Radiation-induced acute myeloid leukaemia and other cancers in commercial jet cockpit crew: a population-based cohort study

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Summary

Background Cockpit crews receive cosmic radiation during flight operations. The increasing total accumulated dose over the years might be expected to cause increased frequency of radiation-induced cancer. The rate should increase with number of flight hours per year, number of years of flying, and higher flight altitude. If the cumulative radiation exposure during flights is of concern, we would expect an increased cancer risk to be present among those crew members flying jets.

Methods Cockpit-crew medical records (pilots and flight engineers) from 1946 onwards, holding information on the individual, flight hours, aircraft type, and date of commercial certification and decertification, were linked to the population-based Danish Cancer Registry, the central population registry, and the National Death Index.

Findings Altogether 3877 cockpit crew members could be traced for follow-up, accruing 61 095 person-years at risk in 3790 men and 661 in 87 women. The total number of cancers observed was 169 whereas 153·1 were expected (standardised incidence ratio 1·1 [95% CI 0·94–1·28]). Significantly increased risks of acute myeloid leukaemia (5·1 [1·03–14·91]), skin cancer, excluding melanoma (3·0 [2·12–4·23]), and total cancer (1·2 [1·00–1·53]) were observed among Danish male jet cockpit crew members flying more than 5000 h. Increased risk of malignant melanoma irrespective of aircraft type was also found among those flying more than 5000 h.

Interpretation Both malignant melanoma and skin cancer were found in excess in cockpit crew members with a long flying history, probably attributable to sun exposure during leisure time at holiday destinations. We cannot confirm previously reported increased risk of brain and rectal cancers in pilots. The study shows that male cockpit crew members in jets flying more than 5000 h have significantly increased frequency of acute myeloid leukaemia.

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Introduction

Aircrews are occupationally exposed to cosmic radiation mainly consisting of neutrons and γ radiation. The mean annual dose-equivalent for flying 950 h has been calculated as 0·2–9·1 mSv.[1] The average aircrew dose lies in the range 3–6 mSv/year.[2] The amount of cosmic radiation depends on number of flight hours, flight altitude and latitude, but also on solar activity. The dose is doubled for every increase in altitude of 1500 m.[3] Estimates on potential health hazards due to radiation exposure have been published.[1,3,4] Mortality studies among small subgroups of pilots in Canadian, Japanese, and British aviation companies have shown a small excess mortality of all cancers, for cancers in the colon, the brain, the nervous system, as well as for Hodgkin's disease and malignant melanoma.[5–8] One study found a small excess of rectal cancer.[5] A recent incidence study including Air Canada pilots from 1950 to 1992 showed small excesses of prostate cancer, skin cancer, and acute myeloid leukaemia.[9] An increased risk of cancer in the urinary bladder and the testis was observed in a large cohort of military pilots compared with ground personnel.[10] However, it is unlikely to be an effect of radiation exposure, since military pilots in general fly few hours at height altitude, hence their exposure to cosmic radiation may be lower than that in commercial airline pilots. So far no comprehensive population-based study has been published that includes all cockpit crew members with a commercial licence in a country. With the records available from the aviation clinic, the cancer registry, and the population registry in Denmark we did a study based on linkage to routine data-collection and follow-up methods. The aim was to study, in a national and population-based setting, whether an increased cancer risk could be shown, and if the risk could be attributed to exposure to cosmic radiation—based on surrogate measures such as aircraft type and flying hours.

Patients and methods

All commercial Danish cockpit crew members on file since 1946 in the National Clinic of Aviation Medicine, University Hospital, Copenhagen, Denmark, were enrolled. A few people starting as cockpit crew as early as 1921 were included. The cohort was cross-checked by company files, and for the retired cockpit crew members, completeness was ensured by comparison with personal records obtained from the Danish Civil Aviation Authority. We used the population-based Danish cancer registry established in 1943 to identify the cancers. Since chronic lymphocytic leukaemia is unrelated to ionising radiation, we separated it out when classifying leukaemias, as well as the specific types identified by the detailed codes used in the Danish Cancer Registry. We used the death and population registries to assess end of follow-up. The linkage was done automatically with the unique person identification number as key or manually for the 24 people who died or migrated before April 1, 1968, when the identification number was put into force. The follow-up for cancer and the person-year calculation started in January, 1943, or at the day of first issue of certificate if later, and ended at

Number of flight hours	Number of person-years
0–999	22 185
1000–4999	15 202
5000–9999	11 837
⩾10 000	11 871
Jet flight hours	22 116
Non-jet flight hours	38 979
Total person-years	61 095

Table 1: **Flight activity of 3790 male pilots and cockpit crew members**

death, migration, or Dec 31, 1995, whichever came first. Flight hours were calculated cumulatively by type of aircraft based on the individual licence of the cockpit crew. After upgrading to jet, all flight hours were accumulated as jet even if the licence to fly lower-altitude aircraft was not cancelled.

The cohort was subdivided into three subgroups with different total numbers of flight hours (1–999 h, 1000–4999 h, and ⩾5000 h), and further into non-jet and jet crew. We calculated the person-years at risk and the expected overall number of cancer cases for the three groups of exposure, applying incidence rates specific for age, sex, and calendar year for all of Denmark to the appropriate person-years. CIs of the observed-to-expected ratios (standardised incidence ratios) were calculated on the assumption of a Poisson distribution, with Byar's approximation.[11]

Results

4246 people with a commercial Danish cockpit-crew licence were listed. 3877 (3790 men and 87 women) could be identified for follow-up. Of the 369 excluded individuals, 300 were foreign, 24 had migrated before the issue of the certificate, and 45 had migrated or died before April 1, 1968, and could not be traced. The number of person-years was 61 095 in men and 661 in women. No substantial flying activity was seen in women. Only 0·8 cancer cases were expected and no cancers were observed, hence the results are not tabulated. The flight activity of the male pilots and cockpit crew members is given in table 1. At start of follow-up the mean age was 25·50 (SD 6·11, range 15–59) years; at the end of the follow-up, it was 41·65 (13·99, 17–90). At the end of exposure (ie, the period of active commercial licensing that ended because of death, retirement, or end of follow-up), the mean age was 39·98 (12·16, 25–84). The mean flight hours were 5284 (6370, 0–29 581) h. Mean follow-up duration was 15·65 (12·12, 0–52) years.

Overall, no excess risk of cancer was seen in pilots and other cockpit crew members (standardised incidence ratio 1·1 [95% CI 0·94–1·28]), but significantly increased risks of both melanoma of skin (2·4 [1·3–4·0]), and carcinoma of the skin (2·3 [1·7–3·0]) was present. Most of the non-melanoma skin cancers were basal-cell carcinomas, and all of the melanomas occurred on trunk and limbs. Other standardised incidence ratios were raised, although not significantly so, for acute myeloid leukaemia, cancer of the stomach, pancreas, colon, larynx, and connective tissue. We did not observe any sites in significant deficit. Subdivision into individuals flying jets and those not showed that higher risks were present for leukaemia, non-melanoma skin cancer, and also total cancer in jet crew, although not significantly so compared with non-jet pilots (table 2). Of previously reported cancers with excess mortality in pilots, the frequency seemed to be higher only for leukaemia, melanoma, and other skin cancer.

Total cancer among jet pilots accumulating more than 5000 flight hours was marginally in excess with 90 observed and 72 expected (standardised incidence ratio=1·24 [95% CI 1·00–1·53]). The excess of acute myeloid leukaemia was 5·1 times that expected (95% CI

Cancer	Jet			Non-jet		
	Observed	Expected	SIR (95% CI)	Observed	Expected	SIR (95% CI)
Colon	4	4·74	0·8 (0·2–2·2)	7	4·23	1·7 (0·7–3·4)
Rectum	1	3·54	0·3 (0–1·6)	2	3·10	0·7 (0·1–2·3)
Prostate	3	3·97	0·8 (0·2–2·2)	3	3·59	0·8 (0·2–2·2)
Skin melanoma	7	2·79	2·5 (1·0–5·2)	7	3·11	2·3 (0·9–4·7)
Other skin	35	12·15	3·0 (2·1–4·2)	18	11·30	1·6 (0·9–2·5)
Brain	2	3·22	0·6 (0·1–2·2)	3	3·93	0·8 (0·2–2·2)
Mb Hodgkin	0	0·79	. .	2	1·46	1·4 (0·2–5·0)
Leukaemia	5	2·05	2·4 (0·8–5·7)	2	2·24	0·9 (0·1–3·2)
Non-CLL*	4	1·28	3·1 (0·8–5·7)	2	1·56	1·3 (0·1–4·6)
AML	3	0·65	4·6 (0·9–13·4)	1	0·75	1·3 (0–7·5)
CLL	1	0·77	1·3 (0–7·2)	0	0·62	. .
Total	92	77·15	1·2 (1·0–1·5)	77	75·98	1·0 (0·8–1·3)

SIR=standardised incidence ratio. CLL=chronic lymphocytic leukaemia. AML=acute myeloid leukaemia.
*Includes one chronic myeloid leukaemia in both jet and non-jet.

Table 2: **Observed and expected cancers and standardised incidence ratios in Danish pilots and cockpit crew for all cancers and selected sites**

	<1000 flight hours				1000–4999 flight hours				⩾5000 flight hours				Total (61 095 person-years)	
	Jet (249 person-years)		Non-jet (21 936 person-years)		Jet (4960 person-years)		Non-jet (10 242 person-years)		Jet (16 907 person-years)		Non-jet (6801 person-years)			
	Observed/ Expected	SIR	Observed/ Expected	SIR	Observed/ Expected	SIR	Observed/ Expected	SIR	Observed/ Expected	SIR	Observed/ Expected	SIR	Observed/ Expected	SIR
Cancer														
Leukaemia	0/0·012	0	1/0·97	1·0	0/0·16	0	1/0·50	0·5	5/1·87	1·9	0/0·77	0	7/4·29	1·6
Non-CLL	0/0·094	0	1/0·73	1·4	0/0·14	0	1/0·38	2·7	4/1·13	3·5	0/0·46	0	6/2·84	2·1
AML	0/0·004	0	1/0·34	3·0	0/0·06	0	0/0·17	0	3/0·59	5·1*	0/0·23	0	4/1·40	2·9
CLL	0/0·003	0	0/0·24	0	0/0·02	0	0/0·13	0	1/0·75	1·3	0/0·31	0	1/1·45	0·7
Melanoma	0/0·017	0	1/1·49	0·7	0/0·31	0	2/0·72	2·8	7/2·47	2·8*	4/0·89	4·5*	14/5·90	2·4*
Other skin	0/0·053	0	7/4·65	1·5	0/0·59	0	3/2·26	1·3	35/11·50	3·0*	8/4·48	1·8	53/23·45	2·3*

SIR=standardised incidence ratio. CLL=chronic lymphocytic leukaemia. AML=acute myeloid leukaemia.
*p<0·05.

Table 3: **Observed and expected cases of leukaemia, melanoma, and skin cancer and standardised incidence ratio by aircraft type and accumulated flying hours**

1·03–14·91), based on three cases in this group, whereas the melanoma and skin cancer risks although elevated and related to flight hours seemed to be unrelated to aircraft type (table 3).

Discussion

Our study showed increased risks of acute myeloid leukaemia and total cancer among Danish male jet cockpit crew members flying more than 5000 h. This finding could be related to cosmic radiation, in as much as the risk is seen in the most exposed group—those flying high (jet) and for many hours. Such crew may receive up to 9 mSv annually,[1] four to five times the natural background radiation, which is still a low radiation dose. However, the impact of high-energy radiation from neutrons with a relative biological effectiveness ten to 100 times that of γ-radiation is of concern. The neutron component is the major difference between aircraft-crew exposure and low-dose exposure to radiation workers apart from other occupational exposures such as jet fumes. We also found significantly increased risks of skin cancer, both melanoma and basal-cell carcinoma, among all Danish male cockpit crew members. The trunk and limbs are commonly affected by acute sunburn, but not the head and neck; thus, the distribution of skin cancers on the trunk and limbs indicates sun-exposure as a risk factor rather than cosmic radiation. Also the fact that a greater risk is also present in men flying non-jet, low-altitude aircraft weakens a link to radiation exposure. Our cohort is likely to be subject to a healthy-worker effect as well as an effect related to the high social status of the pilots.[12] No cancer pattern substantiating the latter effect was seen because there were low cancer rates for colon, prostate, and brain cancers, whereas increased rates were seen for skin cancer and melanoma. The overall cancer risk for the entire cohort was, as expected, similar to the rates in the general population, and that in the subgroup of those who flew high for many hours the risk was raised. On the basis that frequent health checks and the selection of healthy individuals for these jobs also leads to a low cancer rate, the general population as comparison may underestimate the overall cancer risk in this cohort.

Four groups of researchers have shown increased cancer mortality among pilots in studies from 1990 to 1993.[5–8] Pukkala and colleagues[13] found increased incidence of breast and bone cancer in Finnair female cabin crew, flying more than 15 years. They also showed a non-significantly increased incidence of skin cancer (melanoma) and leukaemia. Band and colleagues[9] showed increased incidence of leukaemia (notably acute myeloid leukaemia) and prostate cancer among Air Canada pilots. Our findings corroborate some of these results—by the size of our study, however, we may not be able to pick up the expected small risks related to radiation. But we are confident in excluding a major cancer-related effect of the exposure to cosmic radiation in today's aviation.

Contributors

Hans H Storm proposed and designed the study protocol, obtained and managed the grant for the study, obtained the permissions from the data-inspection agency and the scientific ethics committee, and supervised the computerised data linkages on registries and the analysis. Maryanne Gundestrup was responsible for the data collection, coding and computerisation of data from the Aviation Clinic and the Danish Civil Aviation Authority. Maryanne Gundestrup and Hans H Storm jointly planned and interpreted the analysis and wrote the paper.

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