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Comparative Study on the Relations between Electromagnetic Field (EMF) Exposure with Genotoxicity and Health Symptoms among Children in Klang Valley.

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ABSTRACT

Objective: To determine relation between the electromagnetic field (EMF) exposure from nearby high voltage power line (HVPL) with genotoxicity and reported health symptoms among school children in Klang Valley. **Method**: A comparative cross sectional study was carried out among 128 primary school children. Study group involved 81 children from school located less than 50m from HVPL while another 47 children from school which had no HVPL within 4km as a comparative group. A set of questionnaire were completed by their parents. The magnetic field at both selected school was measured using EMDEX II meter. Genotoxicity was assessed by examining the frequency of micronuclei in the buccal cells of the children. **Result:** The magnetic field levels at the study school were higher than the comparative school, however, the levels were still below the guideline from the International Commission on Non-Ionizing Radiation Protection (ICNRIP 2010) and were also lower than level which were known to be associated with childhood leukemia. The micronuclei frequency in comparative group was significantly higher than study group ($p<0.001$). There was no association of reported health symptom with magnetic field levels among the study as well as the comparative group. **Conclusion**: The magnetic fields levels at study school posed no hazard to the children. However the comparative group showed sign of genotoxicity which were not related to EMF exposure but might be due to other environmental hazards not identified in this study.

Keywords: *electromagnetic field (EMF), genotoxicity, children*

1. Introduction

Electricity is undeniably important to modern technology nowadays. Electricity demand in Malaysia is increasing rapidly as Malaysia is a developing country with the increasing population and industrial growth. In order to fulfil the demand from consumer, high voltage power line (HVPL) were constructed to supply the electricity. Power line is one of the common sources of extremely low frequency of electromagnetic field (ELF EMF). This radiation is considered as non-ionizing radiation (NIR).

Until today, the concern on the effects of electromagnetic field radiated from high voltage power line on human health is increasing and has become a topic of interest since 1979. Previous epidemiological studies confirmed that magnetic field level between 3-4mG was associated with the increased case of childhood leukemia (WHO, 2007). This issue has extensively been investigated after

Wertheimer and Leeper (1979) found that the risk in children living near to power lines was doubled. Another study confirmed the association. Findings showed that an approximately 2-fold increase in childhood leukemia risk due to residential exposure greater than 4.0mG (Ahlbom et., 2000, Greenland et al., 2000).

Power lines become a controversial issue as it produces extremely low frequency electromagnetic field (ELF EMF) which has been classified as possibly carcinogenic to human (Class 2B) by International Agency for Research Cancer (2002). However, a clear evidence on the relationship is still poorly understood even though a numbers of in vitro and in vivo studies have been carried out to understand the biological effects induced by ELF magnetic field. The ELF EMF affects human health when the magnetic field induces electric field and currents in the body (WHO, 2007). According to Giorgi et al., (2014) there were some reports which suggested that ELF magnetic field alone is not genotoxic, however it can increase DNA damage in the presence of genotoxic agents.

Several epidemiological studies also reported the issue of non-specific health complaints related to ELF EMF exposure. The evidence of non-specific health complaints due to ELF EMF exposure is still inadequate. In spite of that, 1.5% - 13.4% of the general population experienced non-specific complaints such fatigue and poor concentration due to the exposure from power line and mobile base station (Baliatsas et al., 2012).

To date, not many studies has been conducted to investigate the effects of magnetic field level in children. Advancement in EMF technologies contributed to the increasing exposure to children at earlier age thus lengthen their lifetime exposure compared to adults. Children are the vulnerable group and environmental exposure can be harmful to them (Kheifets et al., 2005). They are more sensitive to EMF because physiologically, they are still in the development period. This study aims to investigate the influences of EMF from 132/275 kV high voltage power line on children.The DNA toxicity was based on the increased frequency of micronuclei in the DNA.

2. Materials and Method

2.1. Questionnaire Survey

Self-constructed questionnaires and written consent form were distributed to the children and filled out by their parents or legal guardian. Only children who had return written consent form were allowed to participate in this study. The questionnaire consisted of three section, Part 1: the background information of the children, Part 2: information on sources other than HVPL in the school and home environments, such as household appliances (computers, TVs, mobile phones and fixed-line telephone) and HVPL or substation nearby. Part 3: on the reported health symptoms.

2.2 Magnetic Field Measurement at school

Spot measurements were carried out at both selected schools. The sites included classroom and the main activity areas such as football field, school compound and badminton court. Each measurement was repeated three times for every 15s and the minimum and the maximum value was recorded after stabilization with reference to Huang et al. (2013). The spot measurement of magnetic field was carried out using EMDEX II Meter.

For study school, the measurements were conducted at all classroom within 30m from power line and the areas were very likely to have an exposure of 4.0mG or higher (Chung et al., 2007). In comparative school, stratified simple random was used to select a classroom for each grade. Measurements were conducted at five locations in the classroom including the center and four sites near the corners in both schools.

2.3 Buccal Mucosa Collection

Standard operating procedure (SOP) on Buccal Sample Collection from Centers of Disease Control and Prevention (CDC, 2006) were referred to. Children were instructed to rinse their mouth with mineral water before the sampling began. Next, they were instructed to rub the brush up and down along the inside of the cheek. The cytology brush was washed with phosphate buffer solution (PBS) and normal saline. The specimens were kept in a sealed container before being transported to the laboratory for analysis.

2.4 Micronuclei (MN) Assay

Micronuclei assay was used as a biomarker or early biological effects. This assay were conducted on the standard protocol as discussed by Thomas and Fenech (2008). The specimens were analyzed and examined using light microscope (at 400x magnification) in the Environmental Health Laboratory (Faculty of Medicine and Health Sciences, Universiti Putra Malaysia).

2.5 Data analysis

All the data analysis was analyze using the SPSS Version 22. Descriptive statistic was run to analyze the distribution of all variable in this study. The p value from Kolmogorov-Simonov was referred in normality test.

3. Results

3.1 Background information

This study involved 128 school children. Background information of these school children were obtained through questionnaire. The results were tabulated in Table 1. About 81% of children aged 11 years old while the rest were 10 years old. Majority of the school children were Malay (98.4%). Children in study and comparative school had a similar distribution of BMI where, majority of the children were underweight which were 65.4% and 57.4% in study and comparative group respectively. In the study group, majority of the parents obtained Diploma (28.4%) and secondary school (53.2%) certificate.

Table 1 Background information

Background Information	Study Group (n=81)	Comparative Group (n=47)	Overall (n=128)
	n (%)	n (%)	n (%)
Age			
10	-	24(51.1)	24(18.8)
11	81(100.0)	23(48.9)	104(81.2)
Race			
Malay	81(100.0)	45(95.7)	126(98.4)
Others	-	2(4.3)	2(1.6)
Gender			
Male	32(39.5)	18(38.3)	50(39.1)
Female	49(60.5)	29(61.7)	78(60.9)
BMI			
Underweight	53(65.4)	27(57.4)	80(62.5)
Normal	21(25.9)	13(27.7)	34(26.6)
Overweight	5(6.2)	5(10.6)	10(7.8)
Obese	2(2.5)	2(4.3)	4(3.1)
Parents education			
Secondary	21(27.2)	25(53.2)	53(41.4)
Diploma	23(28.4)	11(23.4)	34(26.6)
Degree	22(27.2)	7(2.1)	29(22.7)
Master	6(7.4)	1(2.1)	7(5.5)
PhD	3(3.7)	-	3(2.3)
Second-hand smoke			
Yes	38(46.9)	30(63.8)	68(53.1)
No	41(50.6)	15(31.9)	56(43.8)
Length of residency			
<5 years	15(18.5)	14(29.8)	29(22.7)
5-10years	37(45.7)	13(27.7)	50(39.1)
>10 years	26(32.1)	16(34.0)	42(32.8)

N=128, Descriptive analysis
BMI=body mass index

3.2 Exposure to magnetic field from other sources.

Table 2 presented the results of children exposure to magnetic field other than school environment. Both groups of children spent most of their time on the computers and mobile phones. From the results, there were about 70% of the study group and 51% of the comparative group spend more than two hours on computers. For mobile phones, about 72.8% from study and 38.3% from comparative group used the phones for more than two hours.

Table 2. Exposure to magnetic field from other sources

Sources	Study Group (n=81)	Comparative Group (n=47)	Overall (n=128)
	n (%)	n (%)	n (%)
HVPL surrounding residential area			
< than 100 m	19(23.5)	4(8.5)	23(17.9)
> than 100 m	51(63.0)	23(48.9)	74(57.8)
Substation surrounding residential area			
<than 500 m	8(9.9)	3(6.4)	11(8.6)
>than 500 m	61(75.3)	23(48.9)	84(65.6)
Frequent use of TV			
> 2 hours per day	57(70.4)	24(51.1)	81(63.3)
< 2 hours per day	16(19.8)	4(8.5)	20(15.6)
Frequent use of computers			
> 2 hours per day	24(29.6)	1(2.1)	25(19.5)
< 2 hours per day	23(28.4)	2(4.3)	25(19.53)
Frequent use of mobile phones			
> 2 hours per day	59(72.8)	18(38.3)	77(60.1)
< 2 hours per day	13(16.0)	5(10.6)	18(14.1)
Frequent use of line telephone			
> 2 hours per day	9(11.1)	-	10(7.8)
< 2 hours per day	22(27.2)	1(2.1)	22(17.1)
***Total Number of household appliances**	7.95(3.83)	6.66(2.97)	7.53(3.61)

N=128
*mean (SD)

3.3 Prevalence of reported health symptom

Health complaints were asked in the questionnaire as reported health symptom (headache, sleeping disturbance, concentration difficulties, nausea, anxiety and fatigue). Based on Table 3, the highest reported health symptoms experienced by children at both schools were difficulties in concentrating. However, there was no association between the reported health symptoms with the magnetic field levels in the two study groups. The total score of reported health symptom were summed up, nevertheless, the result also showed there was no significant difference in the total scores between the groups.

Table 3. Prevalence of reported health symptom

Health symptom	Study Group (n=81)	Comparative Group (n=47)
	n (%)	n (%)
Headache	4(4.9)	3(6.4)
Sleeping disturbance	5(6.2)	-
Nausea	1(1.2)	-
Concentration difficulties	18(22.2)	11(23.4)
Anxiety	1(1.2)	1(2.1)
Fatigue	2(2.5)	1(2.1)

N=128

3.4 Magnetic field level measurement at selected schools

Table 4 comparing the results obtained with reference limit of WHO International EMF Project, known to be associated with childhood leukaemia. Magnetic level at study school much lower than the reference limit. Results in Table 5 shows that the magnetic field level at study school was significantly higher than the comparative school ($p<0.05$). The measurements in both selected schools were below than the reference limit and much more lower than limit in guideline exposure of magnetic field to public by ICNRIP (2010).

Table 4. Measurement of magnetic field

School	N	Mean (IQR)	Min	Max	Reference limit*
Study	22	1.12(0.26)	0.6	1.30	4.0mG
Comparative	10	0.27(0.11)	0.2	0.50	4.0mG

N=number of spot measurement
*reference limit WHO International EMF Project

Table 5. Comparison of mean magnetic field between selected schools.

	Mean(SD)		Mean difference	T(df)	p
	School				
	A[a]	B[b]			
MF level	1.03 (0.29)	0.27 (0.07)	0.7571 (0.62,0.89)	11.67 (25.68)	0.014*

Independent t- test; *significant at $p<0.05$; [a]study school [b]comparative school

3.5. Magnetic field and micronuclei (MN) frequency

There was a significant inverse correlation between magnetic field and micronuclei frequency ($p<0.001$) as in Table 6. Based on Table 7, micronuclei frequency between study and comparative group was compared using Mann-whitney U test. There was a significant difference of micronuclei frequency between both groups ($p<0.001$).

Table 6. Correlation between micronuclei frequency and magnetic field.

Variables	**Magnetic field level**	
	r	**p**
MN Frequency	-0.311	<0.001***

N=128, Spearman rank correlation test; ***significant at $p<0.001$

Table 7. Comparison of median micronuclei frequency

Variable	Median(IQR)		Z	p
	Study (n=81)	Comparative (n=47)		
MN Frequency	5 (10.5,2.5)	13.5 (16.5,8.0)	-4.602	<0.001***

N=128,Mann-Whitney U test
***significant at $p<0.001$

3.6 Potential factors that might influence the micronuclei frequency in children

After all the potential factors that might influenced the frequency of micronuclei in children (gender, age, parents' education, BMI, second-hand smoke, length of residency, HVPL surrounding residential area, total number of household appliances) were controlled using multivariate linear regression, significant relationship between parents education and micronuclei frequency was found ($p<0.004$). The result were summarized in Table 8. Table 9 presented the result for study group and second-hand smoke was found

to be significantly related ($p<0.048$) with micronuclei frequency in children after controlling all the potential factors. There was no significant relationship between all the potential factors with micronuclei frequency in children for comparative group. The results were tabulated in Table 10.

4.0 Discussion

4.1 Measurement of magnetic field

The magnetic levels obtained in study school were lower than the guideline limit of magnetic field exposure for public by ICNRIP (2010) and this result was also lower than the reference limit (4mG) which was known to be associated with childhood leukaemia (WHO, 2007). The magnetic field level in this study were lower than those reported by Huang et al.,(2013) who found that the maximum value recorded at school located less than 94m from power line was close to 4mG.

Viloria (2016) found that the level of magnetic field at 30m from power line was 3 to 4mG. According to Sharin et al., (2014), the level of magnetic field could be affected by the environmental temperature, electricity consumption and heat. The distance between conductor of power line and ground level at study school reduced the magnetic field level as this power line is located at higher ground. This finding was also supported by Huzaireee (2014) that the height of the conductor affects the magnetic field reading. Moreover, Chung et al., (2007) claimed that certain indoor sources of ELF magnetic field reduce the impact of HVPL on the indoor ELF magnetic field exposure level.

4.2 Micronuclei (MN) frequency in school children

The purpose of this study was to determine the biological effects in children exposed to EMF by nearby HVPL based on the number of micronuclei in buccal cell of the children. However, in this study, comparative group have a significantly higher micronuclei frequency as compared to study group which was not due to EMF exposure at school environment but it might because of others environmental hazards exist at nearby areas.

Comparative group children might be exposed to ELF magnetic field from others sources. Previous study by Chung et al., (2007) measured the personal exposure of the school children and some of the comparative group children experienced a higher exposure (>0.4mG) and this might be due to others factors than HVPL such as distribution line and transformer, electric wires with various configuration in the walls and also TVs. Therefore, the other sources of ELF magnetic field at home cannot be neglected. However, it is unlikely that ELF fields cause direct genetic damage due to the low level of energy.

Both of selected school located in urban areas, but there was a differences in environmental settings in both location. Study school located in the residential area, there was no main road nearby, low traffic density and no factory within the area as opposed to the comparative group who were exposed to many sources of environmental hazards such as its location in the industrial area. The other possible factors that could influence the micronuclei frequency in comparative group were mobile base station and heavy traffic density as the school located near the a main road, In addition, there were factories within 500m from the school and a storage building for construction materials located within 200m from the school whereby many lorries passed on the main road in front of the school to transport the building materials.

There were free-standing towers and mounted rooftop base station in the vicinity of comparative school Mobile base station produced radiofrequency (RF) wave to the surrounding environment because signal was transmitted when people used cell phones to make calls (American Cancer Society). There were studies conducted to investigate the effects of radiofrequency (RF) on human health. In recent study, Zothansiama et al., (2017) found that people living closer to the cellular antennas had statistically significant effects in blood damage. In placing more emphasis, Gandhi et al., (2014) claimed that the power density in area within 300m from base station was higher compared to area of control sample and the genetic damage parameters of DNA migration length, damage frequency and damage index was significantly higher in the study group.

Transportation and industrial emission were the major sources of pollutants in Klang Valley atmosphere and this problem become worst by the increasing number of mobile sources. A study by Rahman et al., (2015) mentioned that the motor vehicles are the major mobile sources in urban area. The International Agency for Research Cancer has classified outdoor air pollution as carcinogenic to human health. Comparative school in this study located near to main road, factory and storage house for construction materials. This condition has contributed to the air quality of the surrounding area and could be the reason for the increasing micronuclei frequency in the comparative group. There were studies conducted to investigate the association between air pollutants and biomarkers of early biological effects in children. According to Cerretti et al., 2014, children living in town have high level of micronuclei (MN) in buccal cells due to the high exposure to air pollutants. In addition, a recent study by Eunice et al., (2017) concluded that telomere shortening in children may be associated with exposure to traffic-related air pollution.

Table 8. Potential factors that might influenced micronuclei frequency among two groups

Variable	b[a]	p[a]	b[b]	p[b]
Magnetic field level	-7.911	0.007*		
Gender	-0.966	0.670	-	-
BMI	-0.323	0.185	-	-
Parent's education	-2.281	0.004*	-2.957	0.004*
Second-hand smoke	0.791	0.976	-	-
Length of residency	-0.051	0.659	-	-
HVPL surrounding area	-3.452	0.109	-	-
Total number of house-hold appliances	-0.379	0.283	-	-

[a]Simple linear regression; [b]Multiple linear regression; *significant at $p<0.05$; $R^2=0.185$

Table 9. Potential factors that might influenced micronuclei frequency among children of study group

Variable	b[a]	p[a]	b[b]	p[b]
Magnetic field level	2.475	0.434	-	-
Gender	0.082	0.962	-	-
BMI	-0.139	0.480	-	-
Parent's education	-0.323	0.584	-	-
Second-hand smoke	-3.291	0.048*	-3.757	0.048*
Length of residency	-0.152	0.898	-	-
HVPL surrounding area	-2.734	0.172	-	-
Total number of household appliances	-0.206	0.367	-	-

[a]Simple linear regression; [b]Multiple linear regression; *significant at $p<0.05$; $R^2=0.144$

Table 10. Potential factors that might influenced micronuclei frequency among children of comparative group

Variable	b[a]	p[a]	b[b]	p[b]
Magnetic field level	36.676	0.234	-	-
Gender	-3.078	0.547	-	-
BMI	-4.974	0.088	-	-
Parent's education	-4.091	0.036*	-	-
Second-hand smoke	4.161	0.439	-	-
Length of residency	-0.250	0.215	-	-
HVPL surrounding area	-4.392	0.638	-	-
Total number of household appliances	-1.372	0.160	-	-

[a]Simple linear regression; [b]Multiple linear regression; *significant at $p<0.05$; $R^2=0.282$

Multivariate regression was used to control the potential factors. After controlling all the factors that might have influenced on micronuclei frequency of children in both group, only parents' education showed a significant relationship ($p<0.004$) as shown in Table 8.Parental education is one of the reasonable factors in affecting children diet. A study by Sausenthaler et al (2007) has highlighted that low parental education were associated with a low intake healthy food in children. Moreover, DNA damage in healthy children might be influenced by blood micronutrient. (Elizabeth et al., 2015).Based on Table 9, in study group, there was a significant relationship ($p<0.048$) between second-hand smoke and micronuclei frequency. Second hand-smoke also plays an important role in increasing DNA damage in children as mentioned by Zalata et al., (2007) where DNA damage in children exposed to tobacco smoke was higher compared to control group. In comparative group, all the potential factors have no significant relationship. The results were presented in Table 10.

There were a few limitations in our study, Firstly, only spot measurements were taken to assess exposure at school and questionnaire were used to know the exposure in the home environment. We were not able to assess the personal exposure of children to the magnetic field. The questionnaire also did not have information in the personal exposure. Therefore, further studies were required to assess other sources of exposures besides the magnetic field among the children.

5. Conclusion

In conclusion, the magnetic field strength measurements at the study school were below the reference limit known to be associated with childhood leukemia. The levels were also lower than guideline for public exposure by ICNRIP. Nevertheless, the comparative group showed signs of genotoxicity, most likely not because of the EMF exposure at the school but might be due to other environmental sources which existed near the school environment.

6. Ethical Consideration

This study was approved by the University Research Ethics Committee of the Universiti Putra Malaysa (JKEUPM) [Ref: UPM/TNCPI/RMC/1.4.18.2(JKEUPM). Data collection was conducted after consents form were obtained from children's parents. They were allowed to withdraw from this study at any time during data collection. All the data collected were confidential.

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