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Neurodevelopment for the first three years following prenatal mobile phone use, radio frequency radiation and lead exposure

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ABSTRACT

Background: Studies examining prenatal exposure to mobile phone use and its effect on child neurodevelopment show different results, according to child's developmental stages.
Objectives: To examine neurodevelopment in children up to 36 months of age, following prenatal mobile phone use and radiofrequency radiation (RFR) exposure, in relation to prenatal lead exposure.
Methods: We analyzed 1198 mother-child pairs from a prospective cohort study (the Mothers and Children's Environmental Health Study). Questionnaires were provided to pregnant women at ≤20 weeks of gestation to assess mobile phone call frequency and duration. A personal exposure meter (PEM) was used to measure RFR exposure for 24 h in 210 pregnant women. Maternal blood lead level (BLL) was measured during pregnancy. Child neurodevelopment was assessed using the Korean version of the Bayley Scales of Infant Development-Revised at 6, 12, 24, and 36 months of age. Logistic regression analysis applied to groups classified by trajectory analysis showing neurodevelopmental patterns over time.
Results: The psychomotor development index (PDI) and the mental development index (MDI) at 6, 12, 24, and 36 months of age were not significantly associated with maternal mobile phone use during pregnancy. However, among children exposed to high maternal BLL *in utero*, there was a significantly increased risk of having a low PDI up to 36 months of age, in relation to an increasing average calling time (p-trend = 0.008). There was also a risk of having decreasing MDI up to 36 months of age, in relation to an increasing average calling time or frequency during pregnancy (p-trend = 0.05 and 0.007 for time and frequency, respectively). There was no significant association between child neurodevelopment and prenatal RFR exposure measured by PEM in all subjects or in groups stratified by maternal BLL during pregnancy.
Conclusions: We found no association between prenatal exposure to RFR and child neurodevelopment during the first three years of life; however, a potential combined effect of prenatal exposure to lead and mobile phone use was suggested.

1. Introduction

Radio frequency radiation (RFR) exposure is widespread in modern life. Seven billion people, comprising 95% of the global population, live in areas covered by a cellular network (International Telecommunication Union, 2016). However, despite the increasing use of cellular phones across the globe, the health implications of increased RFR exposure are largely unknown.

The developing pediatric brain may be more susceptible to environmental exposure, such as electromagnetic radiation, compared to the

Abbreviations: BSID II, Bayley Scales of Infant Development-Revised; BLL, Blood lead level; GEE, Generalized estimating equation; LOD, Limit of detection; MDI, Mental development index; MOCEH, The Mothers and Children's Environmental Health; PEM, Personal exposure meter; PDI, Psychomotor development index; RFR, Radiofrequency radiation

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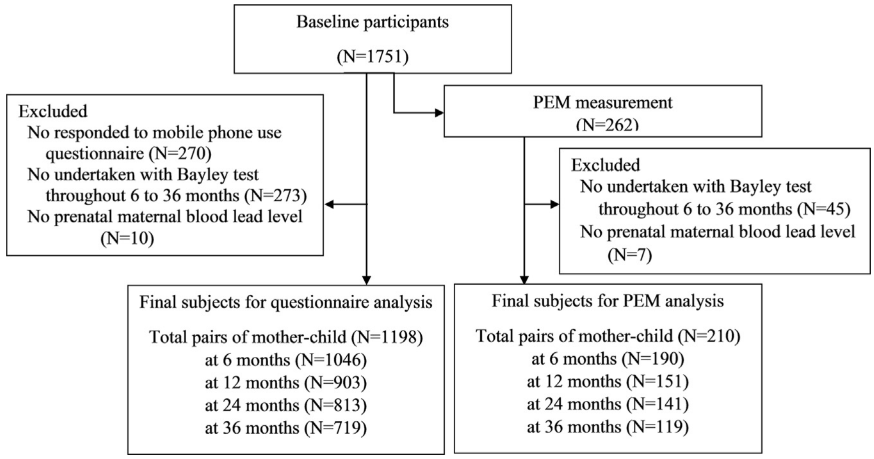

Fig. 1. Selection process of study subjects. PEM: Personal exposure meter, EME Spy100® (Satimo, France).

adult brain (Bellieni and Pinto, 2012). Research derived from animal studies has highlighted positive effects of prenatal RFR exposure in the behavior of animal offspring (Aldad et al., 2012; Haghani et al., 2013; Zhang et al., 2015), although a study reported no adverse effects (Shirai et al., 2017). Epidemiological studies have shown different results regarding maternal mobile phone use during pregnancy and subsequent child neurodevelopment: null findings in earlier ages (Vrijheid et al., 2010; Divan et al., 2011; Guxens et al., 2013) but positive association in later ages (Divan et al., 2008, 2012; Sudan et al., 2016). With the exception of one study, which used a prospective questionnaire (Vrijheid et al., 2010), all studies used questionnaires to retrospectively collect information regarding mobile phone use during pregnancy, which could lead to reporting bias.

On the other hand, lead is a common and environmental neurotoxicant among children (Liu et al., 2014). Even low levels of lead exposure during pregnancy are associated with adverse neurodevelopment outcomes in children (Jedrychowski et al., 2009; Kim et al., 2013; Liu et al., 2014; Shah-Kulkarni et al., 2016; Vigeh et al., 2014). Furthermore, a study showing that child mobile phone use increases the risk of attention deficit hyperactivity disorder (ADHD) in children, particularly among those with high blood lead levels (BLL), suggests an effect modification of blood lead level in association with RFR exposure due to mobile phone use and child neurodevelopment (Byun et al., 2013). However, a possible interaction effect of prenatal RFR exposure and lead on neurodevelopment has not been examined.

Therefore, this study examined the association between prenatal exposure to RFR and child neurodevelopment during the first three years of life in a prospective birth cohort, with consideration of a potential modifying effect arising from prenatal lead exposure.

2. Methods

2.1. Study subjects

The Mothers and Children's Environmental Health (MOCEH) study is a multi-center prospective cohort study that has been conducted in Korea since 2006. Participants were enrolled at ≤20 weeks gestation and the association between prenatal environmental exposure and children's health was evaluated (Kim et al., 2009). The study protocol was approved by the Institutional Review Boards at Ewha Woman's University Hospital in Seoul (a metropolitan city), at Dankook University Hospital in Cheonan (a medium-sized city), and at Ulsan University Hospital in the industrial city of Ulsan. Written informed consent was obtained from each participant prior to enrollment in the study.

Of the 1751 pregnant women enrolled in the MOCEH study, 270 did not respond to the questionnaire concerning mobile phone use, 273 children did not take the neurodevelopment test, and 10 did not provide blood samples for measurement of BLL during pregnancy. Consequently, these mother-infant pairs were excluded from this study. The remaining 1198 mother-infant pairs were included for analysis (Fig. 1).

2.2. Mobile phone questionnaire data

The questionnaire solicited responses regarding average calling frequency (≤2, 3–5, and ≥6 times/day) and average calling time (< 3, 3–10, 10–30, and ≥30 min/day) during pregnancy. Heavy mobile phone use was defined as making ≥6 mobile phone calls per day or using a mobile phone ≥30 min per day. Several months of call data obtained by participants in the present study from their respective telecommunication companies showed moderate-to-high correlations with the questionnaire information about mobile phone use (correlation coefficient, 0.50–0.60) (Choi et al., 2016).

2.3. Twenty-four-hour personal exposure meter monitoring

The EME Spy100® personal exposure meter (PEM) (SATIMO, 2010) was used to measure RFR in 262 study participants who volunteered to be monitored from November 2007 to August 2010. Of the 262 participants, 45 had children who did not undergo a child neurodevelopment assessment, and 7 did not provide blood samples for measurement of BLL during pregnancy; data from these participants was subsequently excluded. Data from 210 subjects were included in the analysis (Fig. 1).

The exposure meter detects 10 different bands of frequency ranging from 88 MHz to 2.17 GHz, such as FM, TV7, TETRA, TV47, uplink and downlink of CDMA, uplink and downlink of PCS, and uplink and downlink of IMT-2000, with electric field strength ranging from 0.05 to 5.0 V/m. Differentiating between uplink and downlink is useful not only for assessment of frequencies contributed by each transmitter, but also for avoiding corruption of the results by phones emitting frequencies close to the dosimeter (SATIMO, 2010). The exposure level was recorded every 15 s for 24 h (5760 measurements in total). For each individual, we calculated the arithmetic mean value 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 cases below the LOD (Helsel, 2005). The total exposure index of each subject was calculated as the sum of the square of the arithmetic mean value for each frequency band divided by the guidance level (Korean Ministry of Science, 2013). The exposure index for mobile communication calculated using the same formula with the total exposure index for specific bands of frequency, such as CDMA, PCS,