

Non-ionising radiation

Exposure to chemicals, radiation and biological agents have been linked to an increased risk of developing cancer and it seems likely that no single event is responsible: rather, the causes of childhood cancer are multi-factorial, operating in *at least* a two-step process.

In this section we are considering the role of electromagnetic fields (EMFs) in cancer initiation or promotion, both power-frequency fields, which arise out of the distribution and use of electricity, and radiofrequency fields which are generated when radio, television or telecommunications signals (primarily) are transmitted.

ELF (powerfrequency) magnetic field exposure

There is quite a difference of opinion as to the involvement of electromagnetic fields in the causation of childhood tumours. This may be because the research has not included differences in genetic susceptibility and type of tumour that makes the risk difficult to quantify with any degree of certainty. In a study by Hug (2010) parental preconceptional magnetic field exposure was estimated according to a job-exposure matrix. No increased cancer risks were found in children whose fathers or mothers were exposed to estimated field levels over 0.2 microtesla. In another study, children whose mothers were occupationally exposed to low levels of powerfrequency magnetic fields during pregnancy, have a slightly increased risk of developing ALL between 0-9 years (Infante-Rivard & Deadman 2003). Pearce (2007) found that paternal occupational exposure to EMFs prior to the child's conception resulted in a significant increased risk of ALL for boys aged less than 6, though the strength of this association is weakened as the research team looked at ionising radiation exposure as well, which has been linked to male susceptibility (see Section 3). Criticisms have been made of studies that rely on estimated field levels, as being unreliable due to the variation in exposure of different jobs, and home exposure was not assessed either.

The evidence is mixed as to whether EMFs directly damage DNA, although indirect effects such as from the bystander effect, may be responsible. It is possible that the way EMF exposure has been measured may be responsible for the mixed results obtained experimentally.

Though experiments may be contradictory or inconclusive, nevertheless, it is suggested that EMFs could act by:

- Directly increasing the level of harmful free radicals within the body
- Affecting other cellular processes (including direct, or indirect tumour promotion), some of which may not even have been investigated as yet
- Decreasing the level of the protective hormone melatonin
- Acting in a synergistic way with respect to other pollutants, making them more harmful

Free radical effects

In body tissue free radicals are dangerous high-energy particles that damage cells and can both cause and accelerate the progression of cancer. Timmel & Henbest (2004) were the first to show that exposure to EMFs can increase the yield of free radicals by more than 60%. The theory was reviewed by Simkó & Mattson (2004), who concluded that EMFs cause a general increase in the levels of free radicals, which could explain the diverse and often inconsistent nature of observed effects of EMFs, free radicals being intermediaries in many natural processes. DNA damage could arise as a result of persistently elevated free radical concentrations, caused by long-term EMF

exposure, or via the radical pair mechanism, by which magnetic fields increase the lifetime of free radicals, allowing more DNA damage to occur (Rollwitz [2004](#), Henshaw 2008).

Effects on other cellular processes

Binhi ([2008](#)) suggested that magnetic nanoparticles in the human body may be one of the avenues by which EMFs may be implicated in the development of childhood cancer. Changes in levels of cellular proteins or ions can affect cell function (such as removing unnecessary or damaged cells) and cause cancer cells to develop. Some experiments have shown that EMFs affect these functions, though they have been difficult to reproduce and therefore remain controversial. Calcium ions play a critical role in determining the rate of cell division, and the overall evidence is that magnetic fields induce changes in apoptosis (cell death), according to a review by MT Santini ([2005](#)). Changes in B lymphocytes can also change cellular division rates. A series of studies (Uckun [1995](#), Dibirdik [1998](#), Kristupaitis [1998](#)) demonstrated EMF effects that made cells more likely to become cancerous. These findings may prove particularly important with regard to B-lineage ALL.

However, cells are not autonomous units responding to damage as independent entities. Recently, there have been many reports of effects arising in non-irradiated cells as a consequence of inter-cellular communication. These non-targeted effects have been demonstrated in the descendants of irradiated cells (radiation-induced genomic instability) (Lorimore [2008](#)) and in cells that have received signals produced by neighbouring irradiated cells (radiation-induced bystander effects) (Wright [2007](#), 2008, [2010](#) Coates [2008](#), Coates [2008b](#), Burr [2010](#)), but the expression of such effects is significantly influenced by genetic factors.

Mair (2008) suggested that *“EMF carcinogenesis involves the transport by macrophages of toxins (possibly including free radicals) to sites of infection or tumour localisation. This could increase mutation rates at these sites, perhaps promoting malignancy by introducing mutations, or by increasing the DNA instability of small early tumours, thereby engendering a more aggressive phenotype.”* Mair also suggested that EMFs could be mutagenic on their own, or could potentiate ionizing radiation mutations.

Melatonin effects

The hormone melatonin, is thought to protect the body from cancer by

- neutralising free radicals
- inhibiting the uptake of growth factors by cancer cells
- by increasing the likelihood of cancer cells undergoing apoptosis (cell death), and
- by inhibiting the growth of blood vessels in tumours.

The production of melatonin at night (when the majority of melatonin is produced by the body's pineal gland) has been found to be reduced significantly by light at night and magnetic fields associated with the electricity supply (Henshaw & Reiter [2005](#), Erren [2005](#)). Lupke ([2004](#), [2006](#)) suggested that EMFs reduced the anti-oxidative protection from melatonin.

Badr ([1999](#)) found that melatonin protects cells from genetic damage. Vijayalaxmi ([1995](#), [1996](#), [1999](#)) found that melatonin helped prevent oxidative damage to the human haemopoietic system and in animal fetuses (Wakatsuki [1999](#), Okatani [2001](#)). Melatonin levels are particularly high during pregnancy (Nakamura [2001](#)), so any change in these levels may result in some of the *in utero* damage which cause the 'first hit' which ultimately leads to cancer.

A variety of bone marrow cells have been shown to produce melatonin (Tan [1999](#), Conti [2000](#), Carrillo-Vico [2004](#)). Whilst the specific function of melatonin in these cells remains unknown, its suppression could have clear implications for leukaemia initiation and/or progression. A

reduction in melatonin in the leukocyte precursor cells would be expected to enhance free radical-mediated DNA damage, thereby increasing the likelihood of these cells becoming carcinogenic.

Melatonin reduces the growth of HL-60 myeloid leukaemia cells *in vitro* (Henshaw 2008).

Light at Night

Evidence suggests that increasing exposure to light at night (LAN) and the consequent disruption of circadian rhythms, especially via reduction in nocturnal pineal melatonin, is a significant factor in the increasing incidence of breast cancer in recent decades in industrialised countries (Blask [2005](#)). Whether LAN features in childhood cancer risk is not known.

For more information, see the “Melatonin” article.

Synergistic effects

Airborne pollutant particles are known to have a significant effect on health and a number of studies have reported an association between childhood cancer and exposure to traffic pollution. The strong electric fields associated with high voltage power lines may affect the charge on the chemicals found in traffic pollution, making them more likely to be absorbed by the body. This effect can be observed up to 7 kilometres downwind of a high voltage powerline (Fews [1999a](#)). The older the cable and the wetter the weather the more charged ions are emitted (Fews [1999b](#)). Very small particles are particularly hazardous because of their ability to penetrate deeply into the lung and pass into the bloodstream (Seaton [1995](#)). These small particles are in the size range where electrical charging can significantly increase lung deposition on inhalation. The report by Draper ([2005](#)) found increased risk of leukaemia in children born within 600 metres of National Grid 400 and 275 kilovolt power lines. This distance is clearly too far away to be a direct EMF effect, but could validate the ion polarisation theory.

Brain and CNS tumours

Women who worked in low-frequency magnetic environments when pregnant, such as machinists, hairdressers, nurses and dry cleaners were twice as likely to have babies that developed brain tumours (Li [2009](#)). Professor Henshaw, Scientific Director of CHILDREN with CANCER UK, said “*Low-frequency magnetic fields can suppress production of melatonin, which, in pregnant women, will deprive the foetal brain of the protective hormone.*”

In a meta-analysis of 13 studies (Mezei [2008](#)), there was a very slightly elevated risk of brain tumours with exposure to magnetic field levels in the home over 0.2 microtesla (μT), with a greater risk at levels of 0.3 or 0.4 μT .

A more recent study not included in the meta-analysis found a positive association between exposure to residential magnetic fields above 0.4 microtesla and the risk of brain tumours (Saito [2010](#)).

Preston-Martin ([1996](#)) found no association, but she concluded that the prevalence of high fields in Los Angeles homes was too low to detect a moderate effect. Gurney ([1999](#)) concluded that electromagnetic fields (EMFs) played no causal role in brain cancer development, and Kheifets (who has been repeatedly funded by the power industry), in a pooled analysis of 10 studies, found no association ([2010](#)).

Leukaemia

There is disagreement as to whether the relationship between EMF exposure and an increased risk of childhood leukaemia is a causal one, or whether there is a coincidental association with some other, as yet undiscovered, factor. However, the relative risk is surprisingly consistent, even though epidemiology is a bit of a blunt instrument to detect causal factors in a multi-factorial illness. Even the Health Protection Agency – Radiological Protection Division, the International Agency for Research on Cancer (IARC, 2001) and the World Health Organisation (WHO) have all agreed that EMFs are a potential carcinogen (Class 2B) and that precaution is warranted.

It is possible that if magnetic fields are causative, it may be the rotating quality of the fields that is responsible. This is rarely measured.

The California EMF Programme report (Neutra 2002), has been recognised as one of the more definitive documents of recent times. The authors concluded that EMFs increased the risk of childhood leukaemia. The International Agency for Research on Cancer (IARC) classified magnetic fields as a “possible human carcinogen”, though this was not sufficient to influence public health policy according to Kheifets (2006). The results of one Canadian study by Green (1999), based on personal measured fields rather than spot measurements found a significant increase in risk of childhood leukaemia at 0.14 microtesla (even lower than most of the published literature, which seems to show a consensus at 0.3 – 0.4 microtesla), though there was no association with living near high voltage powerlines.

An influential report (www.bioinitiative.org) by Hardell & Sage (2008) concluded that in view of the association between electromagnetic fields and childhood leukaemia, a new lower public safety limit for habitable space adjacent to all new or upgraded power lines should be applied. A new lower limit should also be used for existing habitable space for children and/or women who are pregnant.

Kheifets (2011) pointed out some of the difficulties in making sense of the measured levels and childhood leukaemia risk using various statistical tests, and we, at Powerwatch, suggest that it may be as appropriate (if not more so) to take into account peak-level exposure and maternal exposure during pregnancy. Most studies are based on average levels, thus excluding what may be the most important metric, irrespective of analysis procedure.

More than 25 epidemiological studies around the world have investigated the association between childhood leukaemia and EMF exposure. They have found an increased risk of childhood leukaemia with proximity to high voltage powerlines, substations or high residential magnetic fields (Olsen 1993, Fajardo-Gutierrez 1993, Lin & Lee 1994, Kaatsch 1996, Thériault & Li 1997, Linet 1997, Michaelis 1997, 1998, Dockerty 1998, Li 1998, McBride 1999, UKCCS 1999, Bianchi 2000), some showing a 2-3 fold increase with residential proximity to powerlines (London 1991, Feychting & Ahlbom 1993), or even up to 5 times higher (Malagoli 2010, Wunsch-Filho 2011) or more (Sohrabi 2010). Not all studies have found an association (Verkasalo 1993, Tynes & Haldorsen 1997, Kleinerman 2000), and some of these studies used wire codes and calculated fields rather than measured fields from specific sources of EMFs. A study by Lowenthal (2007) found that living within 300 metres of high voltage powerlines within the first 15 years of life tripled the risk of developing a lymphoproliferative or myeloproliferative disorder in later life; and Draper (2005), in the largest single study of childhood cancer and powerlines, reported an increased risk in children whose birth address was within 600 metres of a high voltage power line. The risk was increased 5-fold if it was in the first 5 years of life. This may be due to the air ionisation effect referred to above, which is an electric field effect. Henshaw (2008) who proposed the air ionisation effect, suggested that about 11% of childhood leukaemia cases may be linked to magnetic fields.

Schüz (2001) suggested that night-time levels were of particular importance, though when he made a further analysis of his findings (Schüz 2007) his conclusions were less clear. Schüz also looked at residential exposure to magnetic fields at 16.7 Hz from the electrified railway system in Germany, and found a moderate but statistically non-significant association with childhood leukaemia (Schüz 2001).

Exposure to various electrical appliances, both during pregnancy and in childhood were looked at by Hatch (1998) who found a link with childhood ALL and the use of some appliances.

A review of 152 articles (Pelissari 2009) suggested that *“an association may exist between exposure to low frequency magnetic fields and acute lymphoblastic leukemia in children, but this association is weak, preventing the observation of consistency in the findings.”* The authors concluded that ALL should be the focus of future studies as this seems to be the subtype with the most likely association.

Yang (2008) found genetic markers that showed that those carrying this gene variant were four times more likely to develop childhood leukaemia if they also live within 100 metres of power lines or transformers, compared to those with a fully functioning version of the gene. This groundbreaking piece of research indicates a potential for identifying individual susceptibility. For those already genetically susceptible (children with some congenital syndromes, such as Down syndrome), exposure to magnetic fields seemed to increase the risk of developing leukaemia (Mejia-Aranguré 2007).

Individual studies are often limited because of the relative rarity of childhood leukaemia and the relatively low number of children exposed to high levels of EMFs. Three reports which have pooled the data from individual studies, have found an increase in risk with exposure to magnetic fields of 0.3 – 0.4 microtesla (Ahlbom 2000, Greenland 2000, Wartenberg 2001). This level was confirmed by further studies (Kabuto 2006, Feizi & Arabi 2007).

It seems unlikely that there is a straightforward answer to whether EMFs *cause* cancer. We believe there is increasing evidence that they may play a definite role in affecting the body's ability to cope with pre-cancerous cell damage. There almost certainly will be other factors, such as chemical and other physical exposures (Juutilainen 2006) involved in the final outcome of a diagnosis of leukaemia.

Maslanyj (2010) concluded that taking a precautionary approach with respect to the proximity of powerlines to children was an appropriate one in view of the consistent association with childhood leukaemia in the research. He suggested that low-cost intervention to reduce exposure is timely, accepting that this recommendation was a controversial one as this measure may not fully alleviate the risk, due to other possible interpretations of the data. He did, however, comment that EMF links with Alzheimer's disease may be worth taking into account.

Meanwhile, unaccountably, there seems to be mixed opinion as to whether to recommend more precautionary limits to EMF exposure, bearing in mind that precautions are appropriate when there is uncertainty. If a relationship between the two were *proven*, then it would be the time for legislation. Calvente (2010) calls for an urgent reconsideration of exposure limits for both low frequency and static magnetic fields based on a review of experimental and epidemiological research into the link with childhood leukaemia.

The Stakeholder Advisory Group on ELF EMF (SAGE), the official Department of Health working group which was set up to recommend policy about powerlines to government, produced its First Interim Assessment in April 2007. They concluded that banning the building of new homes and schools within 60 metres of power lines is the best available option for reducing deaths from childhood leukaemia and possibly other diseases. The report fell short of recommending this as government policy because of fierce disagreements within the group. It said that such a policy, if implemented by the government would have a dramatic effect on

property prices within power line corridors. It put the cost of restricting development at £1bn. Michael Jayne of the Royal Institution of Chartered Surveyors (RICS) called on the Government to take precautionary measures in order to ensure that the health risk is minimised by preventing the building of residential properties within specified distances of power lines.

Other places of EMF exposure

Söderberg (2002) found a slightly elevated risk for AML, but not ALL in children who had been exposed to high magnetic fields from infant incubators.

Changes in magnetic field level above 1.6 microtesla, such as can be found when travelling in electric trains, have been linked with an increased risk of miscarriage (Li 2002). It is possible that the magnetic fields may also change DNA in ways that may not be destructive enough to result in a miscarriage, but may have health implications.

Static fields

Very little has been done to identify whether exposure to static fields may be related to the risk of leukaemia. Bowman (1995) suggested that childhood leukaemia may be related to the combined effects of the earth's static magnetic fields and low levels of ELF magnetic fields resulting in various molecular ion resonances. The earth's static magnetic fields vary from country to country and could be significant in the disparity between study results, if it did, indeed, have a role.

Treatment

It has also been suggested that exposure to EMFs may adversely affect the outcome of treatment for childhood leukaemia.

Effects of EMFs on survival after treatment

Exposure to magnetic fields appeared to decrease the survival time of children in remission from leukaemia, at over 0.3 microtesla (Foliart 2006), or over 0.1 microtesla (Svendsen 2007), though a further study by Foliart (2007) concluded that elevated magnetic field levels were not associated with factors that predicted poor survival.

Neuroblastoma

(De Roos (2001) found that paternal exposure to battery-powered forklifts was positively associated with neuroblastoma and there was also a weak association between 0.4 μT paternal magnetic field exposure and neuroblastoma, but not maternal exposure.

Radio-frequency radiation exposure

Older TV and radio masts transmitted analogue signals. The situation has now changed with the arrival of digital radio and TV and the omnipresent telecommunications (mobile phone) masts. There are also other sources of digital signal transmission (digital cordless phones, WiFi, etc) that are being increasingly situated within houses, schools, offices, leisure facilities, etc. that is increasing the general public's exposure to radiofrequency radiation significantly.

It has been suggested by many scientists that digital signals may well have a greater biological impact on living systems than analogue signals; this possible impact includes not only people, but also animals and plants. If this is so, we would expect to see increasing evidence of health

problems associated with exposure, though this may not include an increase in childhood cancer risk.

Navarro (2003) and R Santini ([2002](#), [2003](#)) found evidence of ill-health as a result of living near to mobile phone masts, but they were not specifically looking at cancer incidence. Two studies on adult cancer incidence near masts found significant increases (Wolf & Wolf 2004, Eger 2004) and the Wolf study found a ten-fold increase in female cancer. Neither looked at childhood cancer incidence.

Brain and CNS tumours

People have expressed concern about the use of mobile phones and brain tumours, but this is a relatively new technology. Children have only just begun to use them extensively and brain & CNS tumours can take some time to develop and be diagnosed. Meanwhile, this uncertainty may influence whether we discourage our young people from exposing themselves to such a potential hazard.

As well as the risk from phones, people have wondered whether the radio-frequency emissions from the mobile phone network of masts and other sources may also result in an increased risk of tumours in children who live nearby.

No link was found between the radiation from AM radio transmitters and the incidence of brain tumours (Ha [2007](#)).

Professor Stefaan van Gool, who is a clinic supervisor at the children's Haematology/oncology department at Louvain University hospital in Belgium and treats children with brain cancer says, *"Cordless baby alarms, toys and phones expose children to daily radiation. Although the intensity is less than a mobile phone, children are more susceptible to the effects. A lot of young people have WiFi at school, so their exposure is continual."* He continues *"There is irrefutable proof of the harmful effects of electromagnetic radiation. It should actually be the responsibility of the operators and the industry to demonstrate that they are not harmful"*

Leukaemia

There have been some studies that have found increases in leukaemia risk as a result of living in proximity to radio or TV transmitters (Maskarinec [1994](#), Hocking [1996](#), Dolk [1997a](#), [1997b](#), Michelozzi [2002](#)), that mean we cannot be complacent about the effects of RF signals. The study authors concluded that there was a small increased risk in adult and childhood leukaemia for those who lived within 2 kilometres (Ha [2007](#)), but the confidence levels were low due to the small number of cases involved. One study showed no such increase in risk (Merzenich [2008](#)), and Elliott ([2010](#)) found no link between childhood cancer and maternal exposure to base stations. Elliott has a tendency to find negative links between the environment and health problems, including the fact that he found no evidence for the reality of Gulf War Syndrome; not everybody concurs with his findings.

Hocking & Gordon ([2003](#)) also found an association between living near to TV transmitters and decreased length of survival after leukaemia diagnosis.

Neuroblastoma

De Roos (2001) found that maternal and paternal occupational exposure to a broad grouping of sources that produce radiofrequency radiation was associated with an increased incidence of neuroblastoma in the children.

Conclusion

At an International Commission for Non-Ionising Radiation Protection (ICNIRP) workshop on risk factors for childhood leukaemia, Anders Ahlbom reviewed the epidemiological data looking at childhood leukaemia and electromagnetic fields. He said *“Generally the exposure measures have been too crude, however this would tend to decrease the estimated association rather than increase it. Significant confounding is most unlikely – there would have to be a very large new factor that has not already been considered. Selection bias is possible, but unlikely to be a large effect given the number of very different pooled studies. It will not be due to chance. The evidence that ELF magnetic fields are a causal factor in the development of childhood leukaemia is stronger than that for passive smoking and lung cancer.”*

We believe that childhood cancer is unlikely to be *caused* by exposure to electromagnetic fields, but there seems sufficient evidence that they may have a promotional effect that we think taking a precautionary stance, minimising exposure, is the best course, whilst further research takes place.

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