Review article

Impacts of smartphone radiation on pregnancy: A systematic review

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ABSTRACT

Introduction: The COVID-19 pandemic has impacted all aspects of people's lives, with many tasks and services now being delivered online in the aim of reducing contact and preventing further transmission of the disease. This has resulted in the increase in the use of portable electronic devices (i.e., mobile phones, smartphones, laptops), which emit different frequencies of electromagnetic field (EMF) radiation. However, the evidence on the harmful impacts of EMF radiation exposure on the human body, particularly on the abdomen of the female body during pregnancy, is scarce. Further, the related studies in the literature have yet to be systematically reviewed. If unmanaged, the absorption of EMF radiation by the maternal abdomen during pregnancy is associated with serious birth and infant outcomes.
Purpose: This study aimed to systematically review the published studies on the direct effects of EMF radiation emitted from mobile phones on pregnancy, birth, and infant outcomes.
Methods: After a systematic search using the PRISMA guidelines, a total of 18 articles were retrieved from 5 databases. Studies which addressed the negative outcomes of EMF radiation exposure on mothers, adults, and children's health were included. The research articles were then sorted based on whether their findings were related to the impacts of EMF on physiological or pregnancy outcomes.
Results: The findings of this review showed that EMF radiation exposure is associated with hormonal, thermal, and cardiovascular changes among adults. However, the reviewed studies did not consider the impacts of EMF radiation exposure on pregnancy outcomes specifically, which makes it difficult to draw conclusions from this review. Only four of the reviewed studies were conducted among pregnant women. These studies reported that EMF radiation exposure during pregnancy is associated with miscarriages and fluctuations in the fetal temperature and heart rate variability, as well as infant anthropometric measures.
Conclusions: More research should be conducted to identify the specific impacts of EMF radiation exposure on pregnancy, birth, and infant outcomes. Healthcare providers and researchers are recommended to collaborate to improve public health through public education and updated organizational policies to limit these environmental risks by encouraging the use of safe technologies.

1. Introduction

The smartphone is the most advanced technological device in the mobile phone market today, comprising the features of both computers and mobile phones in one small device. Many people today rely on their smartphones to carry out their daily tasks and for a variety of purposes, including education, communication, entertainment, and shopping. The rates of smartphone ownership by adults worldwide have reached their highest levels yet, ranging from 83% in countries with emerging economies to 94% in countries with advanced economies. In 2020, the COVID-19 pandemic impacted most countries around the world, and

many strategies were implemented to contain the virus. The World Health Organization (World Health Organization, 2020) recommended staying at home, limiting personal contact, and working remotely, if possible, which has increased people's dependency on technologies such as the Internet, mobile phones, tablets, laptops, and TVs. People's dependency on these technologies is reflected by the fact that 93% of American adults worry about any possible sudden interruption of mobile phone or Internet services (Anderson and Vogles, 2020).

However, researchers have reported that technological devices emit harmful, non-ionizing, electromagnetic field (EMF) radiation at a high-frequency level (100 kHz–300 GHz) (International Commission on

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Non-Ionizing Radiation Protection, 2020). Several studies have investigated the biological interaction between the human body and exposure to this radiation. The evidence indicates that the absorption of EMF radiation by the human body is linked with detrimental health impacts, including respiratory problems (Jung, 2016), muscle pains (Park, 2015), headaches (Alattar et al., 2018), and male infertility problems (Al-Bayyari, 2017).

The absorption of EMF radiation increases with the increased duration of technology use, the number of mobile devices used, calling time, and how far away the EMF radiation is from the human body (Alattar et al., 2018; Baykan and Ünal, 2019; Ekici et al., 2016; Isabona and Srivastava, 2017; Karuserci et al., 2019). Surprisingly, mobile devices continue to emit EMF radiation even after they are switched to flight mode (Bauer et al., 2018).

According to Takei et al. (2018), it is reported that the EMF radiation of mobile phones that is absorbed by pregnant women can cause changes in the fetal temperature. Table 3 shows the magnitude of these changes during different gestational periods. This finding has received increasing attention in the recent literature. Many studies undergo constant updates in order to offer evidence-based explanations of how EMF radiation impacts pregnancy, birth, and the infant. Whilst several research studies have been performed among adults to explain the interaction of EMF radiation with human hormones and the associated health outcomes, few of these studies have included pregnant women. Thus, the purpose of this paper is to review the available studies related to the impacts of EMF radiation exposure on physiological and pregnancy outcomes.

2. Methods

2.1. Design

A systematic review was conducted in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA) (Page et al., 2021) to answer the following question: "How does maternal exposure to EMF radiation during pregnancy impact pregnancy, birth, and infant outcomes?".

2.1.1. Inclusion and exclusion criteria

This review included all recent articles published in English and which examined the impacts of electronic devices (TVs, smartphones, and mobile phones) that emit the same EMF frequency as smartphones on health outcomes among adults, pregnant women, and newborns or in non-human subjects or in vitro. No restrictions regarding country, participants' ages, race, or gender were applied.

Abstract-only articles, including conference papers and editorial papers, book chapters, reviews, reports, and dissertations, were excluded. Articles published in languages other than English were also excluded.

2.1.2. Search strategy

In order to find relevant articles published within the past five, an electronic search of the following databases was performed: EBSCO, MEDLINE, CINAHL, and PubMed. Combinations of the following keywords were used: "electromagnetic field (EMF)", "mobile phone", "smartphones", "pregnancy", "miscarriages", "birth", "low birth weight", "small gestation", "neonatal health", "infant outcomes", "hormones", "adult health", and "physiological changes". Also, grey literature databases including Open Grey, Google Scholar, and ProQuest were searched. The databases were searched on April 28, 2019, and updated on February 2, 2021.

The Boolean operators "AND" and "OR" were used in order to conduct a detailed search of the relevant literature. The search was limited to qualitative or qualitative studies published in English within the past five years. After an initial search using combinations of the aforementioned keywords, 10450 articles were retrieved. After eliminating duplicates, the number of articles was reduced to 311, and after applying the inclusion and exclusion criteria, 75 articles remained. The complete texts of

the 75 articles were carefully reviewed for eligibility, resulting in 18 articles being included in this review. Grey literature search did not yield additional articles. The researchers used the PRISMA checklist and flowchart to include the eligible articles in this review (Figure 1).

2.1.3. Data synthesis

The process of data synthesis was executed by two independent reviewers. The researchers used an evidence-based table to summarize the detailed information of the selected articles, including information such as the author/s' name/s, the year of publication, the country in which the study was conducted, and the study aims, design, sample size, and limitations. A summary of the information pertaining to the selected articles is displayed in Table 1.

2.2. Analysis

Each included article was critically appraised using the Johns Hopkins Nursing Evidence-Based Practice Model, an appraisal tool used to assess evidence levels and identify sources of bias (Dang and Dearholt, 2018). The levels of evidence of the reviewed articles are displayed in Tables 2 and 3.

2.3. Quality assessment

Given the variety of study designs used in the selected studies, two independent researchers verified the quality of the different methodologies using: (1) the Risk of Bias in Non-Randomized Studies - of Interventions (ROBINS-I) tool (ROBINS-I tool, 2021), (2) the Risk of Bias 2 (ROB-2) Cochrane tool for randomized studies (ROB-2, 2021), (3) the National Institute of Health (NIH) tool for observational studies (NIH, 2021), and (4) the Toxicological Data Reliability Assessment Tool (ToxRTool; Schneider et al., 2009).

The ROBINS-I tool evaluates the risk of biases in the results of non-randomized studies of intervention (NRSIs) which do not use randomization to allocate units (ROBINS-I tool, 2021). It focuses on internal validity and generalizability and covers 7 domains. The responses to each domain are judged based on 5 options: (1) low risk of bias, (2) moderate risk of bias, (3) serious risk of bias, (4) critical risk of bias, and (5) no information (ROBINS-I tool, 2021). In this paper, studies that have moderate or low risk of biases are included.

The ROB-2 Cochrane tool for randomized studies provides a framework for evaluating the risk of bias (ROB-2, 2021). It consists of 5 domains embedded in signaling questions. Each of the domains is judged as 1) low risks, 2) some concerns, and 3) high risks. These three levels of suspected biases are used to reach overall risk of bias judgments for specific outcomes (ROB-2, 2021).

The NIH tool for observational studies (cohort and cross-sectional) is used to evaluate the risk of biases based on 14 items which are rated on three points Likert scale: yes, no, or not applicable (NIH, 2021). The total scores of items are calculated, with 'yes' responses equaling a score of one and "no" or 'NA' answers equaling zero. A total score of 0–5 is judged as poor, 6 to 9 as fair, and 10–14 as good (NIH, 2021).

The ToxRTool consists of two different parts, one for in vivo and one for in vitro data (ToxRTool; Schneider et al., 2009). For in vitro studies, 18 criteria are used. Each criterion can be assigned either a '1' (i.e., one point – 'criterion met') or a ' = ' (no point – 'criterion not met'). The overall data quality is assessed as 1) reliable without restriction, 2) reliable with restriction, 3) not reliable, or 4) not assigned. Scores 3 and 4 are used to support the evidence (ToxRTool; Schneider et al., 2009).

2.4. Reporting

The selected studies' aims, methods, designs, results, and countries of research were summarized. Based on the risks of EMF radiation exposure on humans, the results were classified into two sections: 1) physiological and 2) pregnancy outcomes, as presented in Tables 2 and 3. Physiological
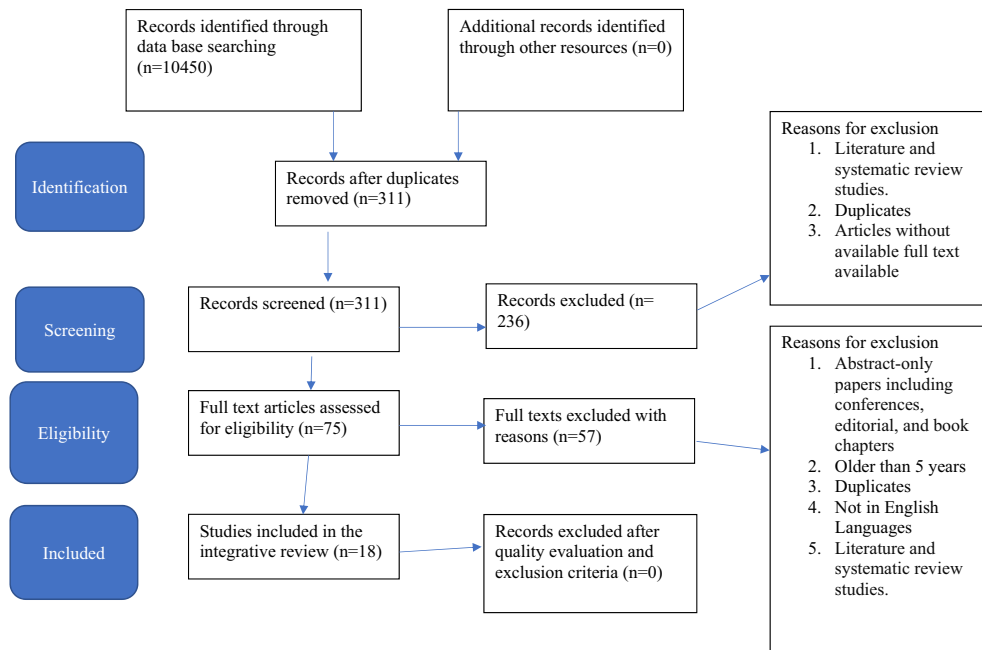
Figure 1. PRISMA flow chart.

Table 1. Searching strategies used in the literature review.

Databases (years)	Authors	Subjects that are affected by technology use	Study methods
PMC (2018–2019)	Tsarna et al.	Pregnant women	A quantitative study
	Saadia	Pregnant women	A quantitative study
Springer (2016–2018)	Yüksel et al.	Mothers	A quantitative study
	Bauer et al.	Adults	A quantitative study
Science Direct (2017)	Birks	Children	A quantitative study
PubMed (2016–2020)	Ekici et al.	Adults	A quantitative
	Hoe et al.	Adults	A quantitative study
	Li et al.	Pregnant women	A quantitative study
Scientific Research (2016)	Elsayed & Jastaniah	Adults	A quantitative study
DergiPark Academik (2019)	Karuserci et al.	Pregnant women	A quantitative study
IEICE Communications Express (2018)	Taki et al.	Pregnant women	Model calculations
Canadian Center of Science and Education (2018)	Alattar et al.	Adults	A quantitative study
Oxford Academic (2019)	Auvinen et al.	Adults	A quantitative study
Indian Journal of Endocrine and Metabolism (2017)	Baby et al.	Adults	A quantitative study
Europe PMC (2017)	Lu et al.	Pregnant women	A quantitative study
Canadian Center of Science and Education (2018)	Rubic	Adults	A quantitative study
Journal of Biomedical Physics and Engineering (2019)	Zarei et al.	Mothers and their children	A quantitative study
World Academy of Science, Engineering and Technology (2017)	Qasim et al.	Adults	A quantitative study

outcomes refer to the effects of EMF radiation on health outcomes among adults in general.

3. Results

The Preferred Reporting Items for Meta-Analysis (PRISMA) checklist and flow chart were utilized in the current review, as shown in Figure 1. The characteristics of the retained citations are presented in Tables 2 and 3.

3.1. Characteristics of the eligible articles

The key characteristics of the identified studies are summarized in Tables 1, 2, and 3. As evident, the included studies differed substantially in terms of their design, sample size, and country of origin. With regards to the study designs employed, eight studies were descriptive cross-sectional correlational, 4 were experimental, 3 were prospective

cohort, two were meta-analysis, and one was model calculation. All of these studies were published within the past five years ago in the English language. The studies were conducted in different countries around the world, including Saudi Arabia, the United States (US), Turkey, South India, Korea, Poland, Sweden and Fenland, Palestine, Jordan, Denmark, Spain, the Netherlands, Japan, Pakistan, Iran, and Norway. The sample sizes varied from one to 83,884 (Birks et al., 2017; Takei et al., 2018).

3.2. Data quality

Using Johns Hopkins Nursing Evidence-Based Practice Model (Dang and Dearholt, 2018), the quality of the reviewed papers was assessed, as summarized in Tables 2 and 3. Seven studies had an evidence level of A, five studies had an evidence level of B, and four studies had an evidence level of C. Therefore, a three quarter (75%) of the papers had an evidence level of A or B.

Table 2. A summary of the reviewed studies on the maternal & physiological outcomes associated with EMF radiation exposure.

Authors and Year	Country	Design and Sample size (N)	Results	Study limitations	Rating Strength/Quality
Elsayed and Jastaniah (2016)	Saudi Arabia	A prospective descriptive correlation N = 110 female and 70 male Adults	Participants who were using smartphones and who had normal thyroid outnumbered those who were not using smartphones and who had thyroid diseases (79.5%: 20.5% respectively)	Convenience sampling method	III/B
Ekici et al. (2016)	Turkey	A cross-sectional correlation design N = 148 healthy adults (85 women and 63 men)	Mobile phone use for > 1hr/day is linked to > HRV[a] and the increase in sympathetic activity ($p < 0.001$).	Small sample size	III/A
Rubik (2017)	US	A randomized, double-blinded, sham-controlled clinical trial (RCT) N = 20 healthy, nonsmoking adults (16 females)	The HRV[a] dropped following the software applications ($p = 0.0013$), suggesting a mild relaxation response ($P < 0.05$.	Small sample size	I/B
Baby et al. (2017)	South India	A cross-sectional correlation design N = 83 undergraduate students (41 males & 42 females)	A significant correlation between total mobile phone radiation exposure and an increase in TSH was found ($P < 0.05$).	Self-report measures	III/A
Heo et al. (2017)	Korea	RCT (double-blind, cross-over, placebo) N = 22 adult males	Users of blue light smartphones experienced an increase in body temperature, serum melatonin levels, and cortisol levels ($P > 0.05$) Body temperatures $>0.1\ °C$ & $<0.08\ °C$ after using smartphones w/wo blue light.	Included males only	I/B
Bauer et al. (2018)	Poland	A cross-sectional correlation design N = 20 healthy adults (9 females and 11 males)	The mean superficial temperature of the auricle region after 5 min of phone calling in case of normal mode was higher ($0.83 \pm 0.04\ °C$), whereas for flight mode it was lower ($0.55 \pm 0.04\ °C$). For women, the mean temperature increase after 5 min of phone calling in normal mode was $0.78 \pm 0.06\ °C$, whereas in flight mode it was $0.49 \pm 0.05\ °C$.	Small sample size	III/C
Auvinen et al. (2019)	Sweden and Finland	A prospective cohort study N = 21049 in Sweden & N = 3120 in Finland.	The participants with the highest decile of recorded call-time (average call-time>276 min per week) at baseline showed a weak, suggestive increased frequency of weekly headaches at 4-year follow-up (Odd Ratio 1.13, 95% CI 0.95–1.34).	-Self-report measure -Non-representative sample	III/A
Alattar et al. (2018)	Palestine	Experimental study N = 203 females, undergraduate students (167 healthy and 36 deaf)	The majority of the participants who used mobile phones for >5 years complained of headache (16.3%), eye pain (35.49%), and ear pain (12.9%). -Salivary levels of Na+ and K+ were lower in mobile phone users when compared to non-users of mobile phones ($P < 0.05$).	-Self-report measure -Non-representative sample	I/C
Qasim et al. (2017)	Jordan	A descriptive cross-sectional correlational N = 228 females and 129 males' adults	Most smartphone users who participated in the survey confirmed that they suffered from headaches (65.5%), eye irritation (66.7%), or ear problems (72.5%).	-Self-report measure -Non-representative sample	III/C

[a] HRV = Heart Rate Variability.

3.3. Study design, tools, and measures

As displayed in Table 1, eighteen studies were included in this systematic review. Of these studies, nine assessed the correlation between mobile phone use among adults and physiological changes (i.e., thyroid hormones, temperature, HRV, and physical problems). These studies are displayed in Table 2. Of these nine studies, two assessed the possible correlation between smartphone use and thyroid hormone changes among females and males using a validated measure (Baby et al., 2017; Elsayed and Jastaniah, 2016). Further, three of these nine studies

Table 3. A summary of included studies on pregnancy outcomes associated with EMF exposure.

Authors and Year	Country	Design and Sample size	Results	Study Limitations	Rating Strength/Quality
Tsarna et al. (2019)	4 studies were included from Denmark, South Korea, Spain, and the Netherlands.	A meta-analysis, longitudinal design N = 55507 pregnant women GA[a] = Not identified	The risk of giving birth with small GA[a] > in the intermediate exposure group than non-exposure group (hazard ratio = 1.04, 95% CI[c]: 1.01, 1.07). Mobile phone use was associated with short pregnancy duration (P < 0.001) and PTB[d] (P = 0.003).	Self-report measures	III/B
Lu et al. (2017)	Japan	A cross-sectional correlational design N = 461 mother-child pairs GA[a] = <27 Wk[b].	Heavy use of mobile devices during pregnancy is associated with high premature birth PMB[d], NICU[e], and small birth chest circumference (P < 0.05).	Small sample size	III/A
Saadia (2018)	Pakistan	Cross sectional correlational N = 69 women (22 obese & 47 non obese) GA[a] = 37–38 Wk[b].	The fetal heart rate variability value was 1.28 among women who were non-mobile phone users and 1.53 among women who were mobile phone users (P = 0.017, BMI<30).	Interview biases	III/B
Li et al. (2017)	California	A prospective cohort study. N = 913 pregnant women GA[a] = <10 Wk[b].	Women who were exposed to higher EMF[f] levels (>2.5 mG) had 2.72 times the risk of miscarriage (hazard ratio = 2.72, 95% CI[c]: 1.42–5.19) than those with lower EMF[f] exposure (<2.5 mG).	Interview biases	III/A
Karuserci et al. (2019)	Turkey	A cross-sectional correlational N = 400 women who have a child aged between 0-5 (boys 199 & 201girls) GA[a] = 27 to 41 Wk[b].	HC[g] < among infants whose mothers watched TV for more than 6 h (watching TV: 35.8 ± 2.8 cm (28–43 cm); not watching TV; 37.0 ± 2.3 cm (33–41 cm); p = 0.040. HC[g] < among mothers based on a nearby base station (no base station near the home: 36.4 ± 2.6 cm (28–43 cm); base station near the home: 35.5 ± 2.7 cm (30–41 cm); p = 0.041.	Use self-report measures	III/B
Birks et al. (2017)	Denmark, Spain, Netherlands, Norway, and Korea	A meta-analysis, prospective and retrospective cohort designs N = 83,884 mother-child pairs GA[a] = Not determined	The risk of having children with hyperactivity/inattention problems increased among mothers who used cell phones during pregnancy (the odds ratio for mothers of medium and high users was 1.11, 95% CI[c]: 1.01, 1.22 and odds ratio 1.28, 95% CI[c]: 1.12, 1.48 respectively).	Recall biases	III/A
Takei et al. (2018)	Japan	A model calculation N = one pregnant mother GA[a] = 13 to 26 Wk[b].	The maternal body absorbs 0.15, 0.11, and 0.35 of magnetic waves per kg at GA[a] 13, 18, and 26 wks[b] respectively. -Fetal temperatures > by 0.025, 0.030, and 0.017 (K) in GA[a] 13, 18, and 26 wks[b] respectively.	Use one case model	V/B
Zarei et al. (2019)	Iran	A cross-sectional design N = 75 mothers of healthy children (control group) and 110 mothers of children aged 3–7 years diagnosed with speech problems GA[a] = Not determined	Associations were found between the use of cordless phones and offspring speech problems for both before pregnancy and during pregnancy maternal exposure (P = 0.005 and P = 0.014, respectively).	Small sample size	III/C
Yuskel et al. (2016)	Turkey	An experimental design N = 32 rats and their 40-newborn offspring GA[a] = NA	Progesterone, prolactin, and estrogen levels in the 900, 1800, and 2450 MHz/1hr groups were lower compared to the control group (p < 0.001, p < 0.05, and p < 0.05 respectively). Estrogen levels were lower in the 2450 MHz group compared to those in the 900 and 1800 MHz groups (p < 0.05).	Use animal subjects	I/A

[a] GA = gestational age, [b] wks = weeks, [c] CI = Confidence Interval, [d] PMB = premature birth, [e] NICU = Neonatal Intensive Care Unit, [f] EMF = electromagnetic field, [g] HC = head circumference.

examined the correlations between physical complaints and mobile phone use using self-report measures (Alattar et al., 2018; Auvinen et al., 2019; Qasim et al., 2017), and two studies assessed the association between increased body temperature and mobile phone use using a reliable and validated measure (Bauer et al., 2018; Heo et al., 2017). Two studies assessed the correlation between HRV and smartphone use using small sample sizes (Ekici et al., 2016; Rubik, 2017), and one of these two

studies used a randomized controlled trial (RCT) design to assess the effects of short-term smartphone use (35 min) on HRV (Rubik, 2017). Meanwhile, the study of Ekici et al. (2016) used a cross-sectional design to assess the effects of prolonged smartphone use (>60 min) on HRV.

Nine of the reviewed studies assessed the effects of EMF radiation on pregnancy, birth, and infant outcomes (Birks et al., 2017; Karsurserci et al., 2019; Li et al., 2017; Lu et al., 2017; Saadia, 2018; Tsarna et al.,

2019; Taki et al., 2018; Yuksel et al., 2016; Zarei et al., 2019). One experimental study was conducted among pregnant rats to assess the effects of EMF radiation exposure on maternal hormones (Yuksel et al., 2016), whilst another study examined the association between mobile phone use during pregnancy and fetal HRV using a validated scale (Saadia, 2018). Three studies examined the effects of EMF radiation exposure on pregnancy duration, child hyperactivity, and speech problems (Birks et al., 2017; Tsarna et al., 2019; Zarei et al., 2019). Of these three studies, one used a cross-sectional design (Zarei et al., 2019) and two used the meta-analysis method (Birks et al., 2017; Tsarna et al., 2019).

One of the reviewed studies used a prospective cohort design to assess the association between EMF radiation exposure and miscarriages by conducting interviews to ascertain the possible confounders of miscarriages (Li et al., 2017). Another study used a case model and measured fetal temperatures after a pregnant woman was exposed to smartphone radiation (Takei et al., 2018). Two studies that assessed the association between maternal exposure to EMF radiation and the risks of giving birth prematurely used a cross-sectional design (Karuserci et al., 2019; Lu et al., 2017).

Based on this review, few studies were found to have examined the physiological impacts of EMF radiation exposure on pregnant women, and the results are displayed in Table 2. To obtain more information about the physiological changes that EMF radiation exposure could leave on human bodies, studies conducted among adults were critiqued and included to meet the objectives of this review.

3.4. Impacts of EMF radiation exposure on physiological outcomes

Exposure to EMF radiation is a factor that may alter the physiological status of adults, potentially leading to hormonal, cardiovascular, and thermal changes (Table 2). Takei et al. (2018) reported that during pregnancy, the maternal placenta absorbs the EMF radiation of smartphones, which leads to an increase in fetal temperatures. According to Takei et al., the placenta serves as the connection between the fetal membranes and maternal tissues; exchanging nutrients and oxygen. Therefore, any rise in the placental temperature may be transferred to the fetus and lead to changes in its metabolic process and placental blood inflow patterns.

In this review, three studies supported the occurrence of hormonal changes in participants who were exposed to EMF radiation (Baby et al., 2017; Heo et al., 2017; Yuksel et al., 2016). For example, a recent RCT which was conducted on pregnant rats explained that, after exposure to electromagnetic radiation (i.e., 1800 MHz radiated from mobile phones) for a period of 1 h per day, levels of maternal plasma prolactin, estrogen, and progesterone decreased from 0.3, 10, and 67 ng/ml to 0.22, 4, and 30 ng/ml, respectively (Yuksel et al., 2016). Another RCT which was conducted on humans showed that exposure to EMF radiation led to an increase in the cortisol hormone level from 14 mg/dl at 9:00 pm to 15 mg/dl at 7:00 am in males who were using smartphones with blue light (i.e., during the night, smartphones emit light-emitting diodes (LEDs) or artificial bright lights) as compared to those who were not (Heo et al., 2017). Furthermore, Baby et al. (2017) explained that males and females who were exposed to electromagnetic radiation from mobile phones had higher thyroid-stimulating hormone (TSH) levels than those who were not, with each one unit increase in exposure to EMF radiation contributing to an increase in TSH values by 0.00004 units (P = 0.025).

Heart rate variability is among the parameters examined when the correlation between smartphone use and cardiovascular changes is assessed, as it is considered a crucial marker of cardiovascular risk factors (Jarczok et al., 2019). Rubik (2017) showed that exposure to smartphone EMF radiation for 35 min at a distance of less than one meter was associated with an increase in HRV (Rubik, 2017). Meanwhile, another

cross-sectional study found that smartphone use lasting for more than 1 h decreased HRV. During pregnancy, the subsequent negative effects of this change could not be ignored. In particular, changes in HRV resulting from smartphone use may be masked by the actual physiological changes in HRV resulting from pregnancy itself. During pregnancy, HRV decreases in the first trimester and increases in the second and third trimesters (Alam and Choudhary, 2018).

Four studies reported information about physical complaints associated with smartphone use, with mobile phone users reported more likely than non-users to experience headaches, ear problems, and eye irritations (Alattar et al., 2018; Qasim et al., 2017). In particular, weekly headaches have been reported to increase with mobile phone use which exceeds 276 min per week (Auvinen et al., 2019).

Moreover, smartphone use was reported by three studies to increase body temperature Bauer et al. (2018); Hoe et al. (2017); Takei et al. (2018). Heo et al. (2017) reported an increase in body temperature after smartphone use lasting 150 min, whilst Bauer et al. (2018) found that during a 5-minute call using a smartphone, the body temperature in the auricle area rose. Table 2 shows the magnitudes of temperature changes by smartphone use. However, Heo et al. (2017) and Bauer et al. (2018) did not take into consideration whether the participating women were pregnant or not. The study of Takei et al. (2018) reported increased temperature in the fetus during the 13th, 18th, and 26th gestational weeks in a pregnant woman exposed to EMF smartphone radiation. Although this study used a case study model of a pregnant woman, the findings provide clear indications that EMF radiated from mobile devices used by women during pregnancy has the potential to penetrate fetal tissues and change the fetal environment. Therefore, studying the impacts of EMF radiation on pregnancy outcomes is crucial.

3.5. Impacts of EMF radiation exposure on pregnancy outcomes

Table 3 presents the reviewed studies which support the presence of risks on pregnancy, birth, and infant outcomes among pregnant mothers exposed to EMF radiation. For example, one study examined the fetal HRV (Saadia, 2018), which is considered a marker of fetal wellbeing (Ayres-de-Campos et al., 2015), and reported that fetal HRV values rise when pregnant women use their mobile phones.

Two of the studies reviewed provided evidence of changes in infant anthropometrics among pregnant women exposed to EMF radiation (Karuserci et al., 2019; Lu et al., 2017). One study reported that pregnant women who used their mobile phones during pregnancy were more likely than non-users to give birth to infants with low birth weight (Karuserci et al., 2019). This study also showed that pregnant women who were exposed to EMF radiated from base stations and TVs were more likely to give birth to infants with small head circumference (Karuserci et al., 2019). Meanwhile, Lu et al. (2017) showed that pregnant women who use their mobile phones excessively tend to give birth to infants with small chest circumference, as compared to women who use their mobile phones moderately.

Length of pregnancy among women who use mobile phones was assessed in two studies, with the large prospective cohort study of Li et al. (2017) reporting that exposure to EMF radiation increases the risk of miscarriage (<10 weeks). Further, the large meta-analysis of Tsarna et al. (2019) reported that mothers in the moderate exposure to mobile phone EMF radiation group were at a higher risk of giving birth at lower gestational age (<36 weeks) than were mothers in the low exposure group.

Two of the reviewed studies examined the long-term effects of mobile phone use by women during pregnancy on their children. One cross-sectional study found that using mobile phones during pregnancy increased the chances of giving birth to children with speech problems (Zarei et al., 2019). Meanwhile, the large metanalysis of Birks et al.

(2017) reported that women who use mobile phones at medium to high levels during pregnancy are at an increased risk of giving birth to children with hyperactivity/inattention problems.

4. Discussion

The studies analyzed in this review show that EMF radiation from mobile phones has health risks on physiological, pregnancy, birth, and infant outcomes. Although these risks have not been widely investigated, some conclusions about the impacts of exposure to EMF radiation on health outcomes may be drawn.

Among these health outcomes are changes in the physiological status of adults, including changes in HRV, temperature, and hormones. Two of the studies reviewed showed that exposure to EMF radiation from smartphones causes changes in HRV, and whilst these studies did not use a standardized mobile phone, the correlation was significant (Ekici et al., 2016; Rubik, 2017). HRV is considered a crucial indicator of cardiovascular risk factors, including blood pressure, lipids, glucose, and inflammation (Jarczok et al., 2019). During pregnancy, changes in maternal HRV are associated with changes in fetal HRV (Arai et al., 2009), with the latter reflecting the developmental status of the fetal nervous system (Schneider et al., 2018). In this review, the two studies which assessed HRV were both conducted among adults (Ekici et al., 2016; Rubik, 2017), which makes it difficult to make conclusions on the impacts of EMF radiation on pregnant women. Thus, further research which examines the health risks and behaviors associated with pregnant women's exposure to EMF radiation is needed to increase healthcare providers' awareness.

Several studies have reported an association between EMF radiation exposure and hormonal changes (Elsayed and Jastaniah, 2016; Baby et al., 2017; Yüksel et al., 2016). However, one of these studies, which examined maternal hormones during pregnancy, was limited to animals (Yüksel et al., 2016). Further, another study used a validated tool among adults with thyroid diseases but failed to yield significant results regarding changes in thyroid hormones among mobile phone users (Elsayed and Jastaniah, 2016).

One study conducted among healthy individuals exposed to EMF radiation reported an increase in thyroid hormones among mobile phone users (Baby et al., 2017). However, there is a lack of evidence related to the association between EMF radiation exposure and changes in thyroid hormones in pregnant women. Increased maternal thyroid-stimulating hormones (TSH) during pregnancy have been found to be associated with intrauterine growth restriction, preterm birth, and maternal problems (e.g., pregnancy loss, preeclampsia, and antepartum hemorrhage) (Shrestha et al., 2019).

Three studies showed that exposure to EMF radiation during pregnancy has negative impacts on pregnancy and birth outcomes. Specifically, one study reported that exposure to EMF radiation during pregnancy increases the risk of miscarriage (Li et al., 2017). Further, two studies reported that mothers who used mobile phones during pregnancy were more likely than non-users to have shorter pregnancies (Tsarna et al., 2019) and give birth to premature infants (Karuserci et al., 2019). These outcomes may be explained by the evidence regarding increased fetal temperatures (Taki et al., 2018) and fetal HRV (Saadia, 2018) among pregnant women who use their mobile phones during pregnancy. These physiological changes may threaten pregnancy and increase the risk of emergency delivery, which also increases the risks of miscarriage or giving birth to premature infants. Therefore, it is important that healthcare providers assess the status of pregnant women who are exposed to EMF radiation and evaluate their pregnancies in terms of the high risks associated with EMF radiation exposure.

The reviewed studies provide evidence for the urgent need for more research which assesses the impacts of EMF radiation exposure on pregnancy, birth, and infant outcomes. Only three of the reviewed studies examined the effects of EMF radiation exposure on pregnancy outcomes, of which one used a metanalysis design with a large sample (Tsarna et al.,

2019). Meanwhile, the remaining studies assessed the impacts of EMF radiation exposure on physiological health outcomes among adults, which limits the generalizability of the findings to pregnant women.

To our knowledge, this is the first systematic review to assess the impacts and associated risks of exposure to EMF radiation during pregnancy on physiological, pregnancy, birth, and infant outcomes. However, this study had limitations which should be considered when interpreting the results. First, the possible risks of EMF radiation exposure on pregnancy limit the feasibility of conducting experimental studies in this field. For example, none of the reviewed studies were interventional, and some studies used self-report tools to assess previous smartphone use, which may have resulted in recall bias (Birks et al., 2017). Second, none of the reviewed studies considered the different impacts of high or low frequencies of EMF radiation on pregnancy, birth, and infant outcomes. Third, the fact that some studies were cross-sectional made it difficult to find causal relationships between EMF radiation from smartphones and negative pregnancy, birth, and infant outcomes. Fourth, the reviewed studies did not assess the impacts of exposure to EMF radiation during different stages of pregnancy, and it is therefore difficult to identify the specific impacts of EMF radiation exposure based on gestational week.

Future research in this field should include large longitudinal prospective studies that assess the impacts of exposure to EMF radiation on pregnancy, birth, and infant outcomes. These studies should consider variables such as maternal HRV, fetal HRV, maternal hormones, maternal temperature, fetal temperature, premature birth, and shortened pregnancy. The correlations between EMF radiation exposure and the aforementioned variables should also be examined in terms of gestational age. Further, the impact of EMF radiation exposure on the physiological outcomes among pregnant women needs further exploration in future studies.

5. Conclusion

The current review found EMF radiation exposure to be linked to hormonal, thermal, and cardiovascular changes in adults. EMF radiation exposure has also been linked with miscarriages and alternations in fetal temperature, HRV, and infant anthropometric measurements. A thorough review of each of the selected studies revealed that further research is needed to find conclusive evidence regarding the impacts of EMF radiation exposure on maternal physiological status and pregnancy, birth, and infant outcomes. This gap in the literature needs to be addressed for the development of effective strategies for safe pregnancy. Follow-up studies conducted among pregnant women who use mobile phones during pregnancy are highly recommended. Healthcare providers need to take into consideration the in the potential maternal and fetal health status changes that are associated with mobile phone use. Fetal temperature, HRV, and anthropometric measures need to be assessed on a regular basis. Health care providers may use this evidence to encourage pregnant women to use their mobile phones in ways which decrease the risks of harm to the woman and the fetus. Women may set limits on their use, keep mobile phones away from their bodies, or use device with very low-frequency EMF radiation.

Declarations

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

No data was used for the research described in the article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

Alam, T., Choudhary, A.K., 2018. Maternal heart rate variability during different trimesters of pregnancy. Natl. J. Physiol. Pharm. Pharmacol. 8 (11), 1475–1480.

Alattar, E.M., Elwasife, K.Y., Radwan, E.S., Abu Warda, H., Abujami, M., 2018. An experimental investigation of the impact of electromagnetic radiations emitted from mobile phone on general health, pH, flow rate and electrolytes concentrations of saliva.

Al-Bayyari, N., 2017. The effect of cell phone usage on semen quality and fertility among Jordanian males. Middle East Fertil. Soc. J. 22 (3), 178–182.

Anderson, M., Vogles, E.A., 2020. Americans turn to technology during COVID-19 outbreak, say an outage would be a problem. In: Pew Research Center. https://www.pewresearch.org/fact-tank/2020/03/31/americans-turn-to-technology-during-covid-19-outbreak-say-an-outage-would-be-a-problem/. (Accessed 9 February 2020).

Arai, Y.C., Ueda, W., Ushida, T., Kandatsu, N., Ito, H., Komatsu, T., 2009. Increased heart rate variability correlation between mother and child immediately pre-operation. Acta Anaesthesiol. Scand. 53 (5), 607–610.

Auvinen, A., Feychting, M., Ahlbom, A., Hillert, L., Elliott, P., Schüz, J., Vermeulen, R., 2019. Headache, tinnitus and hearing loss in the international cohort study of mobile phone use and health (COSMOS) in Sweden and Finland. Int. J. Epidemiol. 48 (5), 1567–1579.

Ayres-de-Campos, D., Spong, C.Y., Chandraharan, E., 2015. FIGO consensus guidelines on intrapartum fetal monitoring: Cardiotocography. Int. J. Gynecol. Obstet. 131 (1), 13–24.

Baby, N.M., Koshy, G., Mathew, A., 2017. The effect of electromagnetic radiation due to mobile phone use on thyroid function in medical students studying in a medical college in South India. Indian J. Endocrinol. Metabol. 21 (6), 797.

Bauer, J., Gorecki, I., Kohyt, M., Migasiewicz, A., Podbielska, H., 2018. The influence of smartphones' operation modes on the superficial temperature distribution in the human auricle region. J. Therm. Anal. Calorim. 133 (1), 559–569.

Baykan, P., Ünal, E.S., 2019. Measurement of electromagnetic radiation emitted by DECT phones used in office environments and evaluation of the results in terms of occupational health and safety. East. Anatolian J. Sci. 5 (1), 7–22.

Birks, L., Guxens, M., Papadopoulou, E., Alexander, J., Ballester, F., Estarlich, M., Kheifets, L., 2017. Maternal cell phone use during pregnancy and child behavioral problems in five birth cohorts. Environ. Int. 104, 122–131.

Dang, D., Dearholt, S., 2018. Supplemental Materials for Johns Hopkins Nursing Evidence-Based Practice: Model and Guidelines. Sigma Theta Tau International.

Ekici, B., Tanındı, A., Ekici, G., Diker, E., 2016. The effects of the duration of mobile phone use on heart rate variability parameters in healthy subjects. Anatol. J. Cardiol. 16 (11), 833.

Elsayed, N.M., Jastaniah, S.D., 2016. Mobile phone use and risk of thyroid gland lesions detected by ultrasonography. Open J. Radiol. 6 (2), 140.

Heo, J.Y., Kim, K., Fava, M., Mischoulon, D., Papakostas, G.I., Kim, M.J., Jeon, H.J., 2017. Effects of smartphone use with and without blue light at night in healthy adults: a randomized, double-blind, cross-over, placebo-controlled comparison. J. Psychiatr. Res. 87, 61–70.

International Commission on Non-Ionizing Radiation Protection, 2019. Guidelines for Limiting Exposure to Electromagnetic Field (100 kHz to 300 GHz). https://www.icnirp.org/cms/upload/publications/ICNIRPrfgdl2020.pdf.

Isabona, J., Srivastava, V.M., 2017. Cellular mobile phone—a technical assessment on electromagnetic radiation intensity on human safety. IEEE, pp. 271–274.

Jarczok, M.N., Koenig, J., Wittling, A., Fischer, J.E., Thayer, J.F., 2019. First evaluation of an index of low vagally-mediated heart rate variability as a marker of health risks in human adults: proof of concept. J. Clin. Med. 8 (11), 1940.

Jung, S.I., et al., 2016. The effect of smartphone usage time on posture and respiratory function. J. Phys. Therapy Sci. 28 (1), 186–189.

Karuserci, Ö.K., Çöl, N., Demirel, C., 2019. May electromagnetic field exposure during pregnancy have a negative effect on anthropometric measurements of the newborn? Cukurova Med. J. 44 (1), 290–295.

Li, D.K., Chen, H., Ferber, J.R., Odouli, R., Quesenberry, C., 2017. Exposure to magnetic field non-ionizing radiation and the risk of miscarriage: a prospective cohort study. Sci. Rep. 7 (1), 1–7.

Lu, X., Oda, M., Ohba, T., Mitsubuchi, H., Masuda, S., Katoh, T., 2017. Association of excessive mobile phone use during pregnancy with birth weight: an adjunct study in Kumamoto of Japan Environment and Children's Study. Environ. Health Prev. Med. 22 (1), 52.

National Institute of Health (NIH), 2021. Study Quality Assessment Tool. https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Moher, D., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372.

Park, J., 2015. The effects of heavy smartphone use on the cervical angle, pain threshold of neck muscles and depression. Adv. Sci. Technol. Lett.

Qasim, T., Obeidat, M., Al-Sharairi, S., 2017. The effect of smartphones on human health relative to user's addiction: a study on a wide range of audiences in Jordan. Int. J. Med. Health Sci. 11 (5), 300–303. Rubik, B. (2017).

ROB-2, 2021. RoB 2 Tool A Revised Tool to Assess the Risk of Bias in Randomized Trials. https://sites.google.com/site/riskofbiastool/welcome/rob-2-0-tool/current-version-of-rob-2.

ROBINS-I tool, 2021. Current Version of Robins-1. https://sites.google.com/site/riskofbiastool/welcome/home/current-version-of-robins-i.

Rubik, B., 2017. Effects of a passive online software application on heart rate variability and autonomic nervous system balance. J. Alternative Compl. Med. 23 (1), 68–74.

Saadia, Z., 2018. Impact of maternal obesity and mobile phone use on fetal cardiotocography pattern. Open Access Macedonian J. Med. Sci. 6 (10), 1813.

Schneider, K., Schwarz, M., Burkholder, I., Kopp-Schneider, A., Edler, L., Kinsner-Ovaskainen, A., Hoffmann, S., 2009. "ToxRTool", a new tool to assess the reliability of toxicological data. Toxicol. Lett. 189 (2), 138–144.

Schneider, U., Bode, F., Schmidt, A., Nowack, S., Rudolph, A., Doelcker, E.M., Hoyer, D., 2018. Developmental milestones of the autonomic nervous system revealed via longitudinal monitoring of fetal heart rate variability. PLoS One 13 (7), e0200799.

Shrestha, A., Tripathi, P., Dongol, A., 2019. Pregnancy outcomes in patients with hypothyroidism. Kathmandu Univ. Med. J. 65 (1), 57–60.

Takei, R., Nagaoka, T., Nishino, K., Saito, K., Watanabe, S., Takahashi, M., 2018. Specific absorption rate and temperature increase in pregnant women at 13, 18, and 26 weeks of gestation due to electromagnetic wave radiation from a smartphone. IEICE Commun. Express 7 (6), 212–217.

Tsarna, E., Reedijk, M., Birks, L.E., Guxens, M., Ballester, F., Ha, M., Olsen, J., 2019. Associations of maternal cell phone use during pregnancy with pregnancy duration and fetal growth in 4 birth cohorts. Am. J. Epidemiol. 188 (7), 1270–1280.

World Health Organization. 2020. https://www.who.int/docs/default-source/coronaviruse/covid-strategy-update-14april2020.pdf. (Accessed 9 February 2020).

Yüksel, M., Nazıroğlu, M., Özkaya, M.O., 2016. Long-term exposure to electromagnetic radiation from mobile phones and Wi-Fi devices decreases plasma prolactin, progesterone, and estrogen levels but increases uterine oxidative stress in pregnant rats and their offspring. Endocrine 52 (2), 352–362.

Zarei, S., Vahab, M., Oryadi-Zanjani, M.M., Alighanbari, N., Mortazavi, S.M., 2019. Mother's exposure to electromagnetic fields before and during pregnancy is associated with the risk of speech problems in offspring. J. Biomed. Phys. Eng. 9 (1), 61.