Original Article

# The Effect of Extremely Low Frequency Electromagnetic Fields on Pregnancy and Fetal Growth, and Development

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**Abstract**

**Background:** Exposure to electromagnetic fields (EMFs) and its effects at different frequencies on living beings has been investigated for decades. However, there are fewer studies that have been conducted on humans, thus this study aims to determine the effect of extremely low frequency (ELF) -EMFs on pregnancy, fetal growth and development in humans.

**Material:** In this epidemiologic analytical cohort study, cases included pregnant women and their newborns. There were 222 women exposed to ELF-EMFs from high voltage electricity towers and cables during pregnancy and 158 women who had no exposure during pregnancy. Data that included pregnancy duration, neonatal birth weight, length, head circumference, gender and congenital malformations were collected through direct questions, measurements and referral to the registered data of related hospital or health center documents. Collected data was analyzed by SPSS-16. $P < 0.05$ was considered significant.

**Results:** No significant difference was found in pregnancy duration and preterm labor, neonatal birth weight, length, head circumference and congenital malformations in the two studied groups.

**Conclusion:** Although the results of this study have shown no significant effects of ELF-EMFs on human pregnancy, fetal growth and development, taking precautionary measures to reduce exposure to EMFs by pregnant women seems logical. Conducting similar studies is strongly recommended.

**Keywords:** Congenital malformations, electromagnetic fields, exposure, growth and development, pregnancy

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## Introduction

During recent years there has been increasing scientific evidence and public concern regarding the potential health risks from power-frequency or extremely low frequency electromagnetic fields (ELF-EMFs) and from radiofrequency/microwave radiation emissions (RF). All individuals are exposed to these two types of EMFs by: (a) ELF fields from electrical and electronic appliances and power lines, and (b) RF radiation from wireless devices such as cell and cordless phones, cellular antennas and towers, and broadcast transmission towers. In this report we have defined EMFs as all electromagnetic fields in general, and the terms ELF and RF when referring to the specific type of exposure. Both are forms of non-ionizing radiation, in that they do not have sufficient energy to break off electrons from their orbits around atoms and ionize (charge) the atoms as ionizing radiation.[1]

To properly address health issues of EMFs, the nature of the field; whether it is electric or magnetic; static or alternating at low, intermediate or high frequency (HF); and possibly the modulation (constant wave or pulsed) has to be taken into consideration. In addition the exposure conditions expressed in terms of electric/magnetic field strength, power density and duration play a role. Table 1 presents electric, magnetic and EMF categorized according to their frequencies and use.[2]

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Similar to all devices that carry an electric current, power lines generate electric and magnetic fields that are collectively called EMFs. Electric fields are measured in kilovolts per meter (kV/m) and magnetic fields in microteslas (μT) and/or Gauss (G), of which 1T equals $10^4$ G.[3] The interaction between low frequency (LF) fields (including ELF fields) and living matter is well known. The electric component of the electric field does not penetrate deeply into an organism, but is largely absorbed by skin and muscle. This absorbance is due to the high conductivity of these tissues. The magnetic field component of fields up to approximately 30 kHz can penetrate deeply into the body and may, under appropriate conditions, induce electric currents. If the current density exceeds a certain threshold value, excitation of muscles and nerves due to membrane depolarization is possible. According to the International Commission on Non-ionizing Radiation Protection (ICNIRP) the current regulatory exposure limits are determined to safely prevent this effect. Chronic exposure to a LF electric field is limited to an electric field strength of 5000 V/m. The limit value for the magnetic field is a magnetic flux density of 100 miliTesla (mT).[2,4] At least four different research groups have shown unusual changes in calcium ion release from a variety of biological samples which resulted from ELF fields.[5] Exposure to ELF-EMFs is considered to be a genotoxic factor because of the resultant DNA breakage and damage. Its role as a risk factor for cancers, particularly brain tumors and childhood leukemia, has been determined in previous studies.[6–10] Satio et al. have shown the teratogenic effects of a magnetic field on developing mice fetuses.[11] Tenorio et al. showed the effect of LF-EMFs on genital organ development in male rats.[12] Cao et al. determined that ELF-EMFs exposure resulted in miscarriage, fetal loss, malformation

**Table 1.** Frequency ranges of electromagnetic fields (EMFs) and typical applications.

| Band Name | Abbreviation | Frequency Range (typical values) | Common Occurrence/Uses (examples) | Medical Uses (examples) |
|---|---|---|---|---|
| Static electric field | — | 0 Htz | Clouds ans thunderclouds, Charged surfaces (e.g. TV sets) and spark discharges, DC rail systems | — |
| Static magnetic field | — | 0 Htz | Terrestrial magnetic field and permanent magnetism | Magnetic Resonance Imaging (MRI) |
| Extremely Low Frequency | ELF | 1–300 Htz | Railway power supply, Household power supply, Household devices (electric blankets or water beds, night storage heaters) | — |
| Low Frequency | LF | 300 Htz–100 KHtz | Visual display units | Stimulation currents, Gradient fields (MRI) |
| High Frequency | HF | 100 KHtz–300 GHtz | Radio, TV, other radio applications, mobile phones, cordless phones, microwave ovens, WLAN, Bluetooth, anti-theft devices radar | Diathermy |

and developmental delays in the offspring of pregnant mice.[13] In a study by Ravera et al., ELF-EMFs of 75 Hz frequency and low intensities produced strong anomalies in the early development of the sea urchin, Paracentrotus Lividus.[14]

Infante-Rivard et al. through a population-based, case-control study has shown an increased risk of childhood leukemia with an odds ratio of 2.5 (95% CI: 1.2–5.0) among children whose mothers were exposed to the highest occupational levels of ELF-MF during pregnancy.[15] Another similar study by Li et al. determined an association between maternal occupational ELF-MF exposure and certain brain tumors in their offspring with an odds ratio of 2.3 (95% CI: 1.0-5.4).[16] According to a study by Juutilainen, the results of ELF electric fields up to 150 kV/m in several mammalian species were rather consistent and not suggestive of adverse developmental effects. The results from studies on ELF magnetic fields have suggested impacts on bird embryo development but this was not consistent in all studies. Results of studies on other non-mammalian experimental models have also showed subtle effects on developmental stability. In mammals, most studies have shown no effects of prenatal exposure to ELF or IF magnetic on gross external, visceral, or skeletal malformations. The only consistent finding is an increase of minor skeleton alterations, according to several experiments.[17]

Limited information is available that pertains to this issue and studies have yielded contradictory results.[18] Thus, the current study is designed to assess the effects of ELF-EMFs due to high voltage electricity towers and cables on pregnant women who reside in the range of these fields, with the intent to determine any potential impact on pregnancy duration, fetal growth and development.

## Materials and Methods

This was a historical, cohort, analytical study undertaken in Qazvin, a city located northwest of Tehran, Iran. This study was conducted in 2011. After obtaining the GIS map of high voltage electricity towers and cables over the city through the Electricity Distribution Network of Qazvin, an experienced team measured the intensity of ELF-EMFs under and around the towers and cables in different areas of the city, by taking the map into consideration. Measurements were performed by means of a device manufactured by the Holiday Factory (USA; model HI-3604) that had a CE certificate and according to the standards determined by the ENEMC Directive 89/336/EEG, EN50082-1, EN55011. This device with sensors for electrical fields in order to move concentric 6.5-inch-diameter plates and with four hundred-coil electrical winding sensitive to electrical field has the ability to switch between electric and magnetic fields. Sensitivity of the device is in the range of 1 V/m-199 kV/m for electric fields and in the range of 0.1 mG-20 G for magnetic fields.

All data, including the areas under the ELF-EM fields were registered on the maps. At the same time, in order to detect control areas without exposure to ELF-EMFs, we chose unexposed locations that were two to three streets farther from the case residences. In order to ensure absence of any contact, we measured those areas. Selection of the unexposed group from areas located close to the case group minimized any socio-economic differences between the study groups. Next, we located all pregnant women that resided within the exposed and unexposed ELF-EMFs areas. To detect the sample size, appropriate to analytic studies which assess the effect of variables out of researcher's control on dependent variable(s), first a pilot study was performed to detect the variance of the study variables and by inserting the obtained variance in the formula, considering alpha value of 0.01 and using Kraemer-Thiemann table, sample size for each group was calculated. Using the appropriate statistical analyses (alpha level: 0.05, statistical test power: 95%, Teta critical effect point: 0.26) the appropriate sample size was determined to be a minimum of 154 per group. To be included in the study, individuals must have continually resided in the location of interest of the study group (with or without ELF-EMFs exposure), prior to pregnancy.

Exclusion criteria were: individuals who used microwave ovens; presence of any diseases which affect pregnancy, fetal growth and development and included cardiovascular, pulmonary and renal diseases, diabetes mellitus, cancers, and TORCH infections; and pregnancy disorders such as pre-eclampsia and eclampsia. Because of the frequent use of mobile phones, the probable effects of its ELF magnetic field and radio-frequency radiation was ignored in both groups.

Both groups completed a study questionnaire following delivery that included the study group and case code; preterm or term delivery; duration of pregnancy; type of delivery (vaginal or caesarean section); the cause for caesarean section; birth weight and length; head circumference at birth; presence or absence of congenital abnormalities; and the type of congenital abnormality, if present. Collection of data was via patient interview, observation, and measurement. In some cases, we referred to the registered data in the local health center where the medical and health history of the family was recorded or the hospital where the delivery

occurred. Collected and registered data were statistically analyzed using statistical methods, including the chi square and *t*-tests, and using SPSS-16 software. *P*-values less than 0.05 were considered significant.

## Results

There were 222 pregnant women in the ELF-EMFs exposure group and 158 pregnant women without exposure to ELF-EMFs. Gestational age in the two groups was 39.087 ± 1.178 and 39.225 ± 1.092 weeks, respectively and was not significant ($P$ = 0.954). The same assessment for probability of cesarean section on preterm labor in neonates through qualitative variable did not show significance ($P$ = 0.890). There was no significant difference observed between normal vaginal delivery and cesarean section among the women from both groups who had preterm labors ($P$=0.710). Table 2 shows the types of delivery in preterm neonates of both groups and the causes for cesarean sections.

The individuals in the exposed group resided in houses just under the cables or up to approximately a 25 meter distance from the cables. The mean magnetic field intensity was 3.104 ± 1.815 mG for the exposed group, whereas this intensity for the unexposed group was 0.419 ± 0.040 mG ($P$ = 0.004). The mean intensity of the electric fields over the houses of the exposed group was 6.656 ± 5.483 kV/m and for the unexposed group, it was 0.0235 ± 0.008 kV/m ($P$ = 0.011). A number of the houses located just under the high voltage electricity towers and cables had 12 kV/m electric field exposure compared to 0.365 kV/m for houses located 25 meters further from the cables. Additionally, some of the houses located under the high voltage electricity towers and cables had a magnetic field of 4.98 mG exposure compared to 0.99 mG for houses located an average of 25 meters distant from the cables in the exposed regions.

To exclude the preterm labours due to elective C/S deliveries unrelated to ELF-EMFs (e.g., mother's will or mother's small pelvis), the statistical comparison for the effect of these elective cesarean sections on preterm labours did not show significance.

There was no significant difference in terms of birth weight in the neonates of the two exposed and unexposed groups, respectively (3.215 ± 0.483 kg and 3.281 ± 0449 kg; $P$ = 0.541). Birth length was 49.321 ± 2.430 cm and 49.740 ± 2.118 cm in two above-mentioned groups, respectively, which was not significant ($P$ = 0.922). In this manner, head circumference in neonates of both exposed and unexposed groups was 34.571 ± 2.677 cm and 34.816 ± 1.847 cm, respectively without any significance ($P$ = 0.927).

In a comparison of the two groups for congenital anomalies did not show any significance ($P$ = 0.637). There were six cases of congenital anomalies in the group with contact, which included cardiac anomalies (2), cleft palate (1), club foot (1), congenital hypothyroidism (1) and brain mass (1). There were three cases with congenital anomalies in the group without exposure, which included cardiac anomaly (1), cleft palate (1), and genitourinary malformation (1). Because of the small number of each type of anomaly, it was not possible to statistically compare the different anomalies.

## Discussion

This study determined that exposure of pregnant women to ELF-EMFs who resided under high voltage electricity towers and cables did not significantly affect pregnancy duration, neonatal birth weight, birth length and head circumference, nor did it lead to preterm labor and/or congenital malformations. Although numerous research has been performed regarding the effects of EMFs on health, there were a few that evaluated ELF range, particularly related to pregnant women who resided in close proximity to high voltage electricity towers and cables.

Blaasaas et al. found that maternal exposure to 50 Hz magnetic fields was associated with increased risks of spina bifida ($P$ = 0.04) and clubfoot ($P$ = 0.04), yet there was a negative association for isolated cleft palate ($P$ = 0.01). In their study paternal exposure was associated with an increased risk of anencephaly ($P$ = 0.01) and "other defects" ($P$ = 0.02). These researchers also evaluated the risk of a number of selected birth defects by residence in close proximity to power lines during pregnancy. The results indicated

**Table 2.** Types of delivery in preterm neonates of both groups and causes for cesarean sections.

| Group | Number | Type of delivery | Reason for cesarean section | Gestational age at delivery (weeks) | Other explanations |
|---|---|---|---|---|---|
| Exposed | 1 | NVD* | — | 35 | |
| | 2 | NVD | — | 37 | |
| | 3 | NVD | — | 37 | |
| | 4 | C/S** | Mother's small pelvis | 37 | Unrelated to ELF |
| | 5 | C/S | Rupture of amniotic membrane | 37 | |
| | 6 | C/S | Vaginal bleeding | 37 | |
| | 7 | C/S | Meconium excretion | 37 | |
| | 8 | C/S | Fetal immobility | 36 | |
| | 9 | C/S | Mother's small pelvis | 35 | Unrelated to ELF |
| | 10 | C/S | Twin pregnancy and labor progression | 32 (twin) | |
| | 11 | C/S | | | |
| Unexposed | 1 | NVD | — | 33 | |
| | 2 | NVD | — | 34 | |
| | 3 | NVD | — | 37 | |
| | 4 | C/S | Breech presentation | 37 | Unrelated to ELF |
| | 5 | C/S | Labor progression | 37 | |
| | 6 | C/S | Labor progression | 37 | |
| | 7 | C/S | Unknown | 34 | |
| $P$=0.899 | | | | | |

*NVD = normal vaginal delivery; **C/S = Cesarean section

some degrees of risk for hydrocephalus (OR: 1.73, 95% CI: 0.26–11.64) and cardiac defects (OR: 1.54, 95% CI: 0.89–2.68).[19,20] Juutilainen revealed that epidemiological studies did not establish an association between human adverse pregnancy outcomes and maternal exposure to ELF fields, although a few studies had reported increased risks associated with some characteristics of magnetic field exposure.[21]

Huuskonen et al. concluded that the epidemiologic evidence did not, taken as a whole, suggest strong associations between exposure to ELF magnetic fields and adverse reproductive outcome, but effect at high levels of exposure could not be excluded.[22] Kheifets et al. have proposed that in mammals, prenatal exposure to ELF magnetic or electric fields did not result in strong adverse effects on fetal development.[23]

Although the findings of the majority of previous studies agree with the results of the current study, others are not in agreement. These differences are mainly due to variations in the intensity of magnetic or electrical fields in the ELF range, in addition to different methods and approaches used in other studies.

The most important limitation of the present study was the use of several devices that produced EMFs at different frequency ranges and could affect health. Because of the common use of these devices, they were ignored, except for microwave ovens. The inability to measure HF-EMF devices was another limitation in this study. In addition, there were some quantities of variations in electric and magnetic fields during a 24 hour time period. Thus we synchronized the measurements of the fields in both areas (cases and controls); we ignored slight differences which could have been present and similarly considered the variations in both areas.

Studies that research exposure of pregnant women to different bands of EMFs and performing an assessment of their effects on pregnancy and the fetus, particularly with regards to high frequencies (for example due to neighborhood to cell phone antennas and towers) are suggested. Although the ICNIRP and the World Health Organization have defined guidelines for occupational exposure and for the general population,[24] because of absence of dosimetric calculations and distinct guideline for exposure of pregnant women and their unborn children to EMFs,[18,23] we recommend that specific guidelines be provided.

In conclusion, regarding the results of this study and the majority of similar studies, it appears that pregnant women and their unborn children who reside in close proximity and are exposed to the ELF-EMFs of high voltage electricity towers and cables are not affected during pregnancy, fetal growth and development. However, additional research should be performed to ensure the safety of high voltage electricity tower and cable ELF-EMFs for pregnant women. Therefore, it is recommended that pregnant women avoid exposure to these fields until additional studies are performed.

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