No effects of GSM-modulated 900 MHz electromagnetic fields on survival rate and spontaneous development of lymphoma in female AKR/J mice

Angela M Sommer[1*], Joachim Streckert[2], Andreas K Bitz[2], Volkert W Hansen[2], Alexander Lerchl[1*†]
[1]School of Engineering and Science, International University Bremen, Research II, Campus Ring 6, D-28759 Bremen, Germany
[2]Chair of Electromagnetic Theory, University of Wuppertal, D-42097 Wuppertal, Germany

Email: Angela M Sommer – a.sommer@iu-bremen.de; Joachim Streckert – joachim.streckert@uni-wuppertal.de; Andreas K Bitz – bitz@uni-wuppertal.de ; Volkert W Hansen – hansen@uni-wuppertal.de ; Alexander Lerchl – a.lerchl@iu-bremen.de

[*] These authors contributed equally to this work
[†]Corresponding author

Abstract

Background

There are several reports that indicate that non-thermal electromagnetic radiation such as from mobile phones and base stations may promote cancer. Therefore, it was investigated experimentally, whether 900 MHz electromagnetic field exposure influences lymphoma development in a mouse strain that is genetically predisposed to this disease. The AKR/J mice genome carries the AK-virus, which leads within one year to spontaneous development of thymic lymphoblastic lymphoma.

Methods

48 groups of 6-7 unrestrained female mice were sham-exposed or exposed (each n = 160 animals) to GSM like 900 MHz electromagnetic fields for 24 hours per day, 7 days per week, at an average whole body specific absorption rates (SAR) values of 0.4 W/Kg. Animals were visually checked daily and were weighed and palpated weekly. Starting with an age of 6 months, blood samples were taken monthly from the tail. Animals with signs of disease or with an age of about 42 weeks were sacrificed and a gross necropsy was performed.

Results

There was no effect of electromagnetic field exposure on body weight gain or survival rate, and lymphoma incidence did not differ between exposed and sham-exposed animals.

Conclusion

These data do not support the hypothesis that exposure to 900 MHz electromagnetic fields is a significant risk factor for developing lymphoma in a genetically predisposed species, even at a relatively high exposure level.

Background

The use of mobile phones is increasing worldwide, although electromagnetic fields emitted by mobile phones and base station are a source of great concern. However, so far it is unclear, if non-thermal exposure have a direct influence on public health. French et al. [1] developed a theoretical model, by which radiofrequency radiation from mobile phones could induce cancer, via the chronic activation of the heat shock response. Non-thermal exposure to electromagnetic fields can result in an increased expression of heat shock proteins (hsp) [2, 3]. This is a normal defense response to cellular stress. However, chronic expression of hsp is known to induce or promote oncogenesis, metastasis and/or resistance to anticancer drugs [1]. Additionally, 72 hours exposure of human lymphocytes to continuous 830 MHz electromagnetic fields caused a linear increase in chromosome 17 aneuploidy with rising specific absorption rates (SAR: 1.6-8.8 W/Kg). This is a signal for genetic instability and may thereby lead to cancer development [4]. In principal agreement, few epidemiological studies suggest a relationship between the use of mobile phones and uveal melanoma [5] or malignant brain tumors [6-9]. However, the overall literature does not provide persuasive epidemiological evidence that mobile-phone-related emissions are carcinogenic, although mobile phones have not been in use long enough to exclude long-term impact on health [10].

It was suggested that non-thermal exposition to high-frequency electromagnetic fields may rather have a tumor promoter than an initiator effect [9], since DNA, generally, does not appear to be significantly altered or damaged by electromagnetic fields [11]. In this respect it was discussed, if a possibly reduced excretion of the oncostatic hormone melatonin by electromagnetic fields may facilitate the development of estrogen dependent tumors [12]. However, the results of different rodent studies concerning tumor promotion are not consistent. On the one hand, no difference in radiation or chemically induced tumor growth could be found after long-term exposure to electromagnetic fields (860-900 MHz) in rats or mice [13-15]. Additionally, exposure of human leukaemia cells to electromagnetic fields failed to induce any changes in apoptosis, micronucleation or differential gene expression [16]. On the other hand, long-term exposure to pulse-modulated electromagnetic fields similar to those used in digital mobile telecommunication significantly increased the incidence of lymphoma in Eμ-*Pim*1 transgenic mice, which are genetically predisposed to develop lymphoma spontaneously [17].

The differences between the studies may indicate that various species or strains as well as cancer types differ in their sensitivity to electromagnetic field exposure. The sensitivity to electromagnetic fields may result from an acquired lower resistance against adverse effects or a genetic predisposition [18]. Different proportions of a sensitive subpopulation within an epidemiological or experimental study would influence the interpretation of a possible role in carcinogenesis. However, national or international thresholds for electromagnetic field intensities must ensure adequate heath protection also for susceptible people.

AKR mice are widely used in cancer research for their high leukaemia incidence (60-100%) [19]. Mice of this strain are viremic from birth and express in all tissues the retrovirus AKV, which is associated with spontaneous leukaemia development in mice [20-22]. Generally, leukaemia induced by a given virus is restricted to a single histopathological type; most common is a lymphocytic leukaemia originating in the thymus. However, the type of leukaemia induced can sometimes be altered by age or experimental manipulation [23, 24]. Using AKR mice, we studied the incidence of tumors and survival rates under life-long influence of high-frequency electromagnetic

fields. Despite some physiological differences between mice and humans, a good correlation between known or assumed human carcinogens and test results in rodent studies has been described, often with the same organs affected in humans and in rodents [25]. Therefore, the results of this study shall help to evaluate a possible health risk of mobile phones.

Methods

Animals and animal husbandry

Female AKR/J mice were airfreighted from the Jackson Laboratory (Bar Harbor, ME, USA), at an age of 4-5 weeks. After arrival, animals were randomized and housed in groups of 6 or 7 on softwood bedding (Altromin, Lage, Germany) in polycarbonate cages (40 x 25 x 15 cm, W x L x H, Ebeco, Castrop-Rauxel, Germany), enriched with paper. Mice were allowed free access to mice standard food pellets (type 1324, Altromin) and tap-water. Twice a week cages were cleaned and water changed. Temperature was controlled at 21°C ± 2°C. The light was on a 12 hours light-12 hours dark cycle, with light on at 8 am. No sterilization measurements were taken, since AKR/J mice are not especially sensitive for pathogens. However, to prevent a possible transfection from humans to mice or mice to mice, respectively, masks and gloves were worn, which were sterilized between handling of different cages. Animals were inspected daily for signs of moribundity and were weighed (accuracy ± 0.1 g) and palpated weekly. Starting with an age of 6 months, blood samples were taken monthly from the tail. A tattoo in the ear allowed individual identification. The Bremen state commission for animal welfare according to §8a of the German animal welfare legislation approved the experiments (522-27-11/2-0).

Field exposure and monitoring

Animals were exposed or sham exposed, respectively, in two identical exposure units consisting of radial waveguides of 4.5 m diameter and 17 cm vertical plate distance. Per unit, 24 cages were placed between the plates at equal distance from the units' centers and covered with trapezoidal lids (3 cages per opening) with wire mesh. This design ensured easy maintenance and also that both light and gas could penetrate the lids while electromagnetic radiation was effectively shielded. At the outer boundaries of the units, absorbers were installed which caused minimal reflection and "hot spots". A signal generator (SMT 06, Rohde & Schwarz, Munich, Germany) and an amplifier (HLV-500, BEKO, Munich, Germany) were connected to the cone antenna of one unit via a "black box" so that it could not be seen which group of animals was exposed (blind design). The signal of the generator was modulated (BS 825F, BUGH Wuppertal, Germany) in a way which simulated an uplink / downlink scenario (i.e., a combination of signals from base stations and mobile phones) [26].

Animals were exposed 24 hours per day with the exception when animals were weighed and palpated, and during which the cages were cleaned (twice weekly). The experiment were performed at a mean value of 0.4 W/kg of the whole body specific absorption rates. This value which was stipulated by the financial backer is five times higher than the limit of whole-body exposure for the general population and is based on the limit value for occupational exposure [27]. Since the mice can move freely the whole body SAR varies with their postures and positions inside their cage. Therefore, the specific absorption rates in the mice were analyzed by numerical computations of the electromagnetic field distribution inside the radial waveguide for different configurations of the animals. It turns out that the standard deviation of the

whole body SAR is ±40 %. The required time-averaged input power of the exposure unit is 35 W. The presence of the field was monitored continuously, again via a "black box". Details of the dosimetry and exposure facilities can be found at Hansen et al.[28] and Streckert et. al [29].

Noise levels provoked by the integrated ventilation system were measured in close proximity to both units and were found to be identical (sound meter model 2218 with 1/3 octave filter set model 1616, Brüel & Kjaer, Naerum, Denmark). The total level was 69 dB (lin), and less than 25 dB at frequencies between 8 and 40 kHz. Thus possible disturbing effects of ultrasound were excluded.

Pathology

Animals were sacrificed by CO_2 gas when signs of a developing disease became evident or at an age of about 42 weeks, after a last blood sample was taken. A gross necropsy was performed focusing on main tissues of disease involvement (spleen, thymus and lymph nodes) and tumor infiltration (liver, kidney, lung, brain). Tissues were immersion-fixed in Bouin's solution for up to 24 h and subsequently in ethanol (70%), embedded in paraffin and sectioned at 5 µm. Blood smears were stained with Pappenheim's stain and tissue slices using hematoxylin and eosin. When a mouse found dead in its cage (5 exposed, 7 sham-exposed mice) a necropsy was performed, but no tissues were fixed.

Statistics

Group mean body weights were tested for a possible exposure influence in dependence of time, using the non-parametric Spearman correlation analysis (InStat 3.05, GraphPad). An unpaired t-test was applied to compare the loss of weight associated with lymphoma development. Survival curves and lymphoma incidence were plotted according to the method of Kaplan and Meier. Differences between curves were compared using the logrank test, with animals censored, which were still alive at the end of the study (Prism 4.01, GraphPad).

Statistical significance of differences was tested two-sided at the $p \leq 0.05$ level. If not indicated otherwise, data are given as means ± standard error of the mean. The exposure code was broken only after completion of the analyses.

Results

Body weight and water consumption

Chronic exposure to 900 MHz electromagnetic fields had no influence on the body weight of female AKR/J mice (Figure 1). Mean weight at the beginning of the study was 24.3 ± 0.2 g for exposed and 23.3 ± 0.2 g for sham-exposed animals. When the experiment was terminated, the mice weighed 39.0 ± 1.6 g or 42.0 ± 2.0 g, respectively. The rapid development of lymphoma in this strain of mice was associated with a loss of individual body weight of about 8.5 % in exposed and 9.2 % in sham-exposed mice, but the group difference was not statistically significant.

Water consumption was approximately 4 g per day and mouse, and not different between exposed or sham-exposed animals (data not shown). This value is in accordance to the water intake measurements published by the Jackson Laboratory [30], and obviously not influenced by the experimental set-up.

Survival and incidence of lymphoma

Similar survival rates were seen in both groups of AKR/J mice (Figure 2). Patterns of tumor-related mortality in the sham-control group were consistent with those observed in a previous study conducted in this laboratory with AKR/J mice [31]. As seen in our previous study, essentially all mortality observed in AKR/J mice was related to the development of hematopoietic diseases (Figure 3). Exceptions were 3 animals with rectal eczema, one animal with unclear findings and two exposed animals with protruded vagine. These findings were considered random findings and not related to the exposure.

Clinical picture

In female AKR/J mice lymphoma developed rapidly, usually associated with lymphadenopathy. In 30.3 % (exposed) and 28.2 % (sham-exposed) of all animals, lymphomas were restricted to the thymus, followed by respiratory distress and protrusion of the eyes. 13 animals (5 exposed, 7 sham-exposed) died in their cages without any earlier sign of distress, although autopsy revealed enlarged mediastinal mass compressing the thoracic space. Other clinical observations like changes in the differential count of leucocytes, splenomegaly and ruffled fur were considered to be associated with neoplastic development and did not correlate with the electromagnetic field exposure. The results of all histopathological analyses will be published after completion.

Discussion

Previous reports indicated that electromagnetic fields may increase the risk to develop malignant lymphoma in genetically predisposed mice [17]. The result of the present study, however, demonstrate no increased risk of lymphoma incidence in female AKR/J mice exposed to 900 MHz electromagnetic fields, modulated according to the global system for mobile communication (GSM). When compared with sham-exposed females of this strain, a mean exposition of 0.4 W/Kg SAR neither influenced the risk to develop lymphoma, nor the malignancy of the disease, nor did it influence the growth pattern or water consumption of the animals.

Exposure to electromagnetic fields increased the growth rate in the nematode *Caenorhabditis elegans* [32], but decreased the birth weight of albino rat offsprings [33]. In contrast, the growth pattern of Eμ-*Pim*1 mice was not changed due to exposure to electromagnetic fields [17, 34]. During the progression of the present experiment, female AKR/J mice showed a tendency to obesity, but the mean weights were the same in both exposed and sham-exposed groups, and similar to animals of the same strain during other experiments in our laboratory [31]. Accumulation of weight was therefore not related to the exposition and seems to be strain-specific. The exposure-independent water consumption may also suggest that no major changes in the intake of food occurred. However, this assumption must be examined by specific studies of the mice's metabolism.

Studies that showed an influence of electromagnetic fields on the animals' weight worked with reproducing animals [32, 33], whereas the present and the 2 Australian studies cited above used only female mice [17, 34]. There is a well-known trade-off between basal metabolism, growth rate, and fecundity [32, 35]. Differences in the results about an impact of electromagnetic fields on growth rate might be, therefore, due to the differences in the species ability to balance these processes.

A demonstration that long-term exposure to electromagnetic fields derived from mobile phones or base stations increases the incidence of tumors in animals would

provide direct evidence that such radiation is carcinogenic. The most positive evidence of an effect of exposure to high frequency electromagnetic fields similar to that used by mobile phones was reported by Repacholi el al. [17], using Eμ-*Pim*1 transgenic mice, that are known to develop spontaneous lymphoma with a high incidence rate. Lymphoma risk was found to be significantly higher in the exposed Eμ-*Pim*1 mice than in the controls, mostly pronounced for non-lymphoblastic lymphoma. Humans are presently not known to carry an activated *Pim*1 gene, but other inherited gene defects are known that predispose carriers to develop cancer [18]. Because of the importance of that study, a replication started according to plan in spring 2002 in Italy. First results are expected 2005. However, the results already indicated the need of further assessment of the relevance of such findings for human health [10].

A Japanese study showed that neither 1.5 GHz nor 929.3 MHz electromagnetic field exposure promotes liver carcinogenesis in a medium-term bioassay system, using partially hepatectomised F344 rats [36]. A monopole antenna close to the constrained animals emitted a "near-field" radiation that resulted in SAR values of 0.45-0.68 W/Kg as a whole-body average and of 0.9-1.9 W/Kg in the liver. It was suggested that the applied "near-field", which is more in line with the actual exposure conditions of cellular telephone users, explains the differences to the study of Repacholi et al.[17], who employed a "far-field" and mean whole-body SAR values of 0.13-1.4 W/Kg. However, the confinement may also affect the results [37, 38], as well as the different animal models: long-term exposure of genetically predisposed animals on the one hand and a medium-term bioassay of chemically induced carcinogenesis on the other hand. Therefore, it is difficult to decide which results are more relevant for human mobile phone users.

In the present study free running mice that are genetically predisposed to develop lymphoma with a high incidence were exposed to a "far-field" similar to Repacholi et al.[17], with the difference that our mice were exposed for 24 h, whereas their mice were exposed for two 30-min periods per day, only. In contrast to the Australian study, we could not observe an increased lymphoma risk. However, our study's results are consistent with an investigation within the electromagnetic energy program of the National Health and Medical Research Council of Australia [34], using the same Eμ-*Pim*1 mice from the same supplier (Taconic Farms, New York) than Repacholi et al. [17], with the difference, that the mice were restrained to better control the exposure data. The authors also did not find a significant effect of 898.4 MHz GSM radiofrequency radiation at SAR values of up to 4.0 W/Kg when compared to sham-irradiated animals.

Conclusions

The present study does not support the hypothesis that chronic exposure to high-frequency electromagnetic fields, similar to those emitted by mobile phones and base stations promote neoplastic development in the hematopoietic system in genetically predisposed mice. However, we cannot rule out that exposure to electromagnetic fields may be risk factors for other neoplastic development.

Competing interests

There are no financial or non-financial interests competing with the results of this paper.

Authors' contributions

AS carried out the study, performed the statistical analysis and drafted most of the manuscript. AL conceived the study, participated in its design and coordination, and drafted some parts of the manuscript. JS, AB and VH developed the technical set up and delivered the dosimetry for the experiment. All authors read and approved the final manuscript.

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Figures

Figure 1 - Growths curves for female AKR/J mice exposed or sham-exposed to 900 MHz electromagnetic fields.

The growth pattern was not influence in female mice by exposure to 900 MHz electromagnetic fields. Although mice tended to obesity, accumulation of weight was not related to the exposition and seems to be strain-specific. Data are given as mean ± standard error of the mean, n = 160 at the beginning of the experiment.

Figure 2 - Survival rates in AKR/J mice exposed to 900 MHz electromagnetic fields

No significant differences in the survival proportion or mean survival time were seen between exposed and sham-exposed animals when average whole body specific absorption rates were 0.4 W/Kg. Data are given as % of 160 animals ± standard error of the mean.

Figure 3 - Lymphoma incidence in AKR/J mice.

Essentially all mortality observed in AKR/J mice was related to the development of hematopoietic diseases independent of electromagnetic field or sham-exposure. Median time for lymphoma development was 183 days (exposed mice) or 193 days (sham-exposed mice), and not significantly different according to the logrank test, with animals censored which were still alive at the end of the study or died of other reasons than lymphoma. Data are given as % of 160 animals ± standard error of the mean.

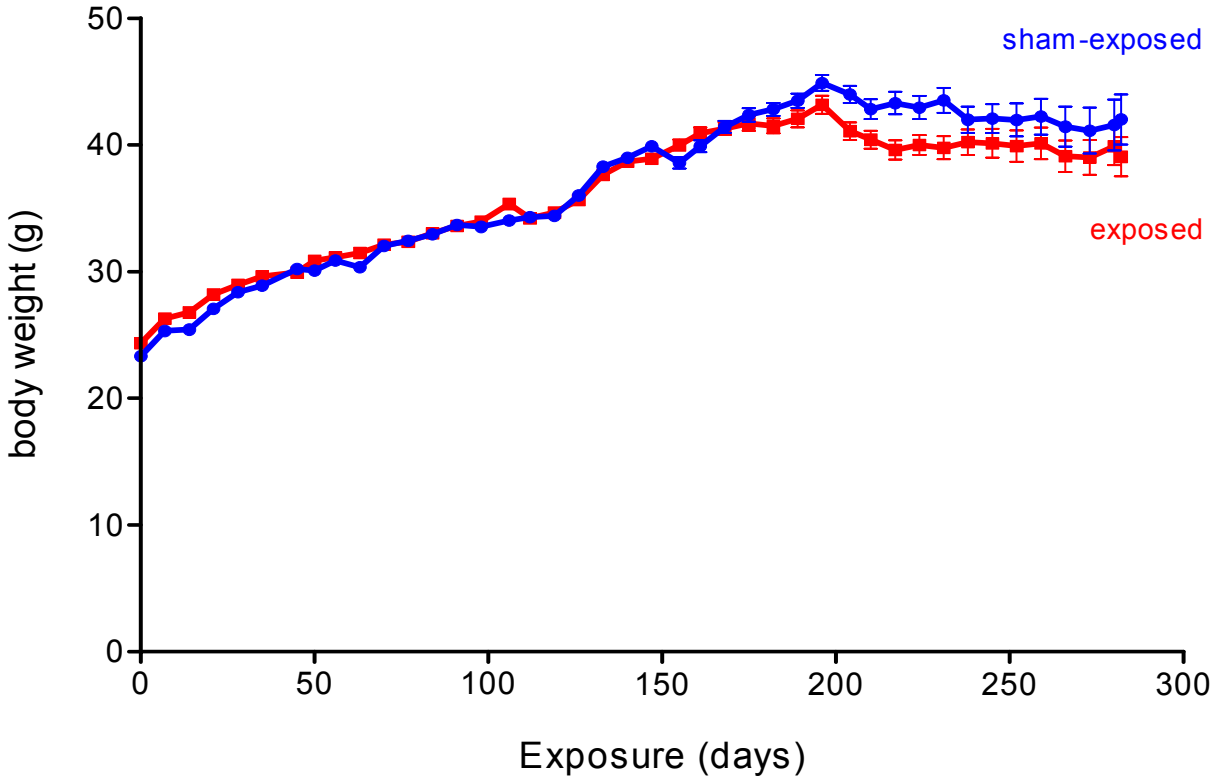
sham-exposed
exposed
body weight (g)
Exposure (days)
0
10
20
30
40
50
0
50
100
150
200
250
300

Figure 1

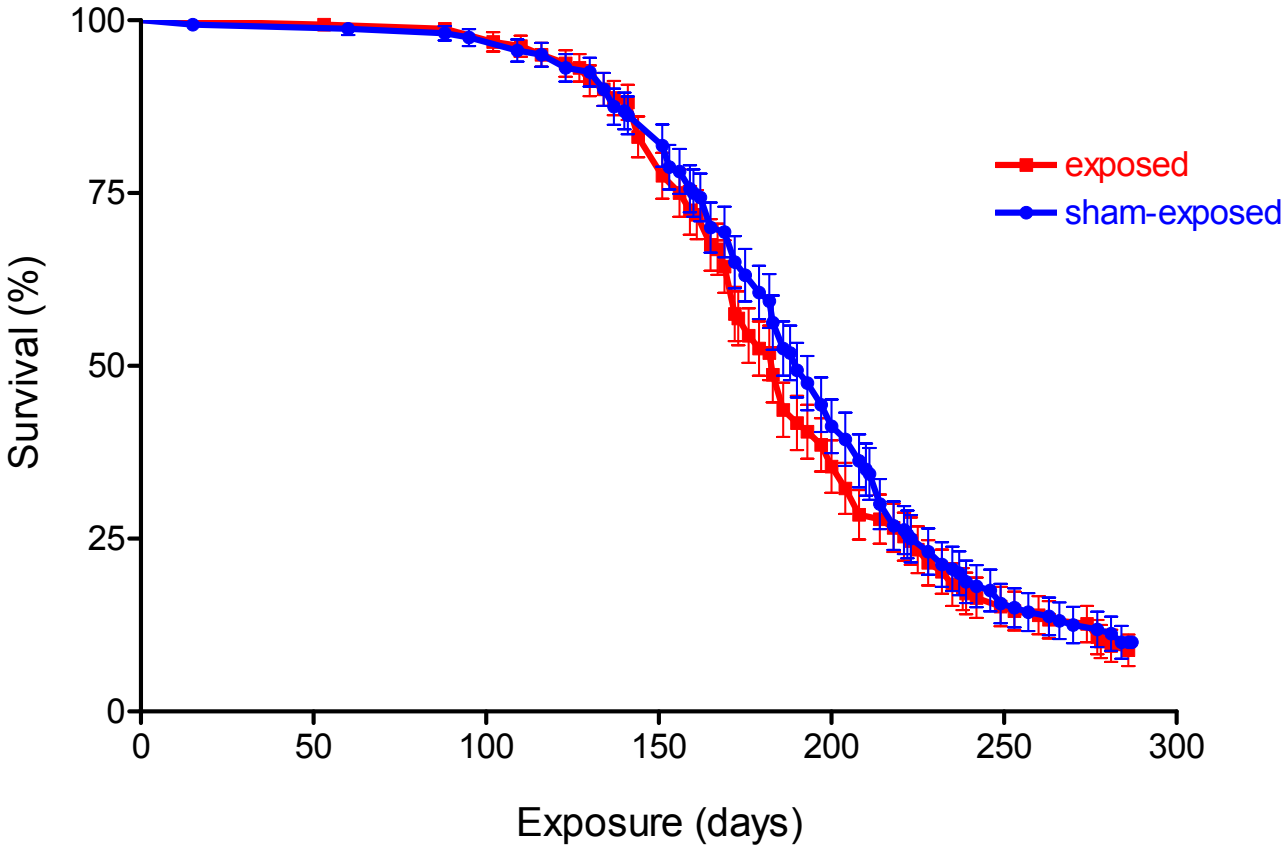
100
75
50
25
0
Survival (%)
0
50
100
150
200
250
300
Exposure (days)
exposed
sham-exposed

Figure 2

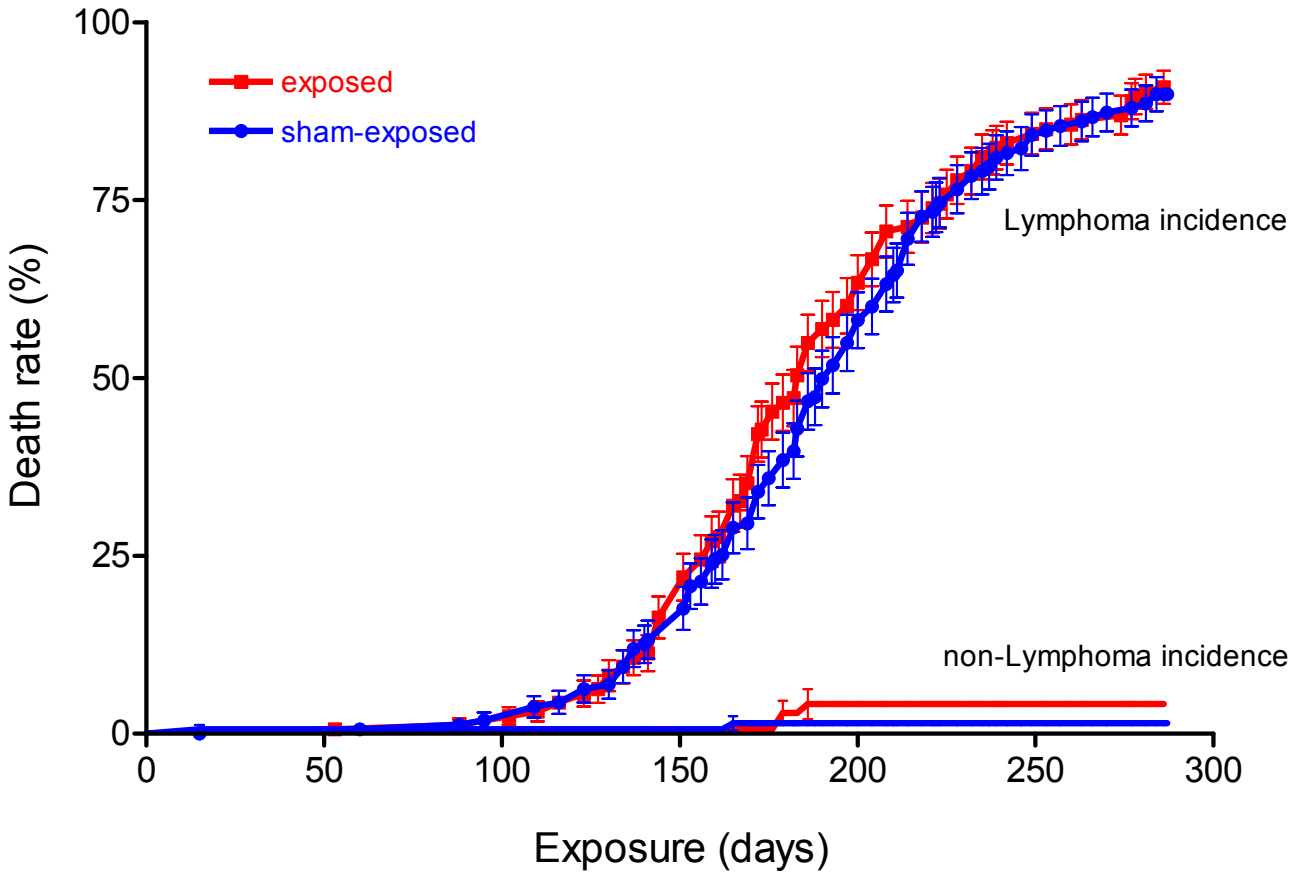
100
75
50
25
0
Death rate (%)
exposed
sham-exposed
Lymphoma incidence
non-Lymphoma incidence
0
50
100
150
200
250
300
Exposure (days)

Figure 3