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Effects of exposure to electromagnetic field from mobile phone on serum hepcidin and iron status in male albino rats

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ABSTRACT

Background: Electromagnetic fields (EMF) created by mobile phones during communication have harmful effects on different organs.

Objectives: To explore the effects of exposure to EMF of mobile phones for different durations on hematological parameters and serum hepcidin in male albino rats.

Methods: Three groups of eight rats: **Sham group:** rats were exposed to a mobile phone while it was switched off, **Experimental group I:** rats were exposed to microwave radiation from a mobile phone at 9 am for 30 min. **Experimental group II:** rats were exposed to microwave radiations from a mobile phone at 9 am for an hour. In all groups, the exposure was conducted daily for a total period of 5 months, followed by estimation of serum hepcidin, total leukocyte count (TLC), interleukin 6 (IL6), serum iron, serum ferritin, plasma hemoglobin (Hb), hematocrit value (Hct), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), unsaturated iron binding capacity (UIBC), total iron binding capacity (TIBC) and 1.25 dihydroxycholecalciferol levels.

Results: In Experimental group II, there was a significant increase in serum hepcidin, TLC, IL6 and serum ferritin; however, serum iron, TIBC, UIBC, 1.25 dihydroxycholecalciferol, plasma Hb, Hct, MCV and MCH were significantly lower in comparison to sham-exposed group. In Experimental group I, there was a significant increase in serum hepcidin, IL6 and TLC, along with non-significant changes in the remaining studied parameters in comparison to the sham-exposed group.

Conclusion: Chronic exposure to EMF from mobile phones increases hepcidin level with subsequent impairment of iron parameters, in addition to negatively affecting both UIBC and TIBC.

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KEYWORDS

Cell phone; electromagnetic fields; hepcidin; ferritin; serum iron

Introduction

With increasingly advanced functions, mobile phones have become the most popular communication devices of our time. Their function is based on the transmission of radio frequency signals, creating an electromagnetic field around them (Valberg et al., 2007).

Electromagnetic forces recently gained more attention as one of the most common and fast-growing environmental influences (Çetkin et al., 2017), due to their ability to penetrate and damage living tissue by inducing free radical formation (Sage et al., 2007). Current literature comprises only a few studies discussing the effects of the electromagnetic fields (EMF) created by mobile phones on hematological parameters and iron status.

Iron is a serum element with an important role in the active sites of a wide range of proteins involved in energy metabolism, respiration and DNA synthesis (Richardson, 2002). Sixty-five percent of iron in humans is bound to hemoglobin (Hb) responsible for oxygen transfer to tissues, 10% of it is found in

myoglobin of muscle tissue, cytochrome and a variety of enzymes necessary for oxidative metabolism and other cell function (Schneider et al. 2005), and the remaining 20–30% of iron in the body is stored bound to ferritin molecules. The transportation of iron is achieved by the transferrin protein, which is the most dynamic iron carrier (Fraga and Oteiza, 2001).

Total iron binding capacity (TIBC) indicates all available iron binding sites on transferrin; hence, the maximum amount of iron essential to saturate serum transferrin (Yamanishi et al., 2003). Decreased levels of this parameter have been observed in anaemia of chronic diseases, while increased levels are typical for iron deficiency anaemia (Karagülle et al. 2013). Unsaturated iron binding capacity (UIBC) is the measurement of the fraction of serum transferrin not bound with iron (Murtagh et al., 2001), and it indicates the amount of iron that can saturate this free transferrin in the blood (Podgórski et al., 2015). UIBC increases when there is an iron deficiency, however, it decreases during haemolytic anaemia, chronic infections and liver diseases (Podgórski et al., 2015).

Ferritin is an intracellular protein that stores iron and releases it in a controlled fashion. Plasma ferritin is an indirect marker of the total amount of iron stored in the body; hence, serum ferritin is used as a diagnostic test for iron deficiency anemia. Presence of low serum iron and ferritin levels with an elevated TIBC is diagnostic of iron deficiency (Weng et al., 2011). Serum ferritin, however, is not a very specific or ideal marker for iron stores, as it is an acute phase reactant elevated in various inflammatory conditions (Khan et al., 2016).

Complete blood count (CBC), can be used to determine Hb concentration, mean corpuscular volume (MCV), that reflects the average size of an individual red blood cell (RBC), mean corpuscular hemoglobin (MCH), which measures the amount of Hb inside an individual RBC, and hematocrit value (Hct) that represents the percentage of RBCs volume to the total blood volume (Stoltzfus, 2001; Tietz et al., 1994). These parameters reflect the erythropoietic activity of the bone marrow that requires sufficient iron to be completed (Ponka, 1997), so, they are decreased in anemia and increased in case of polycythemia (Stoltzfus, 2001).

Previous studies reported that the EMF created by mobile phones decreases serum ferritin (Fattahi et al. 2012), and iron levels (Hachulla et al., 2000). On the other hand, Çetkin et al. (2017) noticed a decrease in serum transferrin levels with no change in serum ferritin and iron levels upon exposure to mobile phones working on EMF with a 900 MHz frequency.

Interestingly, hepcidin is a regulator of iron metabolism, it reduces dietary iron absorption via binding to the iron export channel, ferroportin, located on the basolateral surface of gut enterocytes and the plasma membrane of reticuloendothelial cells (macrophages). Inhibiting ferroportin prevents iron from being exported and the iron is sequestered inside the cells. By inhibiting ferroportin, hepcidin prevents enterocytes from allowing iron absorption into the hepatic portal system, thereby reducing dietary iron absorption (Gulec et al., 2014; Rossi, 2005). There are many diseases in which failure to adequately absorb iron contributes to iron deficiency and iron deficiency anaemia. The treatment will depend on the hepcidin levels that are present, as oral treatment will not likely be effective if hepcidin is blocking enteral absorption, in which cases, parenteral iron treatment would be appropriate. Thus, measuring hepcidin would be of benefit to establish optimal treatment (Bregman et al., 2013; Gardenghi et al., 2010).

An elevated hepcidin level is also implicated as the central pathophysiological alteration in anemia of chronic disease (Datz et al., 2013; Ganz and Nemeth, 2012). Plasma hepcidin levels are increased in chronic inflammatory states frequently associated with

oxidative stress, such as obesity, metabolic syndrome and atherosclerosis (Datz et al., 2013; Galesloot et al., 2015; Valenti et al., 2011). In addition, the discovery of ferroportin 1B expression in erythroblasts and hepcidin regulation of ferroportin (FPN)1 expression and the intracellular iron homeostasis of erythroblasts may have important physiologic implications (Zhang et al., 2011).

However, the effect of the EMFs created by mobile phones on serum hepcidin level is unknown.

Thus, we aimed in this study to investigate the effects of exposure to the EMF created by mobile phones on hepcidin level and iron status parameters in adult male wistar albino rats.

Material and methods

Animals

Twenty-four male albino rats, 2 months of age, weighing 180–200 gm were obtained from the animal house, Faculty of Veterinary Medicine, Zagazig University. All rats were kept in plastic cages (18 inches in length and 12 inches in width) under highly hygienic conditions, had free access to water and were kept on a standard diet consisting of mixed commercial rat laboratory chow (25.88% protein, 62.98% carbohydrate and 11.94% fat) (Ahren and Scheurink 1998). Rats were kept in a comfortable temperature (22 ± 2 °C), and 45–60% humidity, maintained on natural light/dark cycle (Lesourd and Mazari, 1999) and accommodated to laboratory conditions for 3 weeks before starting the experiments (Gui et al., 2004). All experimental procedures were conducted in accordance with the guiding principles for the care and use of research animals and were approved by the Institutional Research Board of Zagazig University.

Experimental Protocol

Animals were divided into three groups each containing eight rats: Sham group: the rats were exposed to the mobile phone while it was switched off, Experimental group I: in which animals were exposed to microwave radiation generated by a mobile phone at 9 am for 30 min and Experimental group II: in which animals were exposed to microwave radiations from a mobile phone at 9 am for 60 min daily.

All groups were exposed for a total period of 5 months, as Çetkin et al. (2017) noticed that serum ferritin and iron levels have a tendency to decrease on exposure to EMF from mobile phones for 10 weeks, but, this change was nonsignificant. To avoid the time

factor, we decide to double the duration to become 5 months.

In this experiment, handsets of mobile phones of the same brand and model were used, the properties of mobile phones were as follows: the highest SAR value was 0.96 W/kg and each of them had an 890–915 MHz carrier frequency band, 217 Hz modulation frequency, 250 mW maximum average power and 2 W maximum peak power (Cetkin et al. 2017). A call was made from one set of GSM (Global System for Mobile Communications) mobile phones to another set of mobile phones after ensuring that each mobile phone was powered-on and with the call accepting mode (answering mode) switched on. Then, the cell phones were placed inside plastic experimental boxes devoid of any metallic fitting (Sokolovic et al., 2008), mobile phones were placed in special sections in the middle of the experimental cages in order to prevent damage that could be caused by rats (Sokolovic et al., 2008). The cell phone was placed in the center of the cage to provide almost equal electromagnetic radiation to the whole body of the animals (Sokolovic et al., 2008). Animals were free to move about in the cage during the exposure period. Sham animals were exposed to a mobile phone switched off in a similarly sized cage for the same period in a separate, similar room (Mailankot et al., 2009).

The electromagnetic field radiation generated by mobile phones was approximately equal the average of downlink frequency of Orange network in Egypt (935–945) MHz electromagnetic field = $935 + 945 = 1880 / 2 = 940$ MHz.

Blood sampling

At the end of the experimental period, blood samples (3 ml) were collected from the retro orbital plexus of each rat under ether anesthesia using glass capillaries. 1 ml of blood from each animal

was collected in EDTA-containing tubes for estimation of complete blood picture. The remaining blood was collected in clean, plastic centrifugation tubes and allowed to clot, then centrifuged for 15 min at 3000 rpm, the supernatant sera were pipetted off using fine-tipped automatic pipettes (Yang et al., 2006) and stored frozen at -20°C until used for analysis of serum iron, serum ferritin, TIBC, serum hepcidin 25 (bioactive form of hepcidin), serum interleukin 6 (IL6) and serum vitamin D.

Estimation of complete blood picture

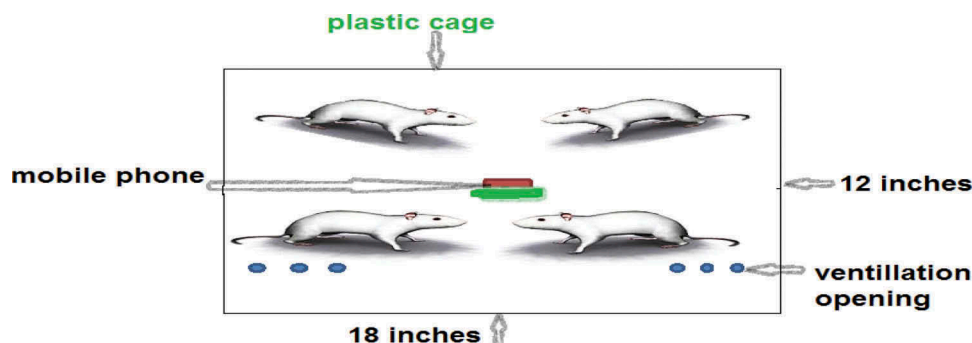
Blood samples collected in EDTA-containing tubes were placed on a rack in the automated blood analyzer (XE-5000; Sysmex, Kobe, Japan) that measures different elements in the blood including red and white blood cells count, Hb, MCV, MCH, Mean Corpuscular Haemoglobin Concentration and Hct ((Buttarelli and Plebani, 2008).

Serum biochemical analysis

Serum iron was measured using the direct colorimetric method according to Tietz et al. (1994). **Serum ferritin** test is based on the reaction between Ferritin in the sample and latex covalently bound anti-rat Ferritin antibodies. Ferritin values are determined photometrically (Tietz et al., 1994).

Total iron binding capacity (TIBC)

A colorimetric assay using two reagents sequentially was used. The decrease in absorbance of the colored dye-iron complex was measured spectrophotometrically at 660 nm and was directly proportional to the TIBC of the serum sample (Gambino et al., 1997).



Schematic representation of the experimental system

Unsaturated iron binding capacity (UIBC)

The TIBC was calculated as the sum of serum iron level and UIBC (Yamanishi et al., 2003). So, $UIPC = TIBC - \text{serum iron}$.

Serum hepcidin-25

Hepcidin-25 was assessed using a commercially-available rat ELISA kit (Quantikine HS, R&D Systems; Minneapolis, MN, USA) (Abbasi et al., 2013). IL6 was measured using a double-antibody sandwich ELISA rat IL-6 kit according to Song et al. (1994).

1. **25-dihydroxycholecalciferol** was assessed using liquid chromatography tandem mass spectrometry measurement (Singh et al., 2006).

Statistical analysis

The data obtained in the present study were expressed as mean $\pm$ SD for quantitative variables and statistically analyzed using SPSS program (version 18 for windows) (SPSS Inc. Chicago, IL, USA). One way analysis of variance test was used to compare means of the groups. The correlations between parameters were analyzed using Pearson's correlation. P -values < 0.05 were considered to be significant.

Results

In experimental group I (Mobile-exposed group for 30 min), there was a significant increase in serum

hepcidin, IL6 ($P < 0.01$) and total leukocyte count (TLC; $P < 0.001$), in comparison to sham-exposed group. However, there was non-significant changes in the remaining studied parameters in comparison to sham-exposed group ($P > 0.05$) (Tables 1 and 2). Additionally, in experimental group II (Mobile-exposed group for 60 min), there was a significant increase in serum hepcidin, TLC, IL6 ($P < 0.001$) and serum ferritin ($P < 0.01$) in comparison to sham-exposed group and experimental group I (Mobile-exposed group for 30 min).

However, in experimental group II (Mobile-exposed group for 60 min), there was a significant decrease in serum iron, TIBC, UIBC, 1.25 dihydroxycholecalciferol ($P < 0.001$) and plasma Hb, Hct, MCV and MCH ($P < 0.01$) in comparison to sham-exposed group. In addition, there was a significant decrease in TIBC, UIBC ($P < 0.001$) and serum iron, plasma Hb, Hct, MC, MCH and 1.25 dihydroxycholecalciferol ($P < 0.01$) in comparison to experimental group I (Mobile-exposed group for 30 min) (Tables 1 and 2).

Regarding correlation of hepcidin with measured parameters, in sham group, serum hepcidin showed a significant positive correlation with TLC, IL6 and serum ferritin ($P < 0.05$), and a significant negative correlation with serum iron, plasma Hb, Hct, MCV, MCH and 1.25 dihydroxycholecalciferol ($P < 0.05$). However, there was a non-significant correlation between serum hepcidin and TIBC, UIBC in the same group ($P > 0.05$) (Tables 3 and 4).

In experimental group I (Mobile-exposed group for 30 min), serum hepcidin showed a significant positive

Table 1. Serum hepcidin, serum iron, serum ferritin, TIBC and UIBC in all groups.

GROUPS			
PARAMETERS	SHAM EXPOSED GROUP	MOBILE-EXPOSED GROUP FOR 30 MIN (EXPERIMENTAL I)	MOBILE-EXPOSED GROUP FOR 60 MIN (EXPERIMENTAL II)
Hepcidin (ng/ml)	352 $\pm$ 25	410 $\pm$ 18 ^{a **}	682 $\pm$ 28 ^{a b ***}
Serum iron (ug/dl)	152.14 $\pm$ 6.12	146 $\pm$ 5.07	121 $\pm$ 3.25 ^{a *** b**}
Serum ferritin (ng/ml)	44 $\pm$ 1.77	48.33 $\pm$ 3.4	67 $\pm$ 2.6 ^{a b **}
TIBC (ug/dl)	509.5 $\pm$ 10.14	485 $\pm$ 12.19	330 $\pm$ 15.66 ^{a b***}
UIBC (ug/dl)	357.35 $\pm$ 7.2	343 $\pm$ 9.3	209 $\pm$ 11.1 ^{a b ***}

Data are expressed as mean $\pm$ SD, a = vs sham group; b = vs experimental I group, ** = significant ($P < 0.01$); *** = significant ($P < 0.001$).

Table 2. Parameters of complete blood picture, IL6 and 1.25Dihydroxycholecalciferol in all studied groups.

GROUPS			
PARAMETERS	SHAM EXPOSED GROUP	MOBILE-EXPOSED GROUP FOR 30 MIN EXPERIMENTAL (I)	MOBILE-EXPOSED GROUP FOR 60 MIN EXPERIMENTAL (II)
Blood Hb (g/dl)	14.85 $\pm$ 0.6	13.5 $\pm$ 0.89	11.2 $\pm$ 1.2 ^{a b**}
MCV(fl)	61.17 $\pm$ 0.07	59.6 $\pm$ 1.03	52.1 $\pm$ 2.06 ^{a b **}
MCH (pg)	30 $\pm$ 2.62	28 $\pm$ 2.3	21 $\pm$ 4.3 ^{a b **}
Hematocrite value (%)	45.1 $\pm$ 1.5	43.2 $\pm$ 1.3	39 $\pm$ 0.9 ^{a b **}
TLC/mm ³	4000.6 $\pm$ 2.5	6500 $\pm$ 3.1 ^{a ***}	8200 $\pm$ 1.5 ^{a b ***}
IL 6 (pg/ml)	46.9 $\pm$ 13	59 $\pm$ 10 ^{a **}	88 $\pm$ 9 ^{a b ***}
1.25Dihydroxycholecalciferol (pg/ml)	58.6 $\pm$ 2.5	54 $\pm$ 1.3	41.2 $\pm$ 0.8 ^{a *** b**}

Data are expressed as mean $\pm$ SD, a = vs sham group; b = vs experimental I group, ** = significant ($P < 0.01$); *** = significant ($P < 0.001$).

Table 3. Correlation coefficient (*r*) value of serum hepcidin with serum iron, serum ferritin, TIBC, UIBC in all studied groups.

GROUPS	SHAM EXPOSED GROUP	MOBILE- EXPOSED GROUP FOR 30 MIN EXPERIMENTAL I	MOBILE-EXPOSED GROUP FOR 60 MIN EXPERIMENTAL II
PARAMETERS			
Serum iron (ug \dl)	<i>r</i> = -0.831*	<i>r</i> = -0.577	<i>r</i> = -0.951***
Serum ferritin (ng/ml)	<i>r</i> = +0.813*	<i>r</i> = +0.842*	<i>r</i> = +0.911**
TIBC (ug\dl)	<i>r</i> = +0.342	<i>r</i> = +0.395	<i>r</i> = +0.485
UIBC (ug\dl)	<i>r</i> = +0.264	<i>r</i> = +0.312	<i>r</i> = +0.422

r = correlation coefficient versus hepcidin level; * = significant ($P < 0.05$); ** = significant ($P < 0.01$); *** = significant ($P < 0.001$).

correlation with TLC, IL6 and serum ferritin ($P < 0.05$). However, there was a non-significant correlation with the remaining mentioned parameters in the same group ($P > 0.05$) (Table 3, Table 4).

Moreover, in experimental group II (Mobile-exposed group for 60 min), serum hepcidin showed a significant positive correlation with TLC, IL6 ($P < 0.001$) and serum ferritin ($P < 0.01$), and a significant negative correlation with serum iron, Hct ($P < 0.001$), plasma Hb, MCV, 1.25 dihydroxycholecalciferol ($P < 0.01$) and MCH ($P < 0.05$). However, there was a nonsignificant correlation between serum hepcidin and TIBC, UIBC in the same group ($P > 0.05$) (Tables 3 and 4).

Discussion

Widespread use of mobile phones has increased humans' exposure to EMFs, so it is of great importance to investigate their effects on the biological systems. In this study, the effect of mobile phone EMF on iron parameters and serum hepcidin level was investigated.

In the current study, exposure to EMF from a mobile phone for an hour per day for 5 months led to a significant increase in serum hepcidin, and it was reported that hepcidin synthesis and secretion by the liver is controlled by inflammation (Nemeth and Ganz, 2009). Interestingly, researchers demonstrated that

electromagnetic waves from cell phones have an inflammatory effect (Koca et al., 2014). This was indicated in our study by a significant increase in the average number of WBCs on exposure to EMF from mobile for an hour per day for 5 months with significant positive correlation with hepcidin level, which was in line with the observations of Alghamdi and El-Ghazaly (2012) who reported an increase in white cells indicating an increase in the body's immune response on exposure to EMF.

Moreover, in the current study, upon exposure to EMF from a mobile phone for an hour per day for 5 months, there was a significant increase in serum IL6 when compared to controls, with significant positive correlation with hepcidin level. IL6 is a proinflammatory cytokine which is a potent stimulus of hepcidin production (Nemeth et al., 2004).

It is interesting that 1.25 dihydroxycholecalciferol has been shown to decrease hepcidin and optimal function of hepcidin may be predicated upon the adequate presence of vitamin D in the blood (Bacchetta et al. 2014). 1.25 dihydroxycholecalciferol was observed to decrease in our study on exposure to EMF from mobile phones for an hour per day, with significant negative correlation with hepcidin level. Many investigators stated presence of oxidative stress on exposure to EMF (Gharib, 2011; Guney et al., 2007), this finding is supported by the findings of Krivošíková et al. (2015) who noticed that 1.25 dihydroxycholecalciferol is decreased in any condition of oxidative stress.

It was clear from the current study that there was a significant decrease in serum iron on exposure to EMF from mobile phones for an hour per day when compared to **sham** with significant negative correlation with hepcidin level, this may be due to increased hepcidin level reported in this study, this is in line with Nourmohammadi et al. (2001) and Hachulla et al. (2000) who stated that iron values were affected negatively by long exposure to EMF.

Table 4. Correlation coefficient (*r*) value of serum hepcidin with parameters of complete blood picture, IL6 and 1.25Dihydroxycholecalciferol in all groups.

GROUPS	SHAM EXPOSED GROUP	MOBILE-EXPOSED GROUP FOR 30 MIN EXPERIMENTAL (I)	MOBILE-EXPOSED GROUP FOR 60 MIN EXPERIMENTAL (II)
PARAMETERS			
Blood Hb (g\dl)	<i>r</i> = -0.798*	<i>r</i> = -0.533	<i>r</i> = -0.892**
MCV(fl)	<i>r</i> = -0.813*	<i>r</i> = -0.545	<i>r</i> = -0.921**
MCH (pg)	<i>r</i> = -0.752*	<i>r</i> = -0.498	<i>r</i> = -0.852*
Hematocrite value (%)	<i>r</i> = -0.799*	<i>r</i> = -0.521	<i>r</i> = -0.963***
TLC/mm3	<i>r</i> = +0.762*	<i>r</i> = +0.892*	<i>r</i> = +0.961***
IL 6(pg\ml)	<i>r</i> = +0.836*	<i>r</i> = +0.923*	<i>r</i> = +0.981***
1.25Dihydroxycholecalciferol (pg\ml)	<i>r</i> = -0.865*	<i>r</i> = -0.822*	<i>r</i> = -0.912**

r = correlation coefficient versus hepcidin level; * = significant ($P < 0.05$); ** = significant ($P < 0.01$); *** = significant ($P < 0.001$).

However, there was a significant increase in the iron storage ferritin, we suggested that the higher serum ferritin concentrations observed on exposure to EMF from mobile phones for an hour per day represent an increased state of inflammation, as it acts as an acute phase reactant (Khan et al., 2016), furthermore, ferritin has significant non-storage roles within the body, such as protection from oxidative damage (Tran et al., 2013). Indeed, its synthesis is increased in response to oxidative stress (Shivasekar et al., 2014) which was stated to occur on exposure to EMF (Gharib, 2011), and it is, therefore, a non-reliable indicator of iron disturbance (Khan et al., 2016). It is worth saying that the increased ferritin in **experimental group II**, may be due to increased serum hepcidin as there was positive correlation between serum hepcidin and ferritin in the same group, this observation is supported by Zhang et al. (2011) who noticed that L-ferritin expression increased with hepcidin treatment.

Additionally, our results showed a significant reduction in Hb, and Hct, in addition to the indices of RBCs; MCV and MCH, on exposure to EMF from mobile phones for an hour per day, with significant negative correlation with hepcidin level. Their decrease may be due to the decreased serum iron level noticed in our study. These results are in line with those of Alghamdi and El-Ghazaly (2012) who found a decline in Hb and hematocrit after long exposure to EMF from mobile phones for 3 months. Interestingly, oxidative stress increases RBC membrane stiffness and decreases deformability, with less number of RBCs and reduced Hb (Nagababu et al., 2008), furthermore, EMFs altered oxygen affinity and Hb structure (Mousavy et al., 2009).

In this work, it was observed that exposure to mobile phones for an hour per day significantly decreased TIBC and UIBC, which represent serum transferrin level that is considered the main iron transport protein in the blood. This was in line with Çetkin et al. (2017), who stated that the reason for the decrease in TIBC may be impaired synthesis as a result of liver damage caused by the oxidative stress created by the EMF (Gharib, 2011), in addition, transferrin was reported to also decrease in inflammation (Ritchie et al., 1999) which was reported in our study.

Moreover, in the present study, exposure to EMF from mobile for 30 min caused a significant increase in levels of hepcidin, WBC and IL6 with significant positive correlation with hepcidin level, however, non-significant changes in iron parameters were reported in comparison to **sham and experimental group II** (1 h exposure to EMF), as there was a slight increase in hepcidin level, and its iron-reducing effect (Knutson, 2010; Nemeth and Ganz, 2009)

that may be counteracted by cellular adaptation, leading to increased iron absorption through duodenal enterocyte via up-regulation of Divalent metal transporter 1 mRNA at brush border and increased expression of ferroportin in basolateral membrane of enterocyte (Goetze et al., 2013).

Moreover, iron deficiency can also alter villus structure and this could also influence the capacity of villi to absorb dietary iron (Smith et al., 2000). Furthermore, under conditions of iron depletion, compensatory mechanisms occur to achieve metabolic needs of the cells. An example of such mechanisms is the increased expression of transferrin receptor 1 (TfR1) mRNA (Wang and Pantopoulos, 2011) present on cell surface with 80% of total TfR1 expressed on erythroblasts (Aisen, 2004). TfR1 is required to import iron from transferrin into the cells by endocytosis (Aisen, 2004; Speckaert et al., 2010). It is interesting that oxidative stress activates iron regulatory proteins (Bresgen and Eckl, 2015) which are critical components of a sensory and regulatory network controlling iron homeostasis as they bind with and stabilise TfR1 to prolong its half-life (Goforth et al., 2010), this enhances iron uptake into erythroblast (Wang and Pantopoulos, 2011).

However, The degree to which adaptation occurs is modest (Smith et al., 2000), and may be insufficient to counteract the effect of high hepcidin level observed in the current study on exposure to EMF for 1 h.

Conclusion

Cell phone exposure could affect iron homeostasis by decreasing TIBC and UIBC that represent the amount of iron binding protein transferrin. Importantly, it increases serum hepcidin that reduces iron absorption, and may be a useful biomarker to determine iron metabolism defects. However, further studies are needed for evaluation of the possible effects of mobile phones radiation and the emitted EMFs on cellular signaling pathways contributing in iron deficiency.

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Declaration of interest statement

The authors declare that there is no conflict of interests regarding the publication of this paper

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