Mortality Among US Commercial Pilots And Navigators

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The airline industry may be an occupational setting with specific health risks. Two environmental agents to which flight crews are known to be exposed are cosmic radiation and magnetic fields generated by the aircraft's electrical system. Other factors to be considered are circadian disruption and conditions specific to air travel, such as noise, vibration, mild hypoxia, reduced atmospheric pressure, low humidity, and air quality. This study investigated mortality among US commercial pilots and navigators, using proportional mortality ratios for cancer and noncancer end points. Proportional cancer mortality ratios and mortality odds ratios were also calculated for comparison to the proportional mortality ratios for cancer causes of death. Results indicated that US pilots and navigators have experienced significantly increased mortality due to cancer of the kidney and renal pelvis, motor neuron disease, and external causes. In addition, increased mortality due to prostate cancer, brain cancer, colon cancer, and cancer of the lip, buccal cavity, and pharynx was suggested. Mortality was significantly decreased for 11 causes. To determine if these health outcomes are related to occupational exposures, it will be necessary to quantify each exposure separately, to study the potential synergy of effects, and to couple this information with disease data on an individual basis.

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1076-2752/98/4011-0980$3.00/0

Commercial pilots, navigators, and other flight crew members are exposed to cosmic radiation and to magnetic fields generated by the aircraft's electrical system. Other factors to be considered are circadian disruption and conditions specific to air travel, such as noise, vibration, mild hypoxia, reduced atmospheric pressure, low humidity, and air quality. Specific disease risks have been identified in health studies among commercial flight crews outside of the United States and among military pilots within the United States. Incidence studies suggest an increase in hormone-sensitive tumors; for example, breast cancer in both Finnish[1] and Danish[2] flight attendants, prostate cancer in Air Canada pilots,[3] and testicular cancer in US Air Force pilots.[4] Mortality studies among flight crews in Japan,[5] Canada,[3,6] and England[7] have produced inconsistent results. This may be due in part to small sample sizes, ranging from only 59 to 411 deaths per study.[3,5–7] It was the purpose of this study to investigate mortality among the much larger group of 1538 deaths among US commercial pilots and navigators.

Methods

Since 1984, industry and occupation have been coded on death certificates in 24 states (Colorado, Georgia, Idaho, Indiana, Kansas, Kentucky, Maine, Missouri, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, North Carolina, Ohio, Oklahoma, Rhode Island, South Carolina, Tennessee, Utah, Vermont, Washington, West

TABLE 1

United States Commercial Pilots and Navigators Proportional Mortality Ratios for All Causes of Death, 1984–1991*

Cause	O	E	O/E (95% CI)
All malignant neoplasms	407	387.81	1.05 (0.95–1.16)
Lip, buccal cavity, and pharynx	14	8.32	1.68 (0.92–2.82)
Digestive organs and peritoneum	92	86.16	1.07 (0.86–1.31)
Stomach	5	10.72	0.47 (0.15–1.09)
Colon†	42	33.22	1.26 (0.91–1.71)
Respiratory system	133	148.67	0.89 (0.75–1.06)
Trachea, bronchus, and lung	130	143.17	0.91 (0.76–1.08)
Melanoma‡	11	8.59	1.28 (0.64–2.29)
Other skin (non-melanoma and not otherwise specified)	3	2.22	1.35 (0.27–3.94)
Breast	2	2.36	0.85 (0.10–3.06)
Prostate	38	27.56	1.38 (0.98–1.89)
Kidney and renal pelvis	19	9.71	1.96 (1.18–3.06)
Brain	19	12.74	1.49 (0.90–2.33)
All lymphatic and hematopoietic	36	39.11	0.92 (0.64–1.27)
Leukemia and aleukemia	16	14.76	1.08 (0.62–1.76)
All causes of death except cancer	1131	1150.19	0.98 (0.93–1.04)
All infective and parasitic disease	18	39.53	0.46 (0.27–0.72)
AIDS	6	22.23	0.27 (0.10–0.59)
Endocrine, metabolic, nutritional diseases, immune disorders	27	36.57	0.74 (0.49–1.07)
Diseases of nervous system and sense organs	31	23.36	1.33 (0.90–1.88)
Motor neuron disease	8	3.40	2.35 (1.01–4.63)
Diseases of circulatory system	449	589.20	0.76 (0.69–0.84)
Arteriosclerotic heart disease, including CHD (IHD)	290	395.80	0.73 (0.65–0.82)
Cerebrovascular disease (all vascular lesions of CNS)	50	62.54	0.80 (0.59–1.05)
All respiratory diseases	72	109.72	0.66 (0.51–0.83)
Pneumonia	17	32.57	0.52 (0.30–0.84)
All diseases of digestive system	40	58.21	0.69 (0.49–0.94)
All external causes of death	442	228.92	1.93 (1.76–2.12)

* O, observed number; E, expected number; 95% CI, 95% confidence interval; CHD, congenital heart disease; IHD, ischemic heart disease; CNS, central nervous system.

† Large intestine, excluding rectum.

‡ Except scrotum.

Virginia, and Wisconsin). The coding scheme used is the Bureau of the Census Index of Industries and Occupations.

The mortality among US airline pilots and navigators (occupational code 226) was investigated using proportional mortality ratios (PMRs) for cancer and noncancer end points. All ratios were calculated for the years 1984 to 1991 and adjusted for race, sex, age, and region, using a mortality analysis program developed by the National Cancer Institute (NCI).[8] Expected numbers were based on the 24-state data for all occupations combined. Proportional cancer mortality ratios (PCMRs) and mortality odds ratios (MORs) were also calculated for comparison to the PMRs for cancer causes of death.

Among pilots and navigators, there was a total of 1538 deaths, with 1502 of these among white males, 11 among non-white males, and 25 among white females. The occupational code 226 for pilots and navigators applies only to civilians; military pilots are listed in the military occupations combined and are not included in this study. Flight attendants could not be included because they are not separated from other airline workers by an individual occupational code.

Results

PMR results for all causes of death, 1984–1991, are given in Table 1. Cancer of the kidney and renal pelvis was the only cancer cause of death to be significantly increased. This finding was supported by significant increases also in the PCMR and MOR analyses (Table 2).

Increased cancer mortality was suggested for prostate cancer, brain cancer, colon cancer, and cancer of the lip, buccal cavity, and pharynx. PMRs, with supporting PCMRs and MORs, for each of these cancers are given in Table 2.

In addition, decreased cancer mortality was suggested for stomach cancer and cancer of the trachea, bronchus, and lung.

Among noncancer causes of death, the only causes to be significantly increased were motor neuron disease and all external causes of death. An increase was suggested for diseases of the nervous system and sense organs, particularly in the age groups of 60–74 years (PMR, 2.05; 95% confidence interval [CI], 1.22–3.25) and 75+ years (PMR, 2.06; 95% CI, 1.03–3.69).

Numerous noncancer causes of death were significantly decreased (seven disease causes and four nondisease causes). Specifically, these

TABLE 2
United States Commercial Pilots and Navigators PCMRs, PMRs, and MORs for Selected Cancer Causes of Death, 1984–1991*

Cancer Cause	PCMR (95% CI)	PMR (95% CI)	MOR (95% CI)
Kidney	1.88 (1.13–2.93)	1.96 (1.18–3.06)	2.00 (1.29–3.10)
Prostate	1.15 (0.82–1.58)	1.38 (0.98–1.89)	1.46 (1.06–2.03)
Brain	1.59 (0.96–2.48)†	1.49 (0.90–2.33)	1.49 (0.95–2.34)
Colon	1.17 (0.84–1.58)	1.26 (0.91–1.71)	1.30 (0.96–1.77)
Lip, buccal cavity, pharynx	1.64 (0.90–2.75)‡	1.68 (0.92–2.82)	1.71 (1.01–2.89)

† Brain/CNS.
‡ Buccal cavity and pharynx.
* PCMRs, proportional cancer mortality ratios; PMRs, proportional mortality ratios; MOR, mortality odds ratios.

were diseases of the circulatory system; arteriosclerotic heart disease, including coronary heart disease (ischemic heart disease); all respiratory diseases; pneumonia; all diseases of the digestive system; infective and parasitic disease; AIDS; motor vehicle and other road vehicle accidents; other nontransport unintentional trauma; homicide; and firearms.

Discussion

In the following discussion, results for diseases identified by this study as potential causes of increased mortality among flight crews are compared with results from other studies. It should be noted that both study design and sample size vary across the studies compared, accounting for some of the variation in the results.

An increase in prostate cancer mortality was suggested among US commercial pilots and navigators. In other studies, prostate cancer was increased in a standardized incidence ratio (SIR) study of Air Canada pilots[3] and in a PMR study of British Airways pilots.[7] Additionally, testicular cancer was significantly increased in a relative risk study of US Air Force pilots.[4]

The sensitivity of the prostate to ionizing radiation appears to be low,[9] but prostate cancer has been associated with magnetic fields. It has been proposed that magnetic field exposure may alter pineal function, leading to reduced production of the pineal hormone melatonin. Reduced melatonin concentration may lead to an increased secretion of prolactin and gonadal steroids (eg, estrogen and testosterone). This increase may, in turn, cause proliferation of cell division in breast or prostate tissue and stimulate growth of initiated cancer cells.[10,11] Patients with primary preoperative mammary and prostate cancer show a clear tumor size–dependent decrease in melatonin secretion.[12] Serum melatonin levels in elderly men showed that those with prostate carcinoma had a significantly lower average nighttime peak than did men without cancer. In Fisher rats inoculated with prostatic adenocarcinoma cells, the injection of melatonin has reduced serum testosterone concentration, reduced the size of the prostate gland, and slowed the growth of prostate cancer cells.[10]

In addition to prostate cancer, suppression of pineal function has been implicated in the etiology of certain other cancers, including breast cancer and melanoma.[10] However, it should be noted that the link between magnetic fields and suppression of pineal function is as yet unproven in humans. Other factors that may affect pineal function are sleep disruption, light at night, and certain medications.

The results of the present study indicated no significant difference in mortality due to melanoma. Other studies finding no significant difference in melanoma were as follows: Finnish flight attendants (SIR study),[1] Air Canada pilots (SIR study),[3] and British Columbia pilots (PMR study).[6] In a study of US Air Force pilots compared with other nonflying officers, the relative risk for melanoma was not significant; however, the SIR approached significance when the pilots were compared with a Surveillance Epidemiology, and End Results population.[4] Significant increases were found among British Airways pilots in PMR and PCMR studies[7] and among pilots in England, Wales, and Sweden in an incidence study.[13] Although results on melanoma are inconsistent, further study seems warranted because of the potential association of melanoma with intense, intermittent sun exposure[14] and with the suppression of pineal function.[10]

A significant increase in mortality due to cancer of the kidney and renal pelvis was consistently demonstrated in each of the PMR, MOR, and PCMR analyses of US commercial pilots and navigators. However, kidney cancer results from other studies of airline flight crews have not shown a significant difference in either mortality or incidence.[3,7]

Kidney cancer is often associated with tobacco use, but tobacco as a contributing agent is counterindicated by significant decreases in all respiratory diseases. The BEIR V report[9] cites epidemiologic evidence for both genders showing that ionizing radiation is associated with cancer of the bladder, and, to a lesser extent, of the kidneys and other urinary organs; however, the associated dose levels (relative risk, 2.3 urinary tract cancer deaths per Gray of absorbed Dosimetry System 1986 dose) are much higher than those encountered by flight crews. The association of kidney and renal cancer to hormonal agents is uncertain but has been investigated. Human kidney tissues (malignant and normal) contain estrogen receptors.[15] Thus it has been suggested that renal cell carcinoma is hormone-dependent in a manner similar to that of breast and prostate cancers. A study of reproductive factors and the risk of renal cell cancer among women[16] found an increased risk among women who used menopausal hormones. A Japanese study[17] found a positive risk of kidney cancer with the use of estrogen; however, a study in Denmark[18] found no association with use of estrogen-containing medication.

Although the degree of pilot exposure to aviation gasoline is uncertain, it should be noted that an association between kidney cancer and aviation gasoline was reported in a population-based case-referent study in Montreal on 12 petroleum-derived liquids.[19] A similar association was found between kidney cancer and jet fuel.[19] Lynge et al[20] reported a 30% elevation in kidney cancer incidence among a cohort of service station workers in Denmark, Norway, Sweden, and Finland. A case-referent study of occupational risk indicators of renal cell cancer in Finland found an elevated risk and an exposure-response relationship for gasoline exposure.[21] In contrast, no indication of increased mortality from kidney cancer was found in a US study of marketing and marine distribution employees who were exposed to gasoline in the petroleum industry, when compared with the general population.[22]

Cancer of the brain has been included in numerous health studies. An increase in mortality due to cancer of the brain was suggested in the present study. Cancers of the brain and central nervous system were significantly elevated in a PMR study of British Airways pilots; significance was approached in a PCMR analysis of the same cohort.[7] Among Air Canada pilots, the SIR for astrocytomas approached significance, but the Standardized Mortality Ratio (SMR) due to cancer of the brain was not significant.[3] Results from other studies indicated no significant difference: Finnish flight attendants (for nervous system)[1]; US Air Force pilots[4]; and British Columbia pilots.[6]

An increase in mortality due to cancer of the lip, buccal cavity, and pharynx was suggested among US commercial pilots and navigators. Other studies have reported no significant differences in cancers of this region.[3,4,7]

The major risk factors for oral cancer in developed countries are alcohol and tobacco.[23] In addition, alcohol interacts with tobacco smoke in the development of cancers of the oral cavity and pharynx such that individuals who use both are at greatest risk.[23]

Increased mortality due to colon cancer (large intestine, excluding rectum) was also suggested among US commercial pilots and navigators. Colon cancer was significantly increased in a PMR study among British Airways pilots.[7] Colon cancer has been associated consistently with increased consumption of red meat and some types of fats, decreased consumption of vegetables, and physical inactivity.[24]

The only noncancer disease found to contribute significantly to excess mortality among US pilots and navigators was motor neuron disease. Despite intensive research into environmental agents associated with the disease, there is no single factor that can be confidently linked over time with regional, national, or international variations in mortality rates.[25] In a study of mortality in Japan, unusual variations in motor neuron disease mortality rate from 1950–1990 were found to correlate highly significantly with variations in radioactive fallout released by atmospheric weapons testing in the Pacific.[25] The most common form of progressive motor neuron disease is amyotrophic lateral sclerosis (ALS).[26] A study of magnetic field exposure and neurodegenerative disease mortality among electric utility workers suggested that both duration of work in exposed jobs and estimated magnetic field strength, particularly with a latency of 20 years, may be positively associated with ALS.[27] This suggestion is supported by a case-control study in a different population, which found a significant positive association between occupational exposure to electromagnetic fields for 20 or more years and ALS.[28]

The mortality ratios reported here for US commercial pilots and navigators are calculated using expected numbers based on all occupations combined. Using employed individuals, rather than the general population, as the comparison population should reduce the healthy worker effect somewhat. However, pilots and navigators are an exceptionally healthy group, as evidenced by the numerous causes of decreased mortality. Therefore, it is important to consider the impact of the healthy worker effect on the relationships between different types of mortality ratios.

A limitation of the PMR is that the proportional mortality for the cause of interest can be affected by the relative frequency of other causes of death. It has been argued that the healthy worker effect may reduce certain causes of death (such as heart disease) among industrial groups, causing other causes of death (such as cancer) to be high, even when there is no true risk.[29] The PMR and the MOR are used to approximate the cause-specific SMR when death data are available but the population at risk is not known.[30] Stewart and Hunting[30] published calculations indicating the following relationships: When there is a healthy worker effect, the MOR will overestimate the SMR and will be greater than the PMR. The PMR is influenced by the relative frequency of the cause of death. For rare causes, such as brain cancer, the PMR will overestimate the SMR to essentially the same degree as the MOR. For more common conditions, such as lung cancer, the PMR will either overestimate or underestimate the SMR, depending on the magnitude of the healthy worker effect. When the SMR is equal to 1 and there is a healthy worker effect, both the PMR and the

MOR are greater than 1, regardless of the disease rate. As the SMR increases, it is likely to be bounded below by the PMR and above by the MOR.[30]

In general, the results of the mortality analyses of US commercial pilots and navigators reflect the relationships between mortality ratios as described by Stewart and Hunting[30] when a healthy worker effect exists. Assuming that the PCMR most closely resembles the SMR for cancer end points, the findings for cancer of the kidney and renal pelvis (the only cancer cause to be significantly elevated in each of the three analyses) show an increase in measures from PCMR (1.88) to PMR (1.96) to MOR (2.00). A similar trend is seen for prostate cancer and colon cancer (Table 2).

In addition to the healthy worker effect, mortality among pilots due to external causes of death warrants comment. The total number of deaths included in the PMR analysis is 1528. Of these, 442 are due to all external causes of death (including the subcategories all accidents, motor vehicle, road vehicle accidents, nontransport, homicide, and firearms). While the number of all accidents is significantly high, those in the other subcategories are significantly low, suggesting that the excess may be due to aircraft accidents. Excesses in aircraft accidents have been found in an SMR study of Air Canada pilots,[3] an SMR study of Japan Airlines cockpit crew,[5] a PMR study of British Columbia pilots,[6] and a PMR study of British Airways pilots.[7] While it would be interesting to repeat the present analysis with aircraft accidents excluded, the original data does not permit a separation of this special category.

Conclusion

In conclusion, the complexities of combined exposures cannot be addressed by mortality studies alone. PMRs are frequently used in studies in which the only information available comes from the death certificates of a group of persons in a specific occupation. However, limitations do exist with this approach. While an observed excess of one cause of death in a particular exposure group may represent a true increased risk, it may also merely represent a deficit of deaths due to some other cause.[31] Thus ratio methods can only suggest that a risk exists. Likewise, mortality may not be a true indication of disease rate. Incidence studies may reflect more consistent findings of disease. Nonetheless, the results of this study suggest a direction and approach for further study. To determine if the health outcomes experienced by flight crews are related to occupational exposures, these exposures should be quantified separately, examined for potential synergy of effects, and analyzed with disease incidence and mortality data on an individual basis.

Acknowledgment

This publication was supported in part by funds from the US Department of Energy cooperative agreement DE-FC02-98CH10902.

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Jumbo Jet Defined

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—From Greenwald J. Is Boeing out of its spin? *TIME*, July 13, 1998, p 68.