ORIGINAL ARTICLE

A higher risk of congenital anomalies in the offspring of personnel who served aboard a Norwegian missile torpedo boat

N Mageroy, O J Mollerlokken, T Riise, V Koefoed, B E Moen

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See end of article for authors' affiliations

Correspondence to: Dr N Magerøy, Researcher at UNIFOB AS, University of Bergen, Department of Public Health and Primary Health Care, Section for Occupational Medicine, Kalfarveien 31, N-5018 Bergen, Norway; nils.mageroy@isf.uib.no

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Background: In the 1990s, congenital anomalies were reported among children whose fathers had served aboard a Norwegian missile torpedo boat (MTB). The Royal Norwegian Navy asked the University of Bergen to look into this problem as one part of a general health and work environment surveillance.
Aims: To estimate any increased risk of having children with congenital anomalies and having stillborn children among the offspring of workers that had served aboard the MTB and to investigate possible differences in exposure and other risk factors between these groups.
Methods: Data from a cross-sectional study among all current employees of the Norwegian Navy (n = 2265, response rate 58%) were analysed.
Results: The prevalence ratio of having a child with congenital malformations associated with working on the ship was 4.0 (95% CI 1.9 to 8.6). The prevalence ratio of having a child who was stillborn or died within one week was 4.1 (95% CI 1.7 to 9.9).
Conclusion: Service aboard the MTB was associated with an increased risk of having children with congenital birth defects and having children that were stillborn. The causes of these findings are unknown.

Epidemiological studies of types of exposure such as ionising radiation, electromagnetic fields, food processing, metals, and organic solvents, and of certain occupations such as machinists, farmers, printers, painters, vehicle mechanics, laboratory personnel, and transportation and communication workers have suggested effects on the pregnancy outcome.[1–7]

Evidence from both animal and human studies indicates male mediated developmental effects to the fetus, although the causative mechanisms are unclear.[1 2 8] Proposed mechanisms for such effects include paternal preconception exposure that results in transmissible genetic changes or effects through epigenetic mechanisms, transmission of chemicals from the father to the conceptus via seminal fluid, and indirect exposure of the mother and the conceptus from the father carrying substances from the workplace into the home environment.

Female mediated developmental effects to the fetus could arise during the formation of an ovum cell the first month before conception through the generation of a new mutation or especially in the first trimester of the pregnancy through a direct action of an agent.[7] Exposure to teratogens during organogenesis is the best known causative pathway for producing birth defects through maternal exposure.[3 7]

In the 1990s, a number of congenital anomalies were reported among children whose fathers had served aboard a Royal Norwegian Navy missile torpedo boat (MTB), the *KNM Kvikk*.[9] This led to an investigation of possible hazardous exposure on the ship. All the ships in the MTB class to which the *KNM Kvikk* belonged cruised at 36 knots, had a crew of 16, were 36.5 metres long, and were equipped with one Bofors cannon, torpedoes, and Penguin missiles.[10] As emitting equipment, the ships had high-frequency, very-high-frequency, and ultra-high-frequency transmitters and radar. The *KNM Kvikk*, which was in service from 1971 until 1995, was equipped in the same way, but from the summer of 1987 to 1994 it had a 750 W high-frequency transmitter in addition to lower-energy transmitters. The use of the transmitters aboard this ship from 1987 was special compared with other MTBs, as the ship was emitting signals over long periods of time as part of electronic warfare.[9] Several of the other MTB classes represented in this study had the same hull and engine, but the superstructure was somewhat different from the class of the *KNM Kvikk* (the Snogg class).

The investigation of the ship in 1998 included measurements of high-frequency electromagnetic fields (on a reconstructed ship) and a study matching workers on the ship with data from the Norwegian birth registry.[11] Further, a broader investigation initiated by the Ministry of Defence in 1999 was also carried out.[12] These studies concluded that no causal link could be established between the high-frequency electromagnetic fields on the *KNM Kvikk* and the cases of congenital anomalies. This was based on an evaluation of the measurements of the electromagnetic fields, on the results of dysmorphological investigations of 13 of 14 known children with congenital anomalies, cluster assessment, and literature review. Nevertheless, an overrepresentation of clubfoot among the officers' children was reported.[12 13]

As a response to concerns regarding various occupational health problems, the Navy decided to conduct major surveillance of the work environment and health among its personnel in 2001. The concerns included exposures to asbestos, pollution on a naval base, many cases of cancer connected with forts, cardiovascular diseases among submarine personnel, and a possible harmful working environment among fire-fighters. Further, due to the inconclusive results from the previous studies, there was still concern about congenital anomalies among offspring in various groups. The University of Bergen conducted the surveillance project to ensure an independent investigation. As one part of the surveillance, a general questionnaire about several health aspects was sent to all employees.[14] In addition, the respondents listed their history of service in the Navy. Specific questions about occupational exposure and lifestyle factors were asked. Questions on the health of

offspring were added as the birth registry had reported that children with congenital anomalies in some cases were missing in the registry.[11] This article presents the part of the study related to having children with congenital anomalies or having stillborn children among the offspring of current workers.

The aims of the study were to estimate the risk of having children with congenital anomalies or having stillborn children among the offspring of workers who had served aboard the *KNM Kvikk* compared with the rest of the study population, and to investigate possible differences in exposure and other risk factors between these groups.

METHODS

Data collection

The data were collected in a cross-sectional study from a questionnaire sent by mail at the end of 2002 to all the employees in the Navy, both military and civilians with different types of work on ships and ashore. The questionnaires were returned directly to the research group at the University of Bergen. The name, address, and the National Insurance number were pre-printed on the form. The overall response rate was 58% (2265 of 3878). The response rate was 59% among the men (2001 respondents) and 52% among the women (250 respondents). We had information on the present workplace among the non-responders, but no information on previous workplace for this group. This meant that we were not able to evaluate whether the response rate for those who had served aboard the *KNM Kvikk* was different from the rest of the study population.

Questionnaire

The respondents were asked about their exposure, their lifestyle, and the health of their children.

The respondents were asked to fill in two lists for exposure, one for their service in the Navy and an identical one for exposure at other workplaces or at leisure. The lists included whether the personnel had been in contact with, worked with, or been exposed to organic solvents and paint, skin contact with oil, gasoline, or diesel and vapour from the same petroleum products, smoke from burning oil, exhaust gas, pesticides or herbicides, dust from grit blasting or sanding, welding or torch cutting or working with the hull, lead, explosives, noise, vibration or shaking, demolition work, heavy lifting, twisted working positions, work with arms above the shoulders, passive smoking, and asbestos. On the same list they were also asked whether they had worked closer to high-frequency aerials than 10 m, closer to radar than 5 m, and closer to communication equipment than 3 m. The scoring was on a Likert scale divided into never, very little, some, much, very much, and do not know.

Questions pertaining to lifestyle such as present alcohol consumption, past and present smoking, and present height and weight were asked.

The respondents were also asked whether they had biological children. For each of these children, they were asked to provide the year of birth, the sex, and whether the child had a congenital anomaly or chromosome anomaly, was born premature, was stillborn or died within the first week, or died during the first year of life. These questions were selected and modified from the European Studies of Infertility and Subfecundity Questionnaire.[15] We had no questions regarding the number of pregnancies.

As part of the occupational history, the respondents were asked whether they had served aboard the *KNM Kvikk* and other workplaces and during which periods.

Questionnaire for parents reporting children with congenital anomalies and validation

The parents who had informed about congenital or chromosomal anomalies for one or more of their children in the first questionnaire were sent a second one-page questionnaire to fill out for each child. They were asked for the date of birth or abortion, the sex of the child, birth weight, gestational length, how the child was delivered or the pregnancy ended, when the diagnosis was established, what the diagnosis was, who diagnosed the child, and a characterisation of the consequences of the diagnosis for the child. No information on the parents' exposure was ascertained from the questionnaire. All the answers were summarised and sent to a physician at Haukeland University Hospital, who collaborated with two paediatricians in deciding whether the child most likely had a congenital anomaly or not based on the parents' report. The physicians were blinded to the kind of service the parents had in the Navy.

Decisions regarding the children

In order for the child to be affected by exposure on *KNM Kvikk* or any other ship, it would have been necessary for the father to have served onboard these ships prior to conception, or the mother to have served prior to giving birth. The exception to this is the possible indirect exposure to the pregnant mother through contamination from the father. We had no exact date of the various engagements onboard the ships, only the year when the engagements began. Therefore, in order to minimise exposure misclassification we assumed that if the parents had served aboard a ship for the first time the year the child was born or later, the child could not have been affected by ''exposure'' from the ship category or the *KNM Kvikk*. We hereafter use the expression ''exposed to'' and the name of the ship or ship category when the parent served aboard the ship at the latest the year before the child was born.

Parents reported 97 children with congenital anomalies, but the parents did not respond to the second questionnaire for 13 of these children. This left 84 children to be evaluated by the physicians. They made a decision for 83 of these children, leaving 14 children without a decision as to whether they had a congenital anomaly or not. None of these 14 children had been exposed to the *KNM Kvikk* (or to any other MTB). For analytical purposes, we decided to divide them into having or not having a congenital anomaly at the same fraction as the children for which a decision had been made and whose parents had not served aboard the MTB ships.

Statistical methods

The prevalence ratio (calculated as the ratio between the prevalence odds) with the 95% confidence interval was used as an estimate of a possible relationship between the workplace and the prevalence of congenital anomalies and stillbirths. We compared the results from the *KNM Kvikk* with all the respondents, with people who had served aboard a ship in general, and with those who had served aboard an MTB. Comparing the *KNM Kvikk* with other ships in the Snogg class was not performed due to low numbers. In comparing groups, Pearson's χ^2 test or Fisher's exact test were used for categorical variables, and *t* tests were used for continuous variables.

RESULTS

Among the 2265 respondents, 1438 had 3122 biological children of their own (table 1).

Twenty two children had to be excluded since the year of birth was lacking. None of these children was reported to have a congenital or chromosome anomaly, but four were reported stillborn or having died within the first week of life.

Table 1 Participants of a cross-sectional study in the Royal Norwegian Navy

	All respondents	Served aboard a ship	Served aboard an MTB	Served aboard the *KNM Kvikk*
Number of respondents	2265	1365	441	62
Number of people with children	1438	842	303	50
Number of children of respondents	3122	1819	650	117
Number of children for whom the year of birth is known	3100	1814	646	116
Number of children with known year of birth and with parent serving aboard the ship before the year of birth		1577	542	87
Number of children likely to have congenital anomalies after paediatric evaluation	82	50	21	8
Number of stillborn children	59	36	18	6

Sixty two people had served aboard the *KNM Kvikk*; 50 had become parents to 117 children. For one child, the year of birth was lacking and for two of them the years of service for the parents aboard the ship were not known, leaving us with 114 children for further analysis. Of the 114, 87 had been exposed to the *KNM Kvikk*. The procedure was similar for the groups of children whose parents had served aboard a naval ship or an MTB.

Congenital anomalies

Of the 1438 parents, 83 reported having 97 children with congenital (n = 77) or chromosomal (n = 20) anomalies in the first questionnaire. Eleven of these children had been exposed to the *KNM Kvikk* (none with chromosomal anomalies). This gave a prevalence ratio of having a child with congenital anomaly of 4.9 (95% CI 2.5 to 9.6) if the child had been exposed to the *KNM Kvikk* compared with all the respondents. Compared with those who had been exposed to any Navy ship and any MTB, the respective prevalence ratios were 4.3 (95% CI 2.2 to 8.7) and 4.0 (95% CI 1.8 to 8.9).

The paediatric evaluation of the 84 children with primarily reported congenital anomalies resulted in eight of the children exposed to the *KNM Kvikk* being considered to have a congenital anomaly. Two had musculoskeletal deformities, two had cerebral affection, two congenital malformation of the heart, and two had different tumours, one in the neck and one sacral. Among the 73 children not exposed to the *KNM Kvikk*, 62 were considered to have a congenital anomaly and 10 no anomaly; one was not classified. Including the estimation for the 14 children with no classification, we ended up with 74 children with congenital anomalies among those not exposed to the *KNM Kvikk*.

Taking the paediatric evaluation into consideration, the prevalence ratio of having a child with congenital malformations if the parent had been exposed to the *KNM Kvikk* was 4.0 (table 2).

Comparing the parent exposed to the *KNM Kvikk* with those who had been exposed to a Navy ship or only exposed to an MTB, the respective prevalence ratios were 3.5 (95% CI 1.6 to 7.7) and 3.4 (95% CI 1.4 to 8.6).

All parents who had served aboard the *KNM Kvikk* and had children with congenital anomalies were men, and none of these children were siblings. The time from the last year of service aboard the *KNM Kvikk* to the year of birth ranged between 1 and 10 years, with an average of 4.9 years for these men.

The mean age of the parents was 30.4 years when the children with congenital anomalies were born and 31.0 years for the children without anomalies (*t* test, p = 0.74).

Stillbirths

The prevalence ratio of having a child who was stillborn or died within one week was 4.1 if the child was exposed to the *KNM Kvikk* compared with all the respondents (table 2). Compared with those exposed to a Navy ship or an MTB, the respective prevalence ratios were 3.6 (95% CI 1.5 to 8.9) and 2.7 (95% CI 1.0 to 7.5).

Both sexes were represented among parents who had served aboard the ship and had a child who was stillborn. The mean age of the parents was 29.7 years at the birth or abortion of the stillborn and 31.0 years for children not stillborn (*t* test, p = 0.50). Two of the stillborn children had congenital anomalies.

All the analyses for congenital anomalies and stillborn were repeated for men only, with similar results. Only one woman aboard the *KNM Kvikk* had a stillborn child, and no sub-analysis was therefore performed.

Comparing lifestyle and exposure

Those who had served aboard the *KNM Kvikk* did not differ significantly from the other respondents on the present use of alcohol in units, having ever smoked daily or not (Pearson χ^2, p = 0.16), and body mass index.

Table 3 shows the self-reported exposure in the Navy. Comparing exposure inside the navy, respondents serving aboard the *KNM Kvikk* reported significant more exposure to vapour from oil, gasoline, or diesel, exhaust gas, noise, vibration and shaking, and passive smoking than the other respondents ($p < 0.05$). In addition, they had worked closer to high-frequency aerials than 10 m, closer to communication installations than 3 m, and closer to radars than 5 m. Those aboard the *KNM Kvikk* also differed significantly from the respondents who had served aboard another MTB regarding exposure to vapour from oil, gasoline, or diesel (p = 0.001), exhaust (p = 0.023), and noise (p = 0.028).

Table 2 Children whose parents were exposed and not exposed to the *KNM Kvikk* according to whether the children had congenital anomalies and whether the children were stillborn or died within one week of birth

Exposed to the *KNM Kvikk*	Children with congenital anomalies		Stillborn or dead within one week of birth	
	No. (%)	Prevalence ratio (95% CI)	No. (%)	Prevalence ratio (95% CI)
No	74 (2.5)	1	53 (1.8)	1
Yes	8 (9.2)	4.0 (1.9 to 8.6)	6 (6.9)	4.1 (1.7 to 9.9)

Table 3 The frequencies and the valid percentages of self-reported exposure to various substances inside the Navy for respondents having served aboard the *KNM Kvikk* versus all other respondents

	Respondents having served aboard the *KNM Kvikk*		All other respondents				
Greatly or very greatly exposed to or worked with:	**n**	**%**	**n**	**%**	**OR**	**95% CI**	**p***
Solvents or paints	6	10.0	133	6.3	1.7	0.7 to 3.9	0.27
Skin contact with oil, gasoline, or diesel	12	20.3	289	13.6	1.6	0.8 to 3.1	0.14
Vapour from oil, gasoline, or diesel	20	33.3	213	10.2	4.4	2.5 to 7.7	<0.0005
Exhaust gas	32	52.5	261	12.4	7.8	4.6 to 13.1	<0.0005
Lead (bullets or weapon)	6	10.0	194	9.2	1.1	0.5 to 2.8	0.84
Explosives	9	15.0	206	9.8	1.6	0.8 to 3.3	0.18
Noise	43	70.5	797	37.2	4.0	2.3 to 7.0	<0.0005
Vibration and shaking	37	61.7	486	23.1	5.4	3.2 to 9.1	<0.0005
Twisted working positions	14	23.7	448	21.0	1.2	0.6 to 2.1	0.62
Passive smoking	19	32.8	390	18.3	2.2	1.2 to 3.8	0.005
Asbestos	4	8.7	59	3.5	2.7	0.9 to 7.7	0.080
Worked closer to a high-frequency aerial than 10 m	29	46.8	445	21.8	3.2	1.9 to 5.2	<0.0005
Worked closer to communication installations than 3 m	24	40.7	319	15.8	3.7	2.2 to 6.2	<0.0005
Worked closer to radar than 5 m	27	45.0	361	17.7	3.8	2.3 to 6.4	<0.0005

*Pearson's χ^2 or Fisher's exact test.

Only very few individuals reported to be greatly exposed to smoke from burning oil, pesticides or herbicides, dust from grit blasting or sanding, and welding, torch cutting, or working with the hull, and demolition work (data not shown). No significant differences were found comparing the *KNM Kvikk* personnel to others (p values 0.44–1.0).

The results for exposure to heavy lifting and work with arms above the shoulders were similar to those of working in twisted positions both inside and outside the Navy, and no significant differences between the two groups (p values 0.37–0.63) were found.

When comparing the various exposures outside the Navy, at other workplaces, and during leisure time, the numbers that had been exposed to the various agents were generally much lower and there were no significant differences between the two groups, including the distance to communication installations.

DISCUSSION

Summary of findings

This study showed a markedly and significantly increased prevalence of congenital malformations among the offspring of personnel who have served aboard the *KNM Kvikk* compared with the offspring of other employees in the Norwegian Navy. Similar results were found for stillborn and perinatal death.

Possible causes

Similar findings from an MTB have not been shown before. Very few studies exist on reproductive health in navies. Most of the published studies on parental occupations and reproduction concern other occupations.[5 16 17] A study from the United Kingdom provides some evidence of an association between Gulf War service and reported infertility,[18] but these findings conflict with the findings from a similar study from Denmark.[19]

However, the study from the United Kingdom suggests either paternal germ cell mutation or other damage to spermatogenic stem cells or the testicular cells necessary for supporting spermatogenesis, and points out the role of stress related conditions as a cause. This is relevant for our present study, as mainly men were working on the *KNM Kvikk*. Unfortunately, we have no specific information about the psychological stress level on the *KNM Kvikk* and cannot draw any conclusions on this.

The *KNM Kvikk* was special in the sense that it had long periods of electronic warfare, and the exposure to radiation might have been different on this ship compared with other vessels. High-frequency electromagnetic fields were measured on a reconstructed ship during the use of equipment emitting various types of radio frequencies. The levels of these fields differed considerably, related to the equipment and frequencies used. Some of the registered values were above the limit values used by the Norwegian Navy (STANAG 2345). There was no systematic comparison with exposure on other ships, and due to methodological difficulties, low-frequency electromagnetic fields were not evaluated.[9]

All congenital birth defects registered among the crew from the *KNM Kvikk* except one occurred after the 750 W high-frequency transmitter was installed. However, our study only includes present employees, and this information must be interpreted with caution. Further, knowledge about these types of exposure and effects on reproductive health is controversial,[4 20] and no conclusions may be drawn regarding the relationship between these factors in the present study.

The people working on the *KNM Kvikk* report more frequent exposure to vapour from oil and petroleum products and exhaust and noise than the others in the study. Several hydrocarbon compounds may affect reproduction,[6 7 21 22] and noise has been mentioned as a possible factor contributing to infertility among women.[23] However, the questions asked in our study about these exposure factors do not relate to work on any specific vessel, and the importance of these exposure factors must be explored further.

As the *KNM Kvikk* was a vessel used in warfare and with different types of weapons, other types of radiation than the ones mentioned here may have been present and caused reproductive health effects.[24] Knowledge about the operations of and work on the *KNM Kvikk* is limited, and these types of theories are only speculative and cannot be answered in the present study.

Study limitations

The study was cross-sectional, including individuals employed as of September 2002. Further, the response rate was only 58%. These limitations on the study population give potential for selection bias. Firstly, the parents who had served aboard the *KNM Kvikk* who had children with congenital anomalies might have left the Navy to a higher or lower extent than the other parents with children with congenital anomalies. We have no information on this, but there is little reason to believe that the *KNM Kvikk* parents stayed longer in the Navy. If the opposite was the case,

Main messages

- Service aboard a naval ship was associated with increased prevalence of congenital anomalies and stillbirths.
- The reason for this association remains unanswered.

meaning they left before the others, this would mean that the risk was underestimated.

Secondly, considering the relatively low response rate, one could speculate whether those who had served aboard the *KNM Kvikk* to a higher degree answered the questionnaire compared with those who had not served aboard this ship. To represent a selection bias in relation to the estimated risk, it would mean that only the parents with children with congenital anomalies showed a higher response rate and not the other employees from *KNM Kvikk*. This is not very likely, since the possible association between serving aboard the ship and congenital anomalies was not the main focus of the study and was not mentioned in the invitation to participate in the study.

Nevertheless, some years prior to this survey there had been a heated discussion in the Norwegian mass media regarding offspring with congenital anomalies associated with service aboard the *KNM Kvikk*. The general awareness of this possible association might have introduced recall bias. Parents serving aboard the *KNM Kvikk* who had children with anomalies might have remembered better that they served aboard the *KNM Kvikk* than parents not having children with these anomalies did.

Thirdly, the parents from the *KNM Kvikk* might have reported less serious anomalies, medically not classified as anomalies, which the rest of the study population would not report. We asked all the parents who had reported children with congenital anomalies to give detailed information about these children and rendered this information blinded to the paediatricians. The validation gave little reason to believe that reporting non-medical anomalies has been a source of error.

Lastly, the parents aboard the *KNM Kvikk* might have accurately reported their children with congenital anomalies, but recall bias could still have been introduced if there has been general underreporting in the rest of the study population. In the total study population, 2.6% of the offspring were reported to have congenital anomalies, taking the paediatric evaluation into account. Internationally, the prevalence of congenital anomalies varies between 1% and 7%.[25–27] During the period 1990–98, the prevalence of congenital anomalies at birth in Norway was 3.3%, with 2.3% classified as serious anomalies.[28] Even if the reported anomalies in our study also include cases that were not discovered at birth and therefore not included in the data from the birth registry, these figures do not support any major underreporting. In summary, it is unlikely that differential recall or selection could entirely explain this fourfold increased prevalence ratio of having a child with congenital anomalies if the parent had been exposed to the *KNM Kvikk*.

Conclusion

Service aboard the MTB was associated with an increased risk of having children with congenital birth defects and having children that were stillborn. The causes of these findings are unknown. As this study only included currently employed personnel, similar relationships need to be studied among previously employed personnel.

Policy implications

- A prospective study on naval service and outcome on reproduction would be of preference in the future.

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Authors' affiliations

N Magerøy, O J Møllerløkken, T Riise, B E Moen, University of Bergen, Department of Public Health and Primary Health Care, Section for Occupational Medicine, Bergen, Norway
V Koefoed, Commander Naval Medicine, Royal Norwegian Navy, Haakonsvern, Norway

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REFERENCES

1 **Sever LE**. Reproductive system: introduction. In: Stellman JM, ed. *Encyclopaedia of occupational health and safety*, 4th edn. Geneva: International Labour Office, 1998:9.2–9.4.
2 **Schrader S**, Lemasters GK. Male reproductive system and toxicology. In: Stellman JM, ed. *Encyclopaedia of occupational health and safety*, 4th edn. Geneva: International Labour Office, 1998:9.4–9.8.
3 **Lemasters GK**. Maternal occupational exposures and adverse pregnancy outcomes. In: Stellman JM, ed. *Encyclopaedia of occupational health and safety*, 4th edn. Geneva: International Labour Office, 1998:9.10–9.14.
4 **Shaw GM**. Adverse human reproductive outcomes and electromagnetic fields: a brief summary of the epidemiologic literature. *Bioelectromagnetics* 2001;(suppl 5):S5–18.
5 **Irgens A**, Kruger K, Skorve AH, *et al*. Birth defects and paternal occupational exposure. Hypotheses tested in a record linkage based dataset. *Acta Obstet Gynecol Scand* 2000;**79**:465–70.
6 **Wennborg H**, Magnusson LL, Bonde JP, *et al*. Congenital malformations related to maternal exposure to specific agents in biomedical research laboratories. *J Occup Environ Med* 2005;**47**:11–19.

7 **Shi L**, Chia SE. A review of studies on maternal occupational exposures and birth defects, and the limitations associated with these studies. *Occup Med* 2001;**51**:230–44.
8 **Silbergeld EK**, Quintanilla-Vega B, Gandley RE. Mechanisms of male mediated developmental toxicity induced by lead. *Adv Exp Med Biol* 2003;**518**:37–48.
9 **Halleraker JH**, Nestas S, Olsen H. *Investigation into a possible causal link between high frequency electromagnetic fields and congenital deformities*, Report no.633-71331-100-002E. Bergen: Royal Norwegian Navy Material Command, 1998:1–48.
10 **Thomassen M**. *Missiltorpedobåter. 90 år under rent norsk orlogsflagg [Missile torpedo boats. 90 years under pure Norwegian Navy flag]*. Bergen: Eide forlag, 1995:162–7.
11 **Irgens L**, Lie RT, Baste V. Perinatal health problems in babies of personnel serving in the Royal Norwegian Navy. Report from the Medical Birth Registry of Norway. In: Halleraker JH, Nestas S, Olsen H, eds. Investigation into a possible causal link between high frequency electromagnetic fields and congenital deformities, Report no. 633-71331-100-002E. Bergen: Royal Norwegian Navy Material Command, 1998:1–19.
12 **Kristensen P**, Jacobsen K, Skyberg K. *Mefødte misdannelser blant barn med fedre som hadde tjeneste på KNM Kvikk [Congenital anomalies among children with fathers who had served aboard the KNM Kvikk]*. Oslo: National Institute of Occupational Health, 3/2000:1–117.
13 **Irgens LM**, Baste V, Wilk P, *et al*. Clubfoot in offspring of servicemen in the Royal Norwegian Navy. *Teratol Int J Abnorm Dev* 1998;**57**:34.
14 **Magerøy N**, Baste V, Bondevik K, *et al*. *En spørreundersøkelse om arbeid og helse blant ansatte i Sjøforsvaret [A questionnaire survey on work and health among employees in the Norwegian Navy]*. Bergen: University of Bergen, Section for Occupational Medicine, 1/2004:1–69.
15 **Karmaus W**, Juul S. Infertility and subfecundity in population-based samples from Denmark, Germany, Italy, Poland and Spain. *Eur J Public Health* 1999;**9**:229–35.
16 **Chia SE**, Shi LM. Review of recent epidemiological studies on paternal occupations and birth defects. *Occup Environ Med* 2002;**59**:149–55.
17 **Chia SE**, Shi LM, Chan OY, *et al*. A population-based study on the association between parental occupations and some common birth defects in Singapore (1994–1998). *J Occup Environ Med* 2004;**46**:916–23.
18 **Maconochie N**, Doyle P, Carson C. Infertility among male UK veterans of the 1990–1 Gulf War: reproductive cohort study. *BMJ* 2004;**329**:196–201.
19 **Ishoy T**, Andersson AM, Suadicani P, *et al*. Major reproductive health characteristics in male Gulf War veterans. The Danish Gulf War Study. *Dan Med Bull* 2001;**48**:29–32.
20 **Ahlbom IC**, Cardis E, Green A, *et al*. Review of the epidemiologic literature on EMF and health. *Environ Health Perspect* 2001;**109**(suppl 6):911–33.
21 **De Celis R**, Feria-Velasco A, Gonzalez-Unzaga M, *et al*. Semen quality of workers occupationally exposed to hydrocarbons. *Fertil Steril* 2000;**73**:221–8.
22 **Gaspari L**, Chang SS, Santella RM, *et al*. Polycyclic aromatic hydrocarbon-DNA adducts in human sperm as a marker of DNA damage and infertility. *Mutat Res* 2003;**535**:155–60.
23 **Nurminen T**. Female noise exposure, shift work, and reproduction. *J Occup Environ Med* 1995;**37**:945–50.
24 **Parker L**, Pearce MS, Dickinson HO, *et al*. Stillbirths among offspring of male radiation workers at Sellafield nuclear reprocessing plant. *Lancet* 1999;**354**:1407–14.
25 **Richards ID**, Bentley HB, Glenny AM. A local congenital anomalies register: monitoring preventive interventions. *J Public Health Med* 1999;**21**:37–40.
26 **Doyle P**, Maconochie N, Davies G, *et al*. Miscarriage, stillbirth and congenital malformation in the offspring of UK veterans of the first Gulf War. *Int J Epidemiol* 2004;**33**:74–86.
27 **Czeizel AE**, Intody Z, Modell B. What proportion of congenital abnormalities can be prevented? *BMJ* 1993;**306**:499–503.
28 **Medical Birth Registry of Norway**. *Annual reports from the Medical Birth Registry of Norway*. Bergen: Medical Birth Registry of Norway, 1990–98.