

Commentary

Exposure Assessment at 30 000 Feet: Challenges and Future Directions

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Few studies of cancer mortality and incidence among flight crew have included a detailed assessment of both occupational exposures and lifestyle factors that may influence the risk of cancer. In this issue, Kojo *et al.* (Risk factors for skin cancer among Finnish airline cabin crew. *Ann. Occup. Hyg* 2013; 57: 695–704) evaluated the relative contributions of ultraviolet and cosmic radiation to the incidence of skin cancer in Finnish flight attendants. This is a useful contribution, yet the reason flight crew members have an increased risk of skin cancer compared with the general population remains unclear. Good policy decisions for flight crew will depend on continued and emerging effective collaborations to increase study power and improve exposure assessment in future flight crew health studies. Improving the assessment of occupational exposures and non-occupational factors will cost additional time and effort, which are well spent if the role of exposures can be clarified in larger studies.

Keywords: cosmic radiation; exposure assessment; flight crew; skin cancer; ultraviolet radiation

Flight crew, including pilots, copilots, other cockpit personnel, and flight attendants, have been represented in cancer mortality and incidence studies for the last 20 years. Assessment of occupational exposures, however, has been limited to surrogate measures in many of these studies. Exposure assessment of pilots has been more comprehensive than that of other flight crew due to availability of more detailed records but few studies have included an assessment of the role of lifestyle factors that may influence the risk of cancer.

The commercial aircraft cabin environment is the workplace of 530 000 flight crew worldwide (IARC, 2000). These workers incur exposures to elevated levels of cosmic radiation and circadian disruption from work at night and travel across multiple time zones. The affected population

expands if one considers frequent fliers and astronauts, who work in a related environment.

The International Agency for Research on Cancer (IARC) considers neutrons, a major contributor to cosmic radiation dose at flight altitudes (Goldhagen, 2000), to be a known human carcinogen (IARC, 2000; El Ghissassi *et al.*, 2009) and shift work that involves circadian disruption to be a probable human carcinogen (IARC, 2010). In flight crew, cosmic radiation and circadian disruption are often correlated (e.g. one incurs both cosmic radiation and circadian disruption on a transoceanic flight) and therefore difficult to study independently. Much of the emphasis in current studies has been on the role of cosmic radiation.

The International Commission on Radiological Protection (ICRP, 1991, 2008) recommends effective dose (ED) limits of 20 millisieverts (mSv) per year averaged over 5 years (100 mSv in 5 years) for radiation workers and 1 mSv per year for the public. The ICRP considers flight crew to be radiation workers.

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European Union member states implemented regulations for flight crew requiring assessment of exposure when exposure is likely to be more than 1 mSv per year (and adjustment of work schedules so that no individual exceeds 6 mSv per year; European Radiation Dosimetry Group [EURADOS], 1996). There are no official dose limits for flight crew members in the USA even though the National Council on Radiation Protection (NCRP, 2009) considers flight crew to have the largest average annual ED of all US workers.

To guide policies to protect flight crew from adverse health effects from cosmic radiation exposure, comparisons to terrestrial radiation workers are of limited value because most of these workers are exposed to low-linear energy transfer (LET) radiation—X-rays and gamma rays. LET is a measure of how much energy a particle or ray transfers into soft tissue. Low-LET radiation is not equivalent to the biologically active neutrons and other high-LET components of cosmic radiation. One could also wish for better exposure records for flight crew. Often company records provide little more than employment dates and for cockpit crew, flight hours, leading to many studies with duration of employment or flight hours mustered to stand in for much more complex exposures.

The challenges in improving the assessment of occupational exposures and non-occupational factors for flight crew studies are exemplified by the study described in ‘Risk factors for skin cancer among Finnish airline cabin crew’ by *Kojo et al.* (2013). Previously, *Rafnsson et al.* (2003) evaluated non-occupational ultraviolet radiation (UVR)-related risk factors in flight crew and a population sample. Although flight crew took more sunny vacations than the population sample, this difference was unlikely to fully explain the increased incidence of malignant melanoma. Cosmic radiation dose estimates were available for pilots but the small number of melanoma cases ($n = 5$) (*Rafnsson et al.*, 2000) precluded modeling the association between melanoma incidence and cosmic radiation dose adjusted for host and UVR exposure risk factors. *Dos Santos Silva et al.* (2013) found a positive association between melanoma incidence in pilots and flight hours, although this relation did not hold in models adjusted for host and UVR risk factors. Cosmic radiation dose was not estimated and information was not provided comparing UVR-related risk factors in pilots with the general population.

Kojo et al. (2013) aimed to resolve the speculation concerning the relative contributions of UVR and cosmic radiation to the incidence of skin

cancers in flight crew by modeling the relation between cosmic radiation and skin cancer, adjusting for host risk factors and non-occupational UVR exposures in Finnish flight attendants.

This is an important and useful contribution. The cosmic radiation exposure assessment methods, developed earlier by *Kojo et al.* (2007, 2004), were based on year of employment, length of career, flight timetable data, and the European Program Package for the Calculation of Aviation Route Doses radiation estimation program. Analogous approaches to assessment have been successfully used in other retrospective flight crew exposure assessments or health studies (*Oksanen, 1998; Tveten et al., 2000; Waters et al., 2009*). The assessment of both cosmic radiation and UVR allowed for risk evaluation in internal analyses after combining melanoma and basal cell carcinoma into one outcome category (due to the small number of cases). The point estimates suggest the relative importance of these exposures and the upper confidence limits indicate that contributions from each of these are not ruled out. In comparison with the general population, no appreciable difference was observed in the risk score for skin cancer based on all UVR-related behavior factors combined but risk scores based on intermittent UVR exposure and solarium use were higher for flight attendants.

This is where we are left due to power inadequacies that could not be overcome because these studies were limited to flight crew from single countries, and because some imprecision remains in the assessment of exposures. Why do flight crew have an increased risk of skin cancer compared with the general population? There seems to be no single clear winner in this etiologic contest for now.

Good policy decisions for this occupational group will result from effective collaborations. The multinational flight crew mortality studies (*Zeeb et al., 2003; Langner et al., 2004*) and Nordic cancer incidence studies (*Pukkala et al., 2012, 2003*) exemplify collaborations improving statistical power. Exposure assessment efforts also benefit from collaboration; the ongoing US National Aeronautics and Space Administration (NASA) and National Institute for Occupational Safety and Health collaboration to assess cosmic radiation exposure from solar particle events (*NASA, 2013*) is an example of an improvement in exposure assessment, which may benefit future flight crew health studies. Improving assessment of the major flight crew occupational exposures

and non-occupational factors costs additional time and effort, which are well spent if we can clarify exposures' etiologic roles in larger studies.

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