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MULTIPLE ASSESSMENT METHODS OF PRENATAL EXPOSURE TO RADIO FREQUENCY RADIATION FROM TELECOMMUNICATION IN THE MOTHERS AND CHILDREN'S ENVIRONMENTAL HEALTH (MOCEH) STUDY

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Abstract
Objectives: To evaluate prenatal exposure to radiofrequency radiation (RFR) from telecommunication using a mobile phone questionnaire, operator data logs of mobile phone use and a personal exposure meter (PEM). **Material and Methods:** The study included 1228 mother–infants pairs from the Mothers and Children's Environmental Health (MOCEH) study – a multicenter prospective cohort study ongoing since 2006, in which participants were enrolled at ≤ 20 weeks of pregnancy, with a follow-up of a child birth and growth to assess the association between prenatal environmental exposure and children's health. The questionnaire included the average calling frequency per day and the average calling time per day. An EME Spy 100 PEM was used to measure RFR among 269 pregnant women from November 2007 to August 2010. The operators' log data were obtained from 21 participants. The Spearman's correlation test was performed to evaluate correlation coefficient and 95% confidence intervals between the mobile phone use information from the questionnaire, operators' log data, and data recorded by the PEM. **Results:** The operators' log data and information from the self-reported questionnaire showed significantly high correlations in the average calling frequency per day ($\varrho = 0.6$, $p = 0.004$) and average calling time per day ($\varrho = 0.5$, $p = 0.02$). The correlation between information on the mobile phone use in the self-reported questionnaire and exposure index recorded by the PEM was poor. But correlation between the information of the operators' log data and exposure index for transmission of mobile communication was significantly high: correlation coefficient (p-value) was 0.44 (0.07) for calling frequency per day, and it was 0.49 (0.04) for calling time per day. **Conclusions:** The questionnaire information on the mobile phone use showed moderate to high quality. Using multiple methods for exposure assessment might be better than using only one method. Int J Occup Med Environ Health 2016;29(6):959–972

Key words:
Prenatal exposure, Validation, Mobile phone, Radio frequency radiation, MOCEH, Personal exposure meter

INTRODUCTION

Humans are ubiquitously exposed to electromagnetic fields (EMF). However, lately exposure to EMF has been increasing rapidly, especially due to the recent development of new broadcasting and communication technologies [1]. One such a device, i.e., a mobile phone, is a common source of EMF. Globally, the number of mobile phone subscribers in 2014 was 6.9 billion [2].

The World Health Organization has recommended that research should be conducted on children's exposure to radiofrequency radiation (RFR) as they are highly vulnerable and are at risk of long-term exposure [3]. Electromagnetic field produced by mobile phones has been classified by the International Agency for Research on Cancer as a possible human carcinogen (group 2B) [4]. In modern life, radiofrequency radiation exposure occurs every day due to proximity of RFR sources, including: broadcasting systems, mobile communication base stations, mobile phones, Wi-Fi and cordless phones. Although RFR exposure from such sources is low, it occurs frequently and over a long period of time.

Thus far, it is unclear whether exposure to RFR during pregnancy affects health of fetuses and children. Previous studies concerning health effects of RFR exposure on children have examined its effects with regard to cancer [5–8], headache [9], low birth weight [10] and neurodevelopment [11–14]. Results of those studies were controversial: some studies have reported no association [6,7,10–12,15], whereas others have reported adverse effects [5,8,9,13,14].

This dichotomy may result from different study designs used, lack of prospective RFR exposure measurements [5–11,13–15] and the use of questionnaires for exposure assessment [9–15]. As information obtained by the use of questionnaires can be limited by recall bias it is less reliable and valid than information obtained using quantitative measurements [16]. Measurement data obtained from mobile communication base stations hardly reflect index's activity for 24 h, because they estimate the values both from a long distance and only for the surrounding residences. On the other hand, they reflect continuous whole-body exposure values relatively well [16]. Therefore, measurement data obtained using a personal exposure meter (PEM) may be more useful for measuring personal exposure to environmental RFR in a daily life, and such data are free from recall and information biases [16,17]. However, the use of PEM is limited by its relatively high cost.

In this study, we used 3 methods – a self-reported questionnaire survey, the operators' log data, and a PEM – to assess RFR exposure in pregnant women and to correlate the results. The data obtained will be valuable for future epidemiological studies examining association between prenatal RFR exposure from telecommunication sources and children's health.

MATERIAL AND METHODS

Study subjects

The Mothers and Children's Environmental Health (MOCEH) study is a multicenter prospective cohort study that was initiated in 2006. Pregnant women were recruited from 2006 to 2010. The participants were enrolled at ≤ 20 weeks of pregnancy and evaluated to determine the association between prenatal environmental exposure and children's health [18]. The study protocol was approved by the institutional review boards at Ewha Womans University Hospital located in Seoul (a metropolitan city), Dankook University Hospital in Cheonan (a medium-sized city), and Ulsan University Hospital, located in the industrial city of Ulsan. A written informed consent was obtained from each woman before enrollment.

Of the 1751 pregnant women enrolled in the MOCEH study, 270 did not respond to a questionnaire concerning mobile phones and, therefore, were excluded. The remaining 1228 mother–infant pairs were analyzed in this study.

Data from the mobile phone questionnaire and operators' log

The questionnaire originally solicited responses on the average calling frequency per day (≤ 2, 3–5, 6–10, 11–20, and ≥ 21 times) and the average calling time per day (< 3 min, 3 to < 10 min, 10 to < 30 min, 30 to < 60 min, and ≥ 60 min). We recategorized them as calling frequency per day (≤ 2, 3–5, 6–10, and ≥ 11 times) and the average calling time per day (< 3 min, 3 to < 10 min, 10 to < 30 min, and ≥ 30 min) to reduce too many categories.

The operators' log data included information only on outgoing calls of 21 women for the previous 3 or 4 months, which was obtained by the participants' request to the corresponding telecommunication company, from March to August 2010. We summed up the frequency and time of each call, and calculated the average calling frequency and time for weekdays and weekends. We defined "heavy users" as the subjects who made calls ≥ 2.5 times per day (median frequency).

Twenty-four hour PEM monitoring

The EME Spy 100 (Satimo, France) PEM [19] was used to measure RFR for 269 pregnant woman from the 1751 MOCEH study subjects from November 2007 to August 2010. Two hundred nine subjects of the 269 women filled in the questionnaire. The subjects wore the instrument on their waist using a belt-type supporter, while overnight it was placed at their bedside. The exposure meter detects 10 different bands, ranging from 88 MHz to 2.17 GHz, and electrical field strength, ranging from 0.05 V/m to 5.0 V/m (Table 1).

The exposure level was recorded every 15 s for 24 h. For each individual, we calculated the arithmetic mean for each frequency band. To allow measurements below the limit of detection (LOD) of 0.05 V/m, arithmetic mean values were calculated using the Kaplan-Meier method, considering left and right censored data, with LOD/2 used in the cases with exposure below the LOD [20]. The total exposure index of each subject was calculated as the sum of the square of the arithmetic mean for each frequency band divided by the guidance level [21]. Exposure index for mobile communication was calculated using the same

Table 1. Measured frequency bands of the EME Spy 100 personal exposure meter

Name	Description	Frequency band [MHz]
FM	FM (frequency modulation) radio broadcast transmitter	88–108
TV7	TV (television) broadcast transmitter	177–213
TETRA	interworking at the inter-system	380–400
TV47	TV broadcast transmitter	473–749
CDMA Tx	code division multiple access, transmission from handset to mobile communication base station	824–848
CDMA Rx	code division multiple access, transmission from mobile communication base station to handset	869–893
PCS Tx	personal communication service, transmission from handset to mobile communication base station	1 750–1 780
PCS Rx	personal communication service, transmission from mobile communication base station to handset	1 840–1 870
IMT-2000 Tx	International Mobile Telecommunications-2000, transmission from handset to mobile communication base station	1 920–1 980
IMT-2000 Rx	International Mobile Telecommunications-2000, transmission from mobile communication base station to handset	2 110–2 170

Rx – radio frequency (RF) for receiving; Tx – RF for transmissing.

formula, with total exposure index used only for specific bands such as CDMA, PCS, and IMT-2000. The exposure index was calculated by classifying frequencies of transmitting and receiving frequencies.

Confounding factors

Data on maternal age during pregnancy (< 30 years, 30–34 years, ≥ 35 years), household income (< 2 000 000 Korean Wons (KRW)/month, 2 000 000 to < 3 000 000 KRW/month, and ≥ 3 000 000 KRW/month), occupation (no or yes) and educational level (≤ 12 years or > 12 years) were obtained by means of the questionnaire at the time of enrollment.

Statistical analysis

The Chi^2 test was performed to test the difference in mobile phone usage according to the general characteristics of the study subjects. The Kruskal-Wallis test or Wilcoxon rank sum test were used to compare distributions of exposure index according to the general characteristics of the study subjects. The Spearman's correlation test was performed to estimate correlation coefficient and 95% confidence intervals (CI) for the information on the mobile phone use from the questionnaire, operators' log and the PEM. The median value of each category of the mobile phone use in the questionnaire was used as a continuous scale in correlation analyses. The original category was used only in the correlation analysis between the questionnaire and the PEM due to a more accurate analysis. All the statistical analyses were performed using R 2.15.2 (R Foundation for Statistical Computing, Austria) [22]. The significance level was set at 0.05.

RESULTS

The subjects who were enrolled more recently, had a higher income level and had an occupation where the use of mobile phones was more frequent. Even after controlling for an income level, the calling frequency by year of recruitment was still significantly different (p = 0.006) (Table 2). Those subjects had also higher average calling time

Table 2. Mobile phone use pattern from the self-administered questionnaire according to the general characteristics of the pregnant women

Variable	Respondents [n]	Mobile phone using pattern [%]									
		average calling frequency/day				p	average calling time/day				p
		1–2 times	3–5 times	6–10 times	≥ 11 times		< 3 min	3 to < 10 min	10 to < 30 min	≥ 30 min	
Total	1 228	18.6	48.9	27.4	5.0		15.1	42.5	30.5	12.0	
Year of enrollment						0.0006					0.260
2006	290	25.5	50.7	19.3	4.5		20.0	42.4	26.9	10.7	
2007	340	19.7	43.2	32.1	5.0		14.7	39.4	34.7	11.2	
2008	249	11.6	51.8	29.7	6.8		13.3	43.8	28.9	14.1	
2009	254	16.9	53.5	25.2	4.3		14.2	44.1	29.9	11.8	
2010	95	15.8	44.2	35.8	4.2		8.4	46.3	31.6	13.7	
Center area						0.0100					0.330
Cheonan	388	16.0	53.9	24.7	5.4		16.0	42.0	31.7	10.3	
Seoul	391	20.2	41.4	32.0	3.8		11.8	43.5	31.7	13.0	
Ulsan	449	19.4	51.2	25.8	3.6		17.1	42.1	28.3	12.5	
Age						0.0010					0.570
< 30 years	542	16.4	48.9	30.4	4.2		13.8	41.9	30.8	13.5	
30–34 years	516	20.0	50.6	25.6	3.9		15.1	44.2	30.0	10.7	
≥ 35 years	170	21.2	44.1	23.5	11.2		18.8	39.4	30.6	11.2	
Education						0.8800					0.500
≤ 12 years	318	18.6	50.3	25.8	5.3		17.0	43.1	28.0	11.9	
> 12 years	894	18.1	48.9	28.1	4.9		14.1	42.2	31.5	12.2	
unknown	16	43.8	25.0	25.0	6.3		31.3	50.0	18.8	0.0	
Household income						0.0090					0.470
< 2 000 000 KRW/month	312	16.0	55.1	26.3	2.6		17.0	43.3	30.4	9.3	
2 000 000 to < 3 000 000 KRW/month	407	22.4	47.4	25.3	4.9		15.0	41.5	31.9	11.5	
≥ 3 000 000 KRW/month	484	17.4	45.7	30.2	6.8		13.6	42.6	29.8	14.0	
unknown	25	12.0	60.0	24.0	4.0		20.0	48.0	20.0	12.0	

Table 2. Mobile phone use pattern from the self-administered questionnaire according to the general characteristics of the pregnant women – cont.

Variable	Respondents [n]	Mobile phone using pattern [%]									
		average calling frequency/day				p	average calling time/day				p
		1–2 times	3–5 times	6–10 times	≥ 11 times		< 3 min	3 to < 10 min	10 to < 30 min	≥ 30 min	
Occupation						< 0.0001					0.005
no	710	21.3	54.1	22.3	2.4		16.9	43.7	29.4	10.0	
yes	432	13.4	42.6	34.3	9.7		12.3	41.0	30.6	16.2	
unknown	86	22.1	38.4	36.0	3.5		14.0	64.0	38.4	7.0	

KRW – Korean Wons.
P estimated using Chi^2 test.

per day. Additionally, the employed subjects reported longer use of mobile phones per day.

Concerning the average calling frequency per day, the correlation between the operator's log data and the questionnaire was moderate high ($\varrho = 0.6$, $p = 0.004$) (Figure 1a). The correlation between the operator's log data and the questionnaire data was higher for the subjects in their 20s ($\varrho = 0.76$), those who were unemployed ($\varrho = 0.68$) and the heavy phone users ($\varrho = 0.8$) as compared to the subjects in their 30s ($\varrho = 0.46$), those who were employed ($\varrho = 0.48$), and the light phone users ($\varrho = 0.52$) (Table 3). The data obtained from the questionnaire and those obtained from the operators' log correlated well in terms of the average calling time per day ($\varrho = 0.5$, $p = 0.02$) (Figure 1b). The subjects in their 30s ($\varrho = 0.85$), those who were unemployed ($\varrho = 0.7$), and the light phone users ($\varrho = 0.53$) showed a stronger correlation than those who were in their 20s ($\varrho = 0.34$), those who were employed ($\varrho = 0.13$) and the heavy phone users ($\varrho = 0.06$) (Table 3).

In the case of exposure index recorded by the PEM for 24 h, median value of the total exposure index was the highest in the subjects enrolled in 2009 as compared to the other years of the study. The median value of the total exposure index or exposure index for mobile communication differed significantly by area (Figure 2), but not by age, educational level or occupation (data not shown).

The data obtained from the operators' log correlated well with the PEM data in terms of calling frequency per day and calling time per day, with correlation coefficients (p-value) of 0.44 (0.07) and 0.49 (0.04), respectively (Figure 3). In contrast, exposure index recorded by the PEM for 24 h and the information on the mobile phone use from the self-reported questionnaire were poorly correlated among 209 subjects (Table 4).

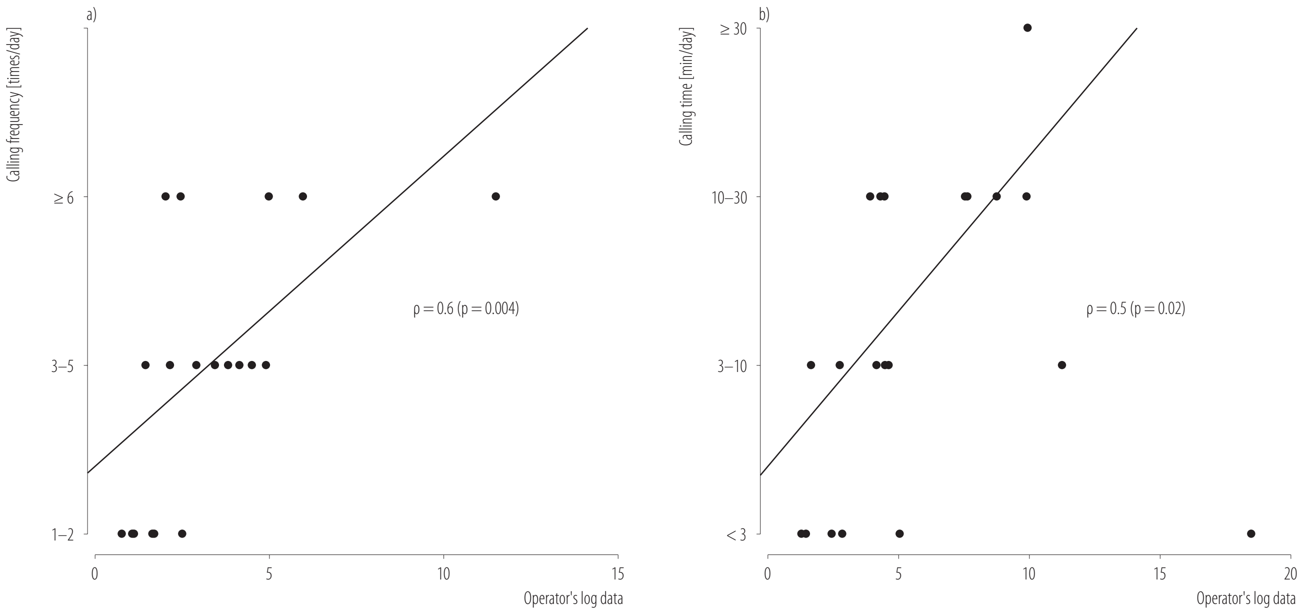
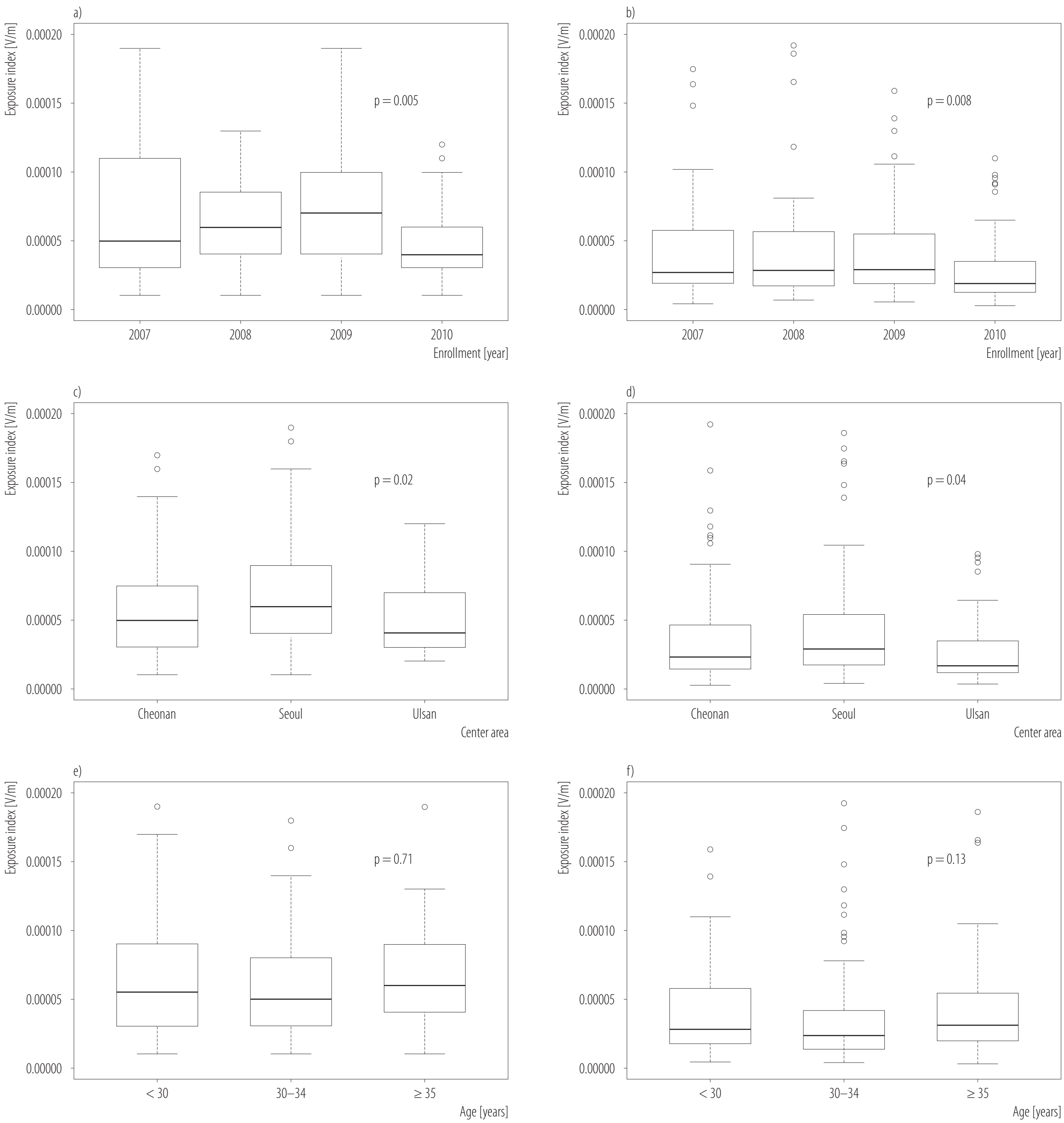


Fig. 1. Correlation between the self-reported questionnaire data and the operator's log data – a) calling frequency, b) calling time

Table 3. Correlation between the self-reported questionnaire data and the operator's log data according to the general characteristics of the pregnant women (N = 21)*

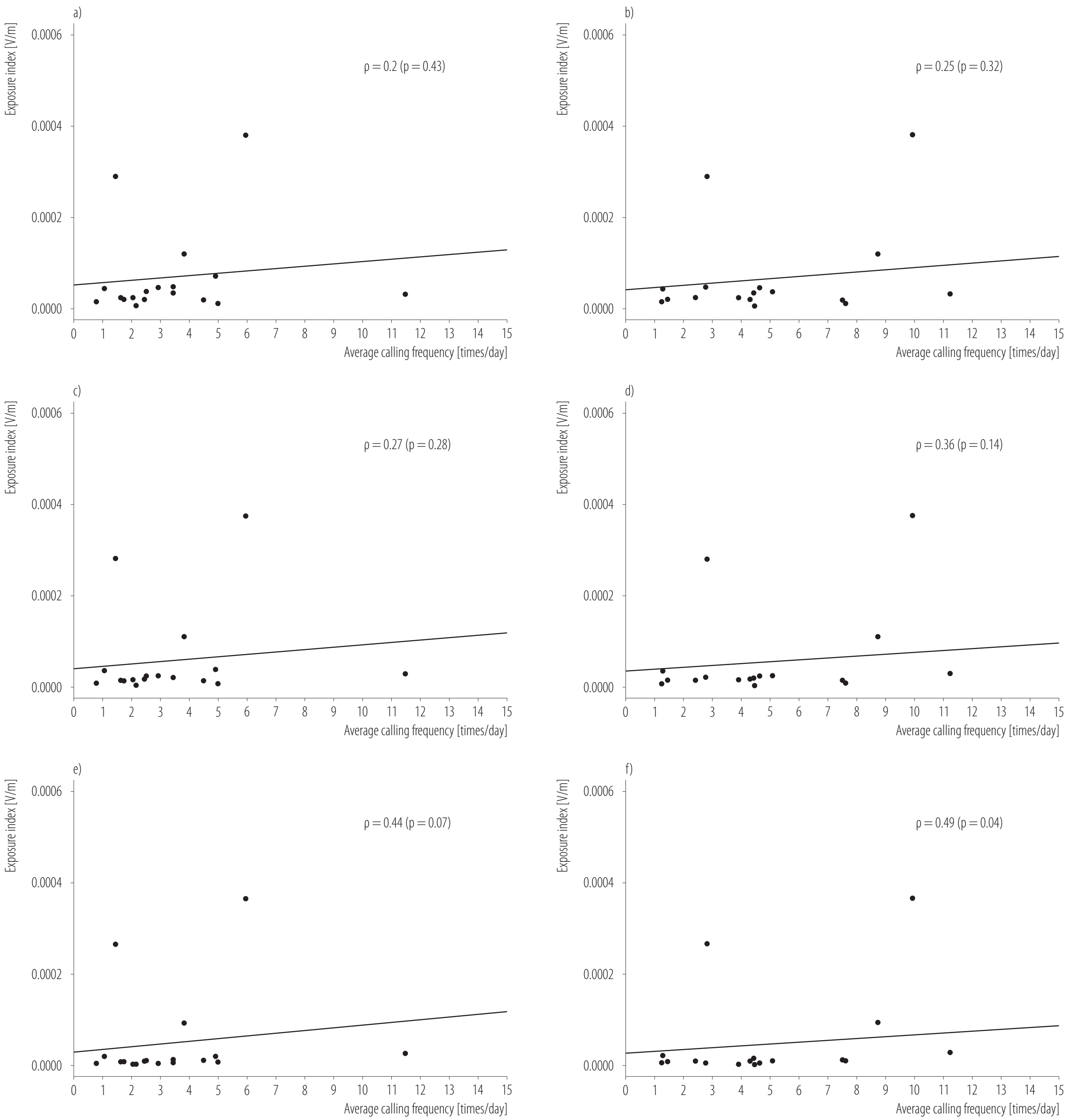
Variable	Correlation coefficient			
	average calling frequency [times/day]		average calling time [min/day]	
	ϱ	p	ϱ	p
Age				
< 30 years	0.76	0.003	0.34	0.260
≥ 30 years	0.46	0.250	0.85	0.008
Occupation				
no	0.68	0.010	0.70	0.007
yes	0.48	0.230	0.13	0.770
Calling amount				
light user[a]	0.52	0.100	0.53	0.100
heavy user[b]	0.80	0.006	0.06	0.860

* Median value was used for correlation test in each category in the questionnaire – average calling frequency per day (non-user: 0; 1–2 times: 1.5; 3–5 times: 4; ≥ 6 times: 9) and average calling time per day (min) (non-user: 0; < 3 min: 2; 3 to < 10 min: 6.5; 10 to < 30 min: 20; ≥ 30 min: 45).
[a] Mobile phone calling frequency per day < 2.5 (median).
[b] Mobile phone calling frequency per day ≥ 2.5 (median).



P-value estimated using the Kruskal-Wallis test.
Exposure index = ∑(mean of each RF electric-field parameters/reference level for public)^2.
Total exposure index of RF including FM, TV7, TETRA, TV47, CDMA Tx, CDMA Rx, PCS Tx, PCS Rx, IMT-2000 Tx, and IMT-2000 Rx; exposure index for mobile communication RF including CDMA Rx, CDMA Tx, PCS Rx, PCS Tx, IMT-2000 Rx, and IMT-2000 Tx.
Abbreviations as in Table 1.

Fig. 2. Exposure index from the personal exposure meter for 24 h according to the characteristics of the pregnant women (N = 269) – a), c), e) total exposure index, and b), d), f) exposure index for mobile communication



Total exposure index of RF including FM, TV7, TETRA, TV47, CDMA Tx, CDMA Rx, PCS Tx, PCS Rx, IMT-2000 Tx, and IMT-2000 Rx; exposure index for mobile communication of RF including CDMA Tx, CDMA Rx, PCS Tx, PCS Rx, IMT-2000 Tx, and IMT-2000 Rx; exposure index for transmission of mobile communication of RF including CDMA Tx, PCS Tx, and IMT-2000 Tx.
Abbreviations as in Table 1.

Fig. 3. Correlation between exposure index using the personal exposure meter for 24 h and the operators' log data (N = 21) – a), b) total exposure index, c), d) exposure index for mobile communication, and e), f) exposure index for transmission of mobile communication

Table 4. Correlation coefficient and p-value between the mobile phone using questionnaire and the personal exposure meter for 24 h (N = 209)*

Exposure index	Correlation coefficient			
	average calling frequency [times/day]		average calling time [min/day]	
	ϱ	p	ϱ	p
Total[a]	0.020	0.79	0.020	0.81
Receiving[b]	0.002	0.98	0.060	0.37
Mobile communication[c]	0.020	0.78	–0.009	0.89
Receiving mobile communication[d]	–0.050	0.45	0.040	0.54
Transmissing mobile communication[e]	0.050	0.46	–0.020	0.79

* Median value was used for correlation test in each category in the questionnaire – average calling frequency per day (1–2 times: 1.5; 3–5 times: 4; 6–10 times: 8; 11–20 times: 15; ≥ 21 times: 25), average calling time per day (min) (< 3 min: 2; 3 to < 10 min: 6.5; 10 to < 30 min: 20; 30 to < 60 min: 45; ≥ 60 min: 75).
[a] RF including FM, TV7, TETRA, TV47, CDMA Tx, CDMA Rx, PCS Tx, PCS Rx, IMT-2000 Tx, and IMT-2000 Rx.
[b] RF including FM, TV7, TETRA, TV47, CDMA Rx, PCS Rx, and IMT-2000 Rx.
[c] RF including CDMA Tx, CDMA Rx, PCS Tx, PCS Rx, IMT-2000 Tx, and IMT-2000 Rx.
[d] RF including CDMA Rx, PCS Rx, and IMT-2000 Rx.
[e] RF including CDMA Tx, PCS Tx, and IMT-2000 Tx.
Abbreviations as in Table 1.

DISCUSSION

The data from the self-reported questionnaire showed a good correlation with the operator's log data. A marginally higher correlation was noted between the mobile phone use and the average calling frequency per day than between the mobile phone use and the average calling time per day. The correlation between the mobile phone use information, which was obtained from the self-reported questionnaire, and exposure index recorded by the PEM was poor, whereas that between the information from the operators' log data and exposure index for transmission of mobile communication was fair.

The obtained information on the mobile phone use from the questionnaire was similar to that obtained in the majority of previous epidemiological studies [11–14,23]. The questionnaire information on the mobile phone use has been previously validated by comparing it with information obtained from operators' log data [24–30] or by using smart phone applications [31–33]. In terms of comparison between the information obtained by the questionnaire and that from the operators' log data, the correlation coefficient for calling frequency was 0.6 in the present study, which is higher than the correlation coefficient in the previous studies, which have reported a kappa value of 0.5 in the Interphone study [29] and 0.42 in a Belgium validation study [30].

The correlation coefficient of 0.5 for calling frequency was similar to the previously reported kappa values of 0.49 in the Interphone study [29] and 0.5 [30] and 0.6 in the Cohort Study of Mobile Phone Use and Health (COSMOS) pilot study [26].

When comparing information on the mobile phone use obtained from a questionnaire with that recorded by smart phone applications, the correlation coefficient (or kappa value) for calling frequency and calling time were 0.21 and 0.4 in the Interphone study [31], 0.3 and 0.1 in the Mobile Radiofrequency Phone Exposed Users' (MoRPhEUS) study [32], and 0.75 and 0.77 in the Mobi-Expo pilot study [33], respectively. Except for the Mobi-Expo pilot study, the present study showed higher validity for the questionnaire information compared to that in the previous studies.

The correlation between the questionnaire data and the operator's log data for calling frequency ($\varrho = 0.6$, $p = 0.004$) was higher than that for calling time ($\varrho = 0.5$, $p = 0.02$). Moreover, majority of the previous studies have reported higher validity for calling frequency than for calling time, and 4 studies have addressed validity of information on the mobile phone use [25,28,29,31]. All these publications were a part of the Interphone study, a case-control study for brain tumors in adults aged 30–59 years. Three of the studies [25,28,29] have shown higher validity for calling frequency than for calling time, which is consistent with the results of the present study, while the 4th study has not shown higher validity for calling frequency [31]. In addition, two previous studies [24,32] have reported higher validity for calling frequency than for calling time, while one study has not shown higher validity for calling frequency [30].

In the present study, higher validity for calling frequency and lower validity for calling time were noted for the young people when compared to old ones. In a previous report, the correlation in persons aged 18–25 years was lower (calling frequency: 0.34, calling time: 0.33) than that in persons aged 25–65 years (calling frequency: 0.4, calling time: 0.61) [30]; this finding is consistent with that of the present study. Another study has reported that the correlation for calling frequency among people in their 30s was higher than that among those in their 40s, but the results were the opposite for calling time [28]; this result was also similar to that obtained in the present study.

In the present study, the information on the mobile phone use obtained during pregnancy may be less likely to have a recall bias depending on the children's current health status. Majority of the previous reports on the prenatal maternal mobile phone use and children's health involved questionnaires completed during the postnatal period [11,13–15], which may explain relatively higher validity of the present study than that of the previous ones.

The EME Spy 100 (Satimo, France) PEM, used as a measurement tool in this study, is capable of receiving the FM radio frequency band in Korea [19]. In Europe, EME Spy 120 (Satimo, France) products from the same company have been used for other research [16,17,34,35]. Personal exposure meter measurements made for 24 h involve all exposure frequencies encountered in a daily life as well as whole-body exposure. The instrument detects radio frequency (RF) from mobile phones that the pregnant women used and from the environment such as mobile phone base stations. The detected signal reflects RF exposure of pregnant women with a fetus in their abdomen. We can assume 2 exposure pathways or effects on the fetus through maternal RF exposure: a direct exposure of the maternal abdomen and a hypothetically indirect effect on the fetus through maternal neuroendocrine disruption due to the maternal use of a mobile phone [36].

However, this also has a limitation – measuring the exposure level only for a human's head. A PEM is an objective measurement device showing a high correlation between information from the operator's log data, particularly with regard to the exposure index of the PEM limited to mobile communication. As compared to using a single method, multiple methods of measurement used together may provide a more comprehensive picture of exposure for better understanding of various aspects of exposure from telecommunications in pregnant women.

CONCLUSIONS

In this study, information on the mobile phone use obtained by the questionnaire administration showed moderate to high validity compared with that obtained from the operator's log data. Similarly, exposure index for mobile communication recorded by the PEM for 24 h showed a moderate to high correlation with that obtained from the operator's log data. Using multiple exposure-measurement methods is helpful in understanding characteristics of exposure from telecommunications in pregnant women.

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