presented separately. The Leigh study, mentioned earlier, observed an SMR of 1.31 (95% CI: 1.08–1.54) in the California Occupational Mortality Study. The authors did not control for smoking, however, although in the same publication they discuss the high smoking rates in this occupational group /13/. Menck and Henderson /29/ surveyed incidence and mortality of lung cancer in Los Angeles County and reported a statistically significantly elevated SMR for lung cancer in the automobile repair industry. The authors examined a wide range of occupations, including automobile mechanics, but listed only the occupations with elevated rates. Automobile mechanics were not included in that list. Petersen and Milham /29/ and Olsen and Jensen /30/ did not observe a statistically significant excess of lung cancer among automobile mechanics in California and Denmark, respectively.

For comparison, we examined the risks of lung cancer reported for other occupations included in these studies. Consistently, occupations with known asbestos exposure, such as pipe fitters, shipyard workers, and steel workers, had elevated risks of lung cancer.

Our search identified five additional survey/cohort studies that defined exposure to the occupational level but did not mention automobile mechanics /31–35/. For these studies, we surmised from the level of detail of the occupation and exposure assessment that 'automobile mechanic' would have been reported if an excess risk had been observed. Typically, such broad surveys examine dozens or even hundreds of categories, but only present the positive or interesting associations. That occupations with asbestos exposure are often identified as linked with lung cancer risk, coupled with silence regarding automobile mechanics, provides further, although indirect, confirmatory evidence against an association.

Case-Control Studies

We categorized the case-control studies by

- whether the study controlled for smoking;
- the source of the control population, and
- whether they specifically include information on automobile mechanics as opposed to a broader category of mechanics.

Control for smoking and other risk factors is closely related to the selection of the control population, as most population and hospital-based studies can obtain information on potential confounders, whereas death-certificate studies are not. The details are presented in Table 3.

The studies that rely on controls selected from the general population and include complete job and smoking histories collected by interview are the most informative. In a U.S. study in areas of New Jersey with high lung cancer rates, Schoenberg and colleagues /36/ identified 763 lung cancer cases from the state cancer registry and 900 population-based controls. The authors defined 'automobile mechanics' as anyone working for at least 3 months after age 12 in that profession. The smoking-adjusted OR was modestly elevated but not statistically significant (OR = 1.4; 95% CI: 0.84–2.30). Vineis /37/ and others incorporated these data with similar information from cancer registries and cooperating hospitals in Louisiana, Florida, Pennsylvania, and Virginia, but also found no statistically significant differences between the case and control groups in previous employment as an automobile mechanic. Lerchen and coworkers /38/ in New Mexico compared 333 men with lung cancer to 499 men selected from the state's

TABLE 3

Case-control studies, organized by population type: Lung cancer results

Author	Study population	Outcomes included	Exposure assessment	Controls	Adjustment for	Mechanic definition; number	Lung cancer Results
Studies that control for smoking							
Schoenberg et al. 1987 (36) *Included in Vineis et al 1988*	NJ, US; 6 geo. Areas with high lung cancer rates fr 1967-76; white males; 1980-81	Lung cancer n=763	Interview; lifetime occupational history; job ≥3 mo after age 12	General population n=800	Race, age, residence, type interview, smoking	Auto mechanics: case=44, control=40	OR=1.4 (0.84-2.3)
Vineis et al. 1988 [1] (37)	Data from 5 US case-control studies (hospital and population based) residents of LA, FL, PA, VA, NJ	Lung cancer n=2,973	Interview lifetime occupational history, job ≥6 mo	n=3,210	Age, birth cohort, smoking	Auto brake worker: case=98, control=90, OR=1.2 (0.9-1.7)	OR=1.2 (0.9-1.7)
Lerchen et al. 1987 (38)	New Mexico, Hispanic white and other white males age 25-84, 1980-82	Lung cancer males n=333	Interview; lifetime occupational history, job ≥1 yr after age 12	General population Males n=[illegible]	Age, smoking	Auto mechanics: case=15, control=26	OR=0.9 (0.5-1.5)
Levin et al. 1988 (39)	Shanghai, China, males age 35-65; 1984-85	Lung cancer n=733	Interview; Lifetime occ history; job ≥ 1 yr after age 16	General population n=760	Age, smoking,	Auto mechanics not mentioned	NA

Abbreviations: DC = death certificates, n=number, OR=odds ratio, sMOR=standardized mortality ratio, RR=relative risk
Confidence bounds = 95% CI unless otherwise indicated

[1] Includes data from Schoenberg et al 1987; other studies did not make our cut, so not included individually

TABLE 3

Case-control studies, organized by population type: Lung cancer results

Author	Study population	Outcomes included	Exposure assessment	Controls	Adjustment for	Mechanic definition; number	Lung cancer Results
Williams et al. 1977 (40)	Third National Cancer Survey Interview Study, U.S.	All cancer; males n=[illegible]	Interview; life time, recent occupational history	Other cancers	Age, race, education, smoking, alcohol, residence	Auto mechanics; cases=[illegible]	Not reported as elevated
Burns & Swanson 1991 (90) *(See Swanson et al. 1993)*	Detroit Occupational Cancer Incidence Surveillance System; age 40-85; 1984-87	Lung cancer n=5,935	Interview; lifetime occupational history, duties, usual occupation	Cancers of colon or rectum n=3,956; compared to occupation and industry with least potential for exp to carcinogens	Age, smoking, race	Motor vehicle mechanic (occupation) v: case=118, control=48, blacks only: case=31, control=6	ALL: OR=1.72 (1.15-2.59); BLACKS: OR=4.16 (1.27-13.64)
Swanson et al. 1993 (41)	(see Burns & Swanson 1991)	Lung cancer n=3,792	Interview; duration of employment	Cancers of colon or rectum n=[illegible]	Age, smoking, race	Auto mechanics, 20+ years employed; Whites: cases=[illegible], control=[illegible]; Blacks: case=[illegible], control=[illegible]	Whites: OR=[illegible] ([illegible]); Blacks: OR=[illegible] ([illegible]-35.0)
Benhamou et al. 1988 (42)	France; 1976-80	Lung cancer n=1,260	Interview lifetime occ history, ≥1 year	Hospital based, non-tobacco related disease cases n=2,064	Gender, age, hospital admission, interviewer, smoking	Motor vehicle mechanics; case=65, control=96	RR=1.06 (0.73-1.54)

Abbreviations: DC = death certificates, n=number, OR=odds ratio, sMOR=standardized mortality ratio, RR=relative risk.
Confidence bounds = 95% CI unless otherwise indicated

TABLE 3 (continued)

Case-control studies, organized by population type: Lung cancer results

Author	Study population	Outcomes included	Exposure assessment	Controls	Adjustment for	Mechanic definition; number	Lung cancer Results
Spinelli et al. 1990 (43)	Diagnoses at Cancer Control Agency of British Columbia, Canada; males ≥20; 1950-75	All cancer n=8,389	Medical records: usual occupation	Hospital based, other cancers	Age, yr (did not control for smoking)	Auto mechanics not listed as elevated	NA
Morabia et al. 1992 (44)	24 hospitals in 9 metropolitan areas, US; males 1980-89	Lung cancer n=1,793	Interview; usual occupation	Hospital based, other cancer and non-cancer admittances, n=3,228	Age, race, hospital, date of admission, smoking	Mechanics, repairmen, auto: controls=39	OR=0.7
Zahm et al. 1989 * (45)	Missouri, US; white males; 1980-85	Lung cancer n=4,431	Registry: occupation at diagnosis	Other cancers reported to Registry excl. lip, oral cavity, esophagus, bladder, ill-defined and unknown n=11,326	Age, smoking at diagnosis	Mechanics and repairers: case=106, control=177	OR=1.3 (1.0-1.7)
Breslow et al. 1954 * (47)	California, US; 11 hospitals 1949-52	Lung cancer n=518	Interview Employed in occupation at least 5 years	Hospital based: Non-cancer or chest disease cases, n=518	Age, race, gender, smoking available	Mechanic and repairmen, not elsewhere classified: cases=15, controls=16	Not calculated
Wang et al. 1995* (46)	Tianjin, China males ≥ 20; 1981-87	Lung cancer n=4,806	Registry: most recent occupation	Other cancers, n=14,885	Used survey data to rank occupations by smoking status	Mechanics, repair industries	Not mentioned as elevated
Decoufle & Stanislawczyk 1977* (48)	Roswell Park *Memorial Institute*, Buffalo NY, US white males, 1956-65	All cancer n=8,434	Interview, *lifetime* occ history	Hospital based: Non-cancer cases unexposed= clerical workers	Age, smoking	Mechanics and repairmen: lung ca: case=84 employed >5 yrs: lung ca: case=63	Ever employed: OR=1.12 p>0.05 Employed >5 yrs: OR=1.10 p>0.05

Abbreviations: DC = death certificates, n=number, OR=odds ratio, sMOR=standardized mortality ratio, RR=relative risk
Confidence bounds = 95% CI unless otherwise indicated

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population. The authors found proportionately fewer automobile mechanics (identified as in the Schoenberg study) among the cases than the controls (OR = 0.9; 95% CI: 0.5–1.9). A similarly designed study in Shanghai China did not mention automobile mechanics in their results /39/.

Next we review case-control studies that compare lung cancer cases to men with other kinds of cancer. This approach is not as reliable as selecting controls from the general population because the authors must assume that automobile mechanics are at the same risk as the general population for those other cancers used for comparison. As in the general population studies, work and smoking histories were obtained by interview. Williams and colleagues /40/ compared lung cancer cases with other cancers in the Third National Cancer Survey population. No excess of lifetime or most recent work as an automobile mechanic was found among cases compared with controls /40/. Burns and Swanson /41/, working in the Detroit Metropolitan Area, found a statistically significant OR for automobile mechanics when comparing lung cancer cases with colorectal cancer cases (OR = 1.72; 95% CI: 1.15–2.59). This result more likely represents a deficit of automobile mechanics among patients with colorectal cancer than a direct link with lung cancer. In a follow-up of this study, the authors evaluated the risk of lung cancer by number of years employed in specific occupations separately for black and white men. The authors observed a significant excess of automobile mechanics who had been working for at least 20 years among black lung cancer cases (OR = 6.9; 95% CI: 1.4–35.0) but not among white cases (OR = 1.5; 95% CI: 0.70–3.00). The number of black cases and controls was small, however, and risk did not increase linearly with increasing years of employment in either white or black subjects. Three case-control studies compared men hospitalized for lung cancer with men hospitalized for other causes, controlled for smoking, and specifically assessed automobile mechanics. None of the three studies found an excess of automobile mechanics among the cases compared with the controls /42–44/.

We also identified six additional case-control studies using cancer controls that included results for a more general grouping of mechanics, presumably including automobile mechanics. Zahm et al. /45/ observed a modest excess of mechanics and repairers among lung cancer controls in Missouri (OR = 1.3; 95% CI: 1.0–1.7). The other five studies found no material association between work as a mechanic and lung cancer risk /46–50/.

In three death-certificate based case-control studies, the controls were drawn from among the non-lung cancer deaths in the general population. These studies relied on the information provided on the death certificate to determine usual or last occupation and did not control for smoking. Dubrow and Wegman observed 29% /51/ and Milne and colleagues 20% more automobile mechanics /52/ among their cases than among their controls. Neither result was statistically significant. In a similarly designed study by Finkelstein and colleagues /53/, 12% fewer automobile mechanics were found among lung cancer deaths than among other deaths.

MESOTHELIOMA

Case-Control and Cohort Studies

Exposure to asbestos is strongly associated with risk of malignant mesothelioma of the pleural and peritoneal lining. A baseline incidence of the disease is not attributable to asbestos exposure, but in the majority of cases some contact with asbestos can be documented /54/. Although only amphibole fibers, as opposed to chrysotile (the asbestos form used in friction products), have been consistently linked with the disease /54/, the association of mesothelioma with work as a brake mechanic has been explored. We reviewed this literature here (Table 4).

Several of the studies discussed above included mesothelioma as well as lung cancer. Four mesothelioma cases were reported in the cohort studies focusing on automobile and bus mechanics (one each by Jarvholm and Brisman /17/ and by Hansen /18/ and two by Gustavsson et al. /21/). In all cases the authors mentioned possible other types of exposure to asbestos from previous employment and concluded that no suggestion of an increased risk of mesothelioma could be ascribed to work as an automobile or bus mechanic. Mesothelioma was reported in three of the general cancer surveys. Olsen and Jensen /30/ stated that no mesothelioma cases were reported among men who repaired automobiles and motorcycles in Denmark. Dubrow and Wegman /55/ reported on mesothelioma but did not observe any cases among automobile mechanics. The NOMS study reported 18 mesotheliomas among white automobile mechanics (PMR = 0.77) and 2 among black mechanics (PMR = 1.54) /15/. The Blair study of cancer mortality among U.S. veterans did not mention mesothelioma /22/, and the follow-up study by Hrubec et al. /23/ grouped all respiratory cancers together.

We identified 11 studies that focused on mesothelioma and occupation /56–67/. None of these studies reported a significant association between mesothelioma and work specifically as an automobile mechanic. Malker and colleagues /68/ observed a statistically significant elevated incidence of mesothelioma among the broad category of mechanics and repairmen (not limited to automobile mechanics). This finding, however, was based on only 16 cases dispersed across a variety of industries, including railroad equipment manufacture, sugar factories, and shipbuilding, so whether the cases were exposed to asbestos through work on brakes is unclear. Jarvholm and Brisman's study /17/, cited earlier, extended Malker's work, focusing more closely on automobile mechanics, among whom only one case of mesothelioma was found. All these studies reported an increased representation of insulation workers and other jobs with overt asbestos exposure among the cases, lending further credibility to the null findings for automobile mechanics.

Woitowitz and Rodelsperger performed a case-control study of 324 cases of mesothelioma in Germany and presented the results relating to automobile mechanics in a separate publication /69/. The authors identified 16 automobile mechanics among the case patients, and 16 among 315 hospital controls, most of whom had lung cancer, and 12 among 182 population controls. The comparison between the cases and the hospital controls is uninformative because lung cancer is also hypothesized to be associated with the exposure. No evidence of an excess risk of mesothelioma was found for automobile mechanics using the population controls. The authors include individual descriptions of duration of employment, history of brake service, and other asbestos exposure for each automobile mechanic. All work histories were very similar, regardless of their disease status. Because no comparison statistics, including ORs, were calculated, and the nature of this study was primarily descriptive, it may be more appropriate to consider this investigation a case series as opposed to a formal case-control study.

In 2001, Wong /70/ published a meta analysis combining the results from six studies that assessed mesothelioma among automobile mechanics—McDonald and McDonald, 1980 /57/, Teta et al., 1983 /58/, Spirtas et al., 1985 /60/, 1994 /61/, Woitowitz and Rodelsperger, 1994 /69/, Teschke et al., 1997 (63) and Agudo et al., 2000 /65/. Wong calculated the RRs for the individual studies from the available data when they were not

TABLE 4

Studies of mesothelioma among male automobile mechanics

Author	Study Population	Outcome Assessment	Exposure assessment	Comparison population	Mesothelioma Results
Studies of all cancer, including a mention of mesothelioma					
Jarvholm & Brisman 1988 (17)	Males, age 20-69, employed as mechanic or in car repair in 1960 in Sweden; n=21,905	Death Registry 1961-73 Cancer Registry 1961-79	Census occupational and industry codes	General population	"Car repair mechanic"; cases=1 (had worked as construction worker)
Hansen 1989 (18)	Occupationally active, skilled male workers, age 15-74 in 1970 in Denmark, n=21,800	Death Registry, DC, 1970-80	Census	Carpenter, electrician, instrument maker, dairyman, upholsterer, glazier n=51,747	"Auto mechanic" or "mechanic, employed at car-repair workshop" cases=1
Gustavsson et al. 1990 (21)	Males employed at least 6 months in 5 Stockholm bus garages from 1945-1970, n=695	Death Registry & other local records 1952-86 Cancer Registry 1958-84	Cumulative exposure to asbestos from Company records and In reports (TWA exposure levels)	Stockholm occupationally active population and general population	Mechanics, servicemen, hostlers, cases=2
Olsen & Jensen 1987 (30)	Denmark, all cancer cases 1970-79 n=90,651	Cancer Registry; Supplementary pension fund; central population registry	Supplementary pension fund; central population registry	Whole cohort of cancer cases	"Repair of motor vehicles and motor cycles" cases=0
Dubrow & Wegman 1984a (55)	Massachusetts US; all deaths 1971-73, white males, age ≥20	DC	DC	DC based: Other (auxiliary) diseases, except cancer and cirrhosis of the liver	"Mechanics and repairman, vehicle (grouped)"; no cases mentioned
NIOSH 2002 (15)	National Occupational Mortality Surveillance (NOMS), 28 states; age 15-90; 1984-1998	DC	DC	NOMS population	"Automobile mechanic": *Pleura and peritoneal* – Whites: n=18, PMR=0.77 Blacks: n=2, PMR=1.54; p>0.05

Abbreviations: DC = death certificates, n=number, OR=odds ratio, PMR=proportional mortality ratio, RR=relative risk, SIR=standardized incidence rate, sMOR=standardized mortality ratio
Confidence bounds = 95% CI unless otherwise indicated

TABLE 4 (continued)

Studies of mesothelioma among male automobile mechanics

Author	Study Population	Outcome Assessment	Exposure assessment	Comparison population	Mesothelioma Results
Studies that focus on mesothelioma					
McDonald et al. 1970 (56)	Quebec Canada deaths from pleural and peritoneal mesothelioma 1959-67, n=165	Identified through registered pathologists	Ever employment from next-of-kin questionnaire	Primary and secondary lung cancer deaths from same pathologists (1 each per each case)	"Brakelining installation" cases=2, controls=0
McDonald and McDonald 1980 (57); *(includes cases from McDonald et al. 1970)*	Quebec Canada 1959-72 and USA 1972, deaths from pleural and peritoneal mesothelioma in n=344 men	Identified through registered pathologists	Next-of-kin questionnaire	Secondary lung cancer deaths from same pathologists (1:1)	"Garage workers" cases=11, controls=12
Teta et al. 1983 (58)	Connecticut, USA, deaths from mesothelioma and other pleural tumors in men > 30 yrs, 1955-77, n=1[illegible] mesotheliomas, 11 other pleural tumors	Connecticut Tumor Registry, confirmed by pathology review	DCs for usual employment; city directories for employment histories 1, 10, 20, 25, 30, 40, 50 yrs before date of diagnosis	Random sample of DC files of the Bureau of Health Statistics of the Connecticut State Department of Health Services, age [illegible]	Job title: "automobile mechanic" – cases not listed; Industry: "Automobile repair and related services" cases=6, RR=0.65 (0.08-5.53)
Malker et al. 1985 (59)	Sweden, incident mesotheliomas 1961-79, n=318	National Swedish Cancer Registry	1960 Census	General Swedish population	"Mechanics and repairmen" SIR=2.4, p<0.01
Spirtas et al. 1985 (60)	LA County, CA, NY State, Veterans Admin hospitals, mesotheliomas 1975-1980, n=259	Cancer Registry	Next-of-kin interviews	Not specified	"Brake lining installation or repair" OR=1.0 (0.6-1.8)
Spirtas et al. 1994 (61) *(update of Spirtas et al. 1985)*	LA County, CA, NY State, Veterans Admin hospitals, mesotheliomas 1975-1980, n=208 confirmed cases	Cancer Registries and VA Central Office	Next-of-kin interviews	Deaths from causes other than cancer, respiratory disease, suicide, or violence, n=533	"Brake lining work or repair" cases=33 (15.8%), controls=72 (13.5%) (at least 55% had additional overt asbestos exposure)
Woitowitz and Rodelsperger 1994 (69)	Patients at the Outpatient clinic of Occupational and Social Medicine of the Justus Liebig University Giessen, Germany, mesotheliomas n=324	Hospital setting	Interview	[illegible] lung cancer cases, 182 population controls	"Motor vehicle mechanics" cases=16, lung cancer controls=16, population controls=12

Abbreviations: DC = death certificates, n=number, OR=odds ratio, PMR=proportional mortality ratio, RR=relative risk, SIR=standardized incidence rate, sMOR=standardized mortality ratio
Confidence bounds = 95% CI unless otherwise indicated

TABLE 4.

Studies of mesothelioma among male automobile mechanics

Author	Study Population	Outcome Assessment	Exposure assessment	Comparison population	Mesothelioma Results
Coggon et al 1995 (62)	England and Wales, males, age 20-74, cancer of pleura (n=2,848), cancer of peritoneum (n=362), asbestosis (n=281) 1979-80, 82-90	DC	DC	General population	"Motor mechanics" pleural cancer: n=12, PMR=48; peritoneal cancer: n=3, PMR=88
Teschke et al. 1997 (63)	British Columbia, pleural mesothelioma, 1990-1992 (n=[illegible])	British Columbia Cancer Agency	Interview with patient or next-of-kin	Random selection from provincial voters list	"Vehicle mechanics – ever employed" cases=[illegible], controls=20, OR=0.8 (0.2-2.3); "brake lining installation or repair": cases=2, controls=17, OR=0.3 (0-1.4); "vehicle mechanics with no work in at-risk occupations": cases=1, controls=15, OR=0.4 ([illegible])
Cocco & Dosemeci 1999 (64)	24 US States, peritoneal mesotheliomas 1984-92, n=408 males	DC	DC	Deaths from non-malignant diseases	"Not specified mechanics and repairers (occ)"as above OR=1.8 (0.5-6.5)
Agudo et al. 2000 (65)	2 provinces in Spain: Barcelona, Cadiz, pleural mesothelioma 1993-96, n=132	Hospital based	Interview: occupation ≥6 months	Other hospital patients	"Occupation: mechanics, motor vehicles" cases=[illegible], controls=14
McDonald et al 2001 (66)	United Kingdom: Surveillance of Work-related and Occupational Respiratory Disease (SWORD), born 1943 or later, mesotheliomas 1990-96, n=115 males	SWORD records	Occupational history from Medical records; interview with practitioner	Census 1960, 1970, 1980, 1990	Automobile mechanics not listed
Wong 2001 (70)	Meta-analysis of McDonald and McDonald 1980, Teta et al. 1983, Spirtas et al. 1985, Woitowitz and Rodelsperger 1994, Teschke et al 1997, Agudo et al 2000	(see individual studies)	(see individual studies)	(see individual studies)	"Automobile mechanics" Combined RR=0.90 (0.66-1.23)
Hemminki et al. 2003 (67)	Sweden, all persons born after 1931 and their parents, peritoneal mesothelioma 1961-98, n=96 males	Cancer registry	Census 1960	Standard European population	"Mechanics" - cases=6, SIR=0.86 (0.31-1.87)

Abbreviations: DC = death certificates, n=number, OR=odds ratio, PMR=proportional mortality ratio, RR=relative risk, SIR=standardized incidence rate, sMOR=standardized mortality ratio
Confidence bounds = 95% CI unless otherwise indicated

presented. All of these studies separately were null and the combined relative risk was 0.90 (95% CI: 0.66–1.23).

Case Series and Case Reports

Because mesothelioma is rare—The Surveillance, Epidemiology and Risk Program (SEER) reports an age-adjusted incidence rate of 2.1 cases per 100,000 males /71/—diagnoses are often described in case series or case reports. Such studies provide little useful information in assessing risk because the lack of a comparison group precludes any quantitative estimate. Because of the rarity of the disease, however, exposure histories do provide important insights into the potential sources of exposure. Therefore, for completeness, we include these studies in our summary.

Case series: We identified six studies in which all mesothelioma cases in a population diagnosed during a specific time period were assessed for their potential exposure to asbestos, including employment as an automobile mechanic. In a series of 41 male patients diagnosed at the London Hospital from 1915 to 1965, one case reported exposure to crocidolite asbestos through the manufacture of brake linings /72/. One case out of 413 identified by the Mesothelioma Register in Great Britain from 1967 to 1968 was employed as an automobile mechanic. Ship workers (n = 75), asbestos factory workers (n = 39), and insulation workers (n = 13) were the most represented occupations /73/. Seventy cases of mesothelioma were observed in the region of Nantes-St. Nazaire, France between 1956 and 1978 /74/. Four were employed as mechanics. In the Australian Mesothelioma Surveillance Program, 1980–1985, 871 confirmed cases were identified. Of these cases, eight were employed as automobile mechanics /75/. In a series of 148 cases of mesothelioma identified among peasants residing in rural parts of Turkey, one patient reported employment as an automobile mechanic /76/. In an additional study, 13 cases of mesothelioma were reported over a 5-year period among members of the International Association of Machinists and Aerospace Workers. One case had been employed as an automobile mechanic /77/.

We also identified two studies where lung-fiber analyses were performed on series of mesothelioma cases identified by occupation. Roggli and colleagues /78/ reported asbestos body counts and levels of commercial and noncommercial amphibole fibers (a form of asbestos consistently associated with mesothelioma) among 1445 cases, including 51 with some work as an automobile mechanic, brake-repair worker, or brake-line worker. The results of the fiber burden analysis led the authors to conclude that the tumors were unlikely to be due to exposure to automotive brakes (chrysotile fibers). The same researchers also published a study focusing on 10 cases of mesothelioma for which brake dust was the only known source of asbestos exposure /79/. (Whether these cases were included in the 2002 study is not clear.) Again the lung fiber analysis suggested that work as an automobile mechanic is unlikely to contribute to the development of mesothelioma.

Case reports: Three reports of individual mesothelioma cases potentially associated with exposure to asbestos through brake-repair work were published in the 1980s. Two were automobile mechanics who experienced no other recorded potential exposure to asbestos /80–81/. The other case was an elevator mechanic who worked with elevator brake pads /82/. In a letter in response to this report, Kilpatrick /83/ argued that elevator mechanics often work in buildings that are undergoing renovations and construction. Thus, primary exposure might have been to amphibole from asbestos fire retardants sprayed into the building by other workmen, as opposed to chrysotile asbestos in brake pads. Without a quantitative comparison, the case reports are merely anecdotal.

DISCUSSION AND CONCLUSIONS

In this paper, we have reviewed the analytical studies of risks of lung cancer or mesothelioma among automobile mechanics, plus all available case series and case reports. These studies represent thousands of cases of disease and hundreds of thousands of individuals who were followed. When examined in aggregate, the consistent pattern that emerges from this research indicates no increase in risk of either lung cancer or mesothelioma in this occupational group.

Many studies have important limitations, principally in the exposure assessment in most instances. In many studies, men were grouped into occupation based on one-time reports of usual or last occupation on death certificates, medical records, or the census. Other studies included some assessment of lifetime work history, but often it was not detailed. One consequence of such inadequate exposure assessment is that the duration of exposure was largely ignored; men who worked an entire lifetime as an automobile mechanic might be grouped together with those who had worked in this occupation for only a short time. Furthermore, some automobile mechanics who were employed in the past might not have been identified because at the time of reporting they were working in another occupation. Employment as an 'automobile mechanic' also does not necessarily capture exposure to brakes or clutch repair work. Few of the studies actually included an assessment of exposure to friction products. The length of time spent repairing brakes, the actual activities, the condition of the brakes, and the implementation of safety measures all might influence a person's exposure. Grouping together workers with such different experiences leads to a misclassification of exposure, which may tend to attenuate relative risk estimates.

Another potential source of misclassification of exposure is the long latency of lung cancer and mesothelioma. It is estimated that it takes at least 10 to 20 years after first exposure to a carcinogen for these diseases to develop. When duration and timing of employment is not considered, essentially unexposed people are included within the exposed group, possibly leading to biased relative risks. The few studies that considered this latency, however, did not find increased risks.

Potential confounding factors are inadequately evaluated in the majority of these studies. Cigarette smoking, the key risk factor for lung cancer, was seldom assessed. Several studies indicate that smoking among brake mechanics was more common than in the comparison group, which would yield observed relative risks that are overestimates. Although nearly all studies reported relative risks near the null value, those that adjusted for smoking tended to yield relative risks closer to 1.0, as one might expect from confounding by smoking. In addition, some automobile mechanics may have been employed in other occupations or involved in other activities with overt exposures to asbestos, potentially leading to an over-estimated relative risk.

All these limitations also apply to evaluations, in many of these same studies, of other occupations with known overt exposures to asbestos such as pipefitters, construction workers, and insulation workers. The expected elevated relative risks, however, were indeed observed for these other workers, implying that if an excess risk of lung cancer or mesothelioma had been present among automobile mechanics, these studies would have been able to detect it. Furthermore, the exposure to asbestos, in a form likely to be carcinogenic, was found to be quite small in industrial hygiene surveys of brake repair work /10/. In addition, studies of workers in factories that manufacture asbestos-containing brakes do not appear to be at higher risk for such cancers /11; 84–88/. Thus, these observations, along with the weight of the evidence from the studies described here, supports the conclusion that automobile mechanics are not at elevated risk of lung cancer or mesothelioma from their occupation.

ACKNOWLEDGMENTS

The authors thank Sarah Corey, Rachel Adams, Jeanne Grol, and Jaime Hart for their help with the preparation of the manuscript. This work was supported in part through a consultation agreement with the law firm of Barnard, Mezzanotte, and Pinnie, who had no control over the content of this paper and did not see any draft of the text prior to the final proofs. Dr. Laden was also supported by a National Institute of Health National Research Service Award T32HL07427.

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HWBUI0011524