Cancer incidence among 41 000 offshore oil industry workers

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Aims To determine the overall cancer incidence in both cohorts merged, with an extended follow-up.

Methods The merged cohort yielded 41 140 individuals followed for cancer diagnoses 1999–2009. Standardized incidence ratios (SIRs) with 95% confidence intervals (CIs) were computed by gender and by period of first employment using cancer registry data.

Results Among female workers, the total number of cancers was slightly higher than expected (SIR 1.17, 95% CI 1.02–1.34), and excesses of acute myeloid leukaemia (AML) (SIR 5.29, 95% CI 1.72–12), malignant melanoma (SIR 2.13, 95% CI 1.41–3.08) and lung cancer (SIR 1.69, 95% CI 1.03–2.61) were observed. Among male workers, the total number of cancer cases was close to that expected (SIR 1.03, 95% CI 0.99–1.08), but cases of pleural cancer (SIR 2.56, 95% CI 1.58–3.91) and bladder cancer (SIR 1.25, 95% CI 1.05–1.49) were higher than expected. Among male workers first employed before 1986, the numbers of observed cancer cases were higher than expected for most sites, while this was not evident among those employed later.

Conclusions Further studies with exposure data and confounder control are needed to address whether the observed excesses of pleural cancer and AML can be attributed to offshore work.

Key words Cancer incidence; cohort studies; occupational cohort; offshore workers; petroleum industry.

Introduction

Offshore production of crude oil and natural gas developed in the North Sea from the late 1960s onwards. Offshore work may involve skin contact and inhalation exposure to crude oil and oil derivatives such as solvents, natural gas, oil vapour, exhaust fumes and drilling mud components [1]. Additionally, the diet offshore has been reported to be rich in fat and calories, there is access to slightly cheaper tobacco and workers follow extreme tour of duty patterns, some with night shifts, all factors that may influence the risk of cancer [1,2].

In Norway, cancer incidence has been reported from two cohorts of offshore workers, both of about 28 000 workers. In 1998, the Cancer Registry of Norway established a survey-based cohort for prospective follow-up, and by 2004, a historical cohort was established from the Norwegian State Register of Employers and Employees (hereafter ‘the register-based cohort’) and a matched reference group from the same register. Thus far, excess risks of acute myeloid leukaemia (AML), multiple myeloma, oesophageal cancer and pleural cancer have been reported from the two cohorts with follow-up through 2005 and 2003 for the survey-based and register-based cohorts, respectively [2–4]. The aim of this study was to merge these two cohorts in order to update the analysis of cancer incidence in a larger and more complete sample of Norwegian offshore workers with follow-up extended to 2009.

Methods

The survey-based cohort was established from a roster of 57 328 men and women who were assumed to have worked offshore based on personnel lists from oil companies, labour unions and safety courses. They all received a questionnaire on work history and lifestyle factors by September 1998.
A total of 22,025 never responded, 7,316 persons reported never to have worked offshore and 70 were excluded because they worked on ships only or had inconsistent personal identification number. The remaining 27,917 men and women confirmed offshore work and constituted the survey-based cohort. The register-based cohort was established by identifying 27,919 workers with employments within the Norwegian offshore petroleum industry according to new entries between 1981 and 2003. The establishment of each cohort is described in detail elsewhere [2–4].

For this study, the two cohorts were merged by Statistics Norway, and duplicates (overlapping workers) were removed. The merged cohort was linked to the national database of incident cancers at the Cancer Registry of Norway for information on cancer diagnoses and to the Norwegian National Population Register for information on vital status, year of death or year of emigration, if relevant. The workers were followed for cancer diagnoses from 1 January 1999 or from year of first employment if later, to date of emigration, date of death or to 31 December 2009 (end of study), whichever came first. Reporting of incident cancers to the Cancer Registry is compulsory in Norway and data from a number of sources ensure a high degree of completeness [5]. Information on cancer localization was based on a modified version of the International Classification of Diseases 7th and 10th revisions (ICD-7 and ICD-10), all converted into ICD-10 codes. Subtypes of oesophageal cancer were classified according to morphology codes from the ICD-Oncology second revision and subtypes of lymphohae matopoietic cancer were classified according to morphology codes from the Kiel-based system [5]. Neoplasms are classified as low grade (LG) or high grade (HG) in the Cancer Registry based on the degree of cell differentiation reported by pathologists. We grouped non-Hodgkin lymphoma (NHL) into HG or LG subgroups and considered acute lymphoid leukaemia (ALL) and chronic lymphoid leukaemia (CLL) as subgroups of NHL according to the most recent World Health Organization classification of lymphomas [6]. In addition to analysing NHL, ALL and CLL separately, we combined HG-NHL with ALL (HG-NHL/ALL) and LG-NHL with CLL (LG-NHL/CLL) and analysed these subtypes as two groups.

Standardized incidence ratios (SIRs) were calculated by gender and period of first employment (1965–85 and 1986–2003) from national gender-, 5-year age- and 1-year time-specific incidence rates for the entire Norwegian population (4.9 million persons by 31 December 2009). The employment periods were chosen to compare with those of a report from the register-based cohort [3]. Confidence intervals (95% CIs) were calculated around the SIRs assuming a Poisson distribution of the observed cases. Analyses were performed using Stata software, version 13 (StataCorp LP, TX, USA).

Data on offshore work from the State Register of Employers and Employees were also provided for the survey non-respondents, which enabled us to estimate the response rate among offshore workers.

The study was approved by the Norwegian Regional Committee for Medical and Health Research Ethics, South East D, but, to protect personal privacy after linkage with multiple sources, the committee allowed only a limited set of data from each cohort, restricted to gender, birth year and year of first employment offshore.

### Results

After 13,285 duplicates (overlapping workers) were removed, the merged cohort yielded 42,629 individuals. Those whose year of first employment was before 1965 (n = 289), aged under 15 or over 67 at first employment (n = 45) and those who died or emigrated before the start of the follow-up period for cancer (n = 1155) were excluded, leaving a sample of 41,140 individuals working offshore in the period 1965–2003 for analysis. A total of 2191 new cancer cases were identified during follow-up.

Among the 22,025 survey non-respondents only 5915 were identified as offshore workers in the State Register. The number of responding offshore workers also found in the State Register (i.e. the overlap between the two cohorts) was 13,124, suggesting a response rate of 69% (13,124/5915 + 13,124)) offshore workers invited to the survey.

Table 1 displays background characteristics of the merged cohort, as a whole and by cohort affiliation. The merged cohort consisted largely of male workers (90%), the major part of the cohort began working offshore after 1985 and the mean start age was 30. The survey-based cohort contributed the larger number of workers (n = 14,460) to the merged cohort, while the register-based cohort contributed the larger number of workers (n = 10,440) with year of first employment after 1985. The historical profile of the work histories according to cohort affiliation is illustrated in Figure 1.

Observed (Obs) and expected numbers of cancers by gender are shown in Table 2. In female workers, the overall cancer incidence (all sites) was slightly above that expected based on incidence rates from the general Norwegian population (Obs 211, SIR 1.17, 95% CI 1.02–1.34). Moreover, significant excesses were observed for cancer of the lung (Obs 20, SIR 1.69, 95% CI 1.03–2.61), for malignant melanoma (Obs 28, SIR 2.13, 95% CI 1.41–3.08) and for AML (Obs 5, SIR 5.29, 95% CI 1.72–12). In male workers, no difference was found for cancer of all sites (Obs 1980, SIR 1.03, 95% CI 0.99–1.08) compared with the general Norwegian population. Significant excesses in men were observed for pleural cancer (Obs 21, SIR 2.56, 95% CI 1.58–3.91) and bladder cancer (Obs 133, SIR 1.25, 95% CI 1.05–1.49).

In Table 3, observed and expected numbers of cancers are shown by period of first employment for male workers. A total of 1,414 cancer cases occurred among the
16 373 workers with first employment between 1965 and 1985, while 556 cancer cases occurred among the 20 470 workers first employed after 1985. A slight excess in the total number of cancers was observed among those who started in the earliest period (Obs 1414, SIR 1.08, 95% CI 1.03–1.14). This was not evident among those starting in the latest period.

For those with first employment before 1986 significant excesses were observed for cancer of the lung (Obs 178, SIR 1.21, 95% CI 1.04–1.40), pleural cancer (Obs 14, SIR 2.29, 95% CI 1.25–3.84) and bladder cancer (Obs 97, SIR 1.28, 95% CI 1.04–1.56). For those with first employment after 1985, the significant excess of pleural cancer persisted (Obs 7, SIR 3.35, 95% CI 1.35–6.91), while there was no striking divergence from the expected numbers for other types of cancer, except for a deficit of non-melanoma skin cancer (Obs 9, SIR 0.47, 95% CI 0.22–0.90).

**Discussion**

In this large group of offshore workers, we found an overall cancer incidence in line with expected numbers for men and a slightly elevated incidence (17% in excess of expected) for women. The cohort was merged from two cohorts that had been studied earlier and we confirmed the excess risk of pleural cancer in male workers, while the excess AML in female employees was a novel finding. There was no sign of any overall excess of lymphohaematopoietic cancers in men. There was a doubled risk of malignant melanoma
and a 69% increase of lung cancer in women, while in male workers a 25% excess of bladder cancer was observed.

Strengths of this study include the large study population, its prospective design and the use of a national cancer registry, which reduce the probability of errors caused by random variation and secure unbiased estimates of cancer incidence. The large number of female offshore workers allowed for gender-specific analyses. An important limitation was the lack of information on exposure, work history and lifestyle factors, which hampered the identification of possible causal factors.

All 21 pleural cancers were mesotheliomas and asbestos exposure, the most likely explanation, may have taken place while asbestos was used offshore as a drilling mud additive (until 1980) and in derrick brake bands (until 1991) [7]. However, our finding of a similarly increased risk among workers with first employment after 1985 suggests that exposure outside the offshore industry may have played a part, at least for the seven cases observed in the latter group. Excess mortality and incidence from pleural cancer have been reported in Australian petroleum workers [8,9], both ascribed largely to asbestos exposure in oil refineries.

An excess of bladder cancer observed in male workers has not been reported in earlier analyses of Norwegian offshore workers. A similar observation was, however, made in Australian petroleum workers [10], although it was not confirmed in a later update [9]. Thus, there is not much evidence of a generally increased risk of bladder cancer in petroleum workers and the possibility of a

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#### Table 2. Standardized incidence ratios with 95% confidence intervals for cancer in 41140 Norwegian offshore workers, followed by gender (1999–2009)

<table>
<thead>
<tr>
<th>Cancer site, subgroup</th>
<th>ICD-10</th>
<th>Females, n = 4297</th>
<th>Males, n = 36 843</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Obs</td>
<td>Exp</td>
<td>SIR</td>
</tr>
<tr>
<td>Oral cavity and pharynx</td>
<td>C01–C14</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>Oesophagus</td>
<td>C15</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Squamous cell carcinoma</td>
<td>C15</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Stomach</td>
<td>C16</td>
<td>5</td>
<td>1.9</td>
</tr>
<tr>
<td>Colorectal</td>
<td>C18–C21</td>
<td>16</td>
<td>16.9</td>
</tr>
<tr>
<td>Pancreas</td>
<td>C25</td>
<td>5</td>
<td>2.7</td>
</tr>
<tr>
<td>Larynx</td>
<td>C32</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>Lung</td>
<td>C34</td>
<td>20</td>
<td>11.8</td>
</tr>
<tr>
<td>Pleura</td>
<td>C38.4</td>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>Malignant melanoma</td>
<td>C43</td>
<td>28</td>
<td>13.1</td>
</tr>
<tr>
<td>Non-melanoma skin</td>
<td>C44</td>
<td>5</td>
<td>4.1</td>
</tr>
<tr>
<td>Breast</td>
<td>C50</td>
<td>67</td>
<td>61.8</td>
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<tr>
<td>Prostate</td>
<td>C61</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Testis</td>
<td>C62</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Lung</td>
<td>C71</td>
<td>10</td>
<td>3.0</td>
</tr>
<tr>
<td>Lymphohaeatomatopoietic</td>
<td>C81–C96</td>
<td>8</td>
<td>10.9</td>
</tr>
<tr>
<td>Hodgkin lymphoma</td>
<td>C81</td>
<td>3</td>
<td>8.3</td>
</tr>
<tr>
<td>Non-Hodgkin lymphoma</td>
<td>C85</td>
<td>1</td>
<td>4.8</td>
</tr>
<tr>
<td>Multiple myeloma</td>
<td>C90</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>Acute lymphoid leukaemia</td>
<td>C91.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Chronic lymphoid leukaemia</td>
<td>C91.1</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Acute myeloid leukaemia</td>
<td>C92.0</td>
<td>5</td>
<td>0.9</td>
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<tr>
<td>Chronic myeloid leukaemia</td>
<td>C92.1</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Myelodysplastic syndrome</td>
<td>D46</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Other specified sites</td>
<td>C76–C80</td>
<td>3</td>
<td>2.0</td>
</tr>
<tr>
<td>All sites</td>
<td>C00–C96</td>
<td>211</td>
<td>180.3</td>
</tr>
</tbody>
</table>

ICD-10, International Classification of Diseases 10th revision; Obs, no. of observed cancer cases; Exp, no. of expected cancer cases. **Bold** SIRs and CIs indicate statistically significant estimates at a 0.05 level.

*Male breast cancer cases placed under other specified sites.*
chance finding cannot be discounted. The modest 14% excess of lung cancer in men suggests only little contribution from smoking on bladder cancer risk.

The incidence of lymphohaematopoietic cancer is of particular interest in workers with potential benzene exposure from oil and natural gas. Benzene exposure is a recognized cause of AML and a suspected cause of other types of leukaemia, multiple myeloma and non-Hodgkin lymphoma [11]. The excess of AML in women was marked, but based on only five cases, and should therefore be interpreted with caution. Unpublished data from the contributing survey-based cohort showed that three out of four women with AML were engaged in catering or administrative services where exposure to benzene is less likely to occur. However, the possibility that exposure to other solvents, either in cleaning work or other tasks, may have contributed to this finding cannot be ruled out. A preliminary cancer report on men from the survey-based part of our merged cohort suggested a doubling of AML risk of borderline significance [2], which was not confirmed in this analysis. Kirkeleit and co-workers identified an excess of leukaemia among workers with their first employment offshore before 1986 in the register-based cohort [3]. There was only a 5-year overlap between the follow-up periods in the Kirkeleit study and this follow-up (1981–2003 versus 1999–2009, respectively). The lack of increased leukaemia risk among male offshore workers in this follow-up could be a result of lower exposures in recent years and an attenuation of risk with time after last exposure [12].

In this study, the general Norwegian population was used as reference population in all analyses. Two earlier
reports from the register-based cohort used a reference group of nearly 370 000 non-offshore and non-oil-industry workers drawn from the same register (the Norwegian State Register of Employers and Employees), matched for age, employment date and municipality of residence [3,4]. Recently, the authors compared cancer incidence in their reference group with the general Norwegian population and found a 10% lower than expected SIR for all cancers combined in men but not in women [13]. The authors argued that use of the general population as reference might bias the cancer risk downwards in working populations as a result of a healthy worker effect. Interestingly, their reference group showed a 20% lower than expected incidence of bladder cancer, leukaemia and lung cancer, while a 10% and 30% increase was found for malignant melanoma in men and women, respectively. Potentially, this may change the interpretation of our results and it suggests that we may have underestimated the risk for bladder cancer, lung cancer and leukaemia. A healthy worker effect would, however, be expected to decrease with age and length of observation and rates based on data from the general population have the advantage of being more robust than those based on a selected reference group.

The increased risk of malignant melanoma observed in female workers has not been noted in earlier reports from Norwegian offshore workers, either in the register-based or in the survey-based cohort. However, the finding is in line with mortality and incidence reports from UK and Australian refinery workers [8,9]. An occupational explanation is not obvious as ultraviolet radiation is widely accepted as the predominant risk factor [14] and the excess was only evident in women. Further analyses with exposure data, adjusted for sunbathing habits, would be necessary to uncover a possible occupational cause.

In conclusion, the overall cancer risk among offshore workers in this study was close to that expected. However, marked excesses of AML and cancer of the pleura were observed in female and male workers, respectively. The possibility of a causal relationship with offshore work warrants further study, with data on exposure and control of possible confounding factors.

Key points
- The overall numbers of cancers in Norwegian offshore workers were close to those expected from population background rates.
- In women, a significantly increased risk of acute myeloid leukaemia was found but based on five cases only. In men, a significant excess of pleural cancer was observed.
- Further clarification of the possible role of offshore work in cancer aetiology requires information on exposure and potential confounders.

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Conflicts of interest
None declared.

References
and cancer incidence in the Australian petroleum industry. 


do:10.1093/occmed/kqu085

I learned (a bit) about aviation medicine from that

Over 40 years ago, I was a very new, junior medical officer at an RAF flying training school. On one morning surgery day, I was asked by one of the pilots and his wife to arrange for him to undergo a vasectomy. As an Aberdeen graduate, I was used to stoic farmers from the Mearns. On one occasion, when I was doing sperm counts in surgical outpatients in Aberdeen, one such stalwart had commented to me that he did not think his vasectomy had worked. He explained that when he did it to his bullocks, their testicles had swollen and fallen off—and his had not. I also had in mind the vision of a Royal Naval doctor of my acquaintance who had his vasectomy performed under local anaesthetic, after which he cycled back to work.

I briefed our intrepid pilot on what was involved and how the operation was done and I arranged for the local Simon Clinic to carry out the procedure, as neither the NHS nor the RAF offered the service in our region. He had the operation and, unknown to me, returned to flying the next day. After his first sortie, he was brought to the station medical centre by an admiring group of colleagues. He was virtually unable to walk as a result of a scrotal haematoma about the size of an ostrich egg.

I had obviously not reminded him to avoid activities that could induce complications such as haematoma. It transpired that his sortie had involved aerobatics and the pulling of up to 5g.

Allowing a central venous pressure of 5 mmHg and a measurement from the right atrium to the scrotum of 17 inches, the normal orthostatic pressure at the level of the scrotum would be in the order of 36 mmHg. The level of centrifugal force involved would therefore have exerted approximately 180 mmHg of venous pressure at the site of surgery. Fortunately, he was able to pass urine without difficulty and the condition resolved in a few days with mild analgesia and the use of a jock strap—and abstinence from flying. But I did learn a bit about aviation medicine from that … and it did cost me a few pints of beer.

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