Erciyes Med J 2019; 41(4): 444–9 • DOI: 10.14744/etd.2019.55798
ORIGINAL ARTICLE – OPEN ACCESS

Radioprotection in Prenatal Care Using a Nonwoven Fabric with Electromagnetic Shielding Property

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ABSTRACT

Objective: Electromagnetic shielding fabrics (EMSFs) have been marketed by several manufacturers within the past few years. However, their efficacies in protecting living organisms against the harmful effects of EM noise have yet to be established. The aim of the present study was to accomplish this task with novel in vivo experiments where fetal development and the pathological consequences of wearing protective fabric against EM radiation during pregnancy were investigated.

Materials and Methods: Nine pregnant rats were equally divided into three groups. Sham controls were kept unexposed, but the remaining six were subjected to EM radiation at 900 MHz for 1 h daily throughout the pregnancy. However, three of the rats were protected by a nonwoven fabric manufactured locally and characterized previously. After birth, the kidneys of newborns were extracted and evaluated by histopathology. Histometry data were analyzed statistically.

Results: EM exposure affected the kidney structure and morphology as revealed by the disruption of glomerular basement membrane continuity, increased Bowman capsule and proximal tubule sizes (from 15.01±2.56 μm to 29.94±4.42 μm), and thickened cortex and medulla (from 261.13±4.10 μm to 284.57±10.93 μm for cortex and from 594.25±23.48 μm to 732.61±20.46 μm for medulla). However, the effects were significantly attenuated in those kidneys placed behind the fabric.

Conclusion: EMSF effectively protects the fetal kidney against EM radiation at 900 MHz during the developmental phase and possibly at other frequencies and for other organs. It is advisable to wear such fabrics during pregnancy when EM pollution is of significant concern.

Keywords: Radioprotective textile, electromagnetic field, shielding fabric, nonwoven, prenatal

Cite this article as: Sahmelikoğlu AG, Karakaş S, Metin Tellioğlu A, Acer N, Bilgen M. Radioprotection in Prenatal Care Using a Nonwoven Fabric with Electromagnetic Shielding Property. Erciyes Med J 2019; 41(4): 444-9.

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Submitted 06.05.2019

Accepted 23.09.2019

Available Online Date 02.10.2019

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INTRODUCTION

Electrical and electronic devices emit electromagnetic (EM) radiation. Some radiation is considered as background noise, and the others are deliberately produced for information transfer as in wireless communication or energy delivery as in power lines. The fields created by these devices are invisible, but interact with biological tissues. The interaction creates morphological and physiological disorders as a consequence of the absorption of EM energy and thus became the active focus of current research (1). Textile fabrics with EM shielding capabilities have been developed as a counter measure using conducting hybrid yarns and special knitting processes to protect living organisms against the potentially harmful effects of EM radiation (2, 3).

Biological tissues in young and adults respond to EM field differently (4). Exposure to high EM field induces greater effects in developing systems than in mature organs. Long-time exposure to wireless internet frequency at the pre- and postnatal periods was reported to cause chronic kidney damage (5). From this aspect alone, maternal cell phone or wireless usage during pregnancy is of great concern (5–9). Thus, EM shielding fabric (EMSF) can be used in prenatal care. The shielding characteristics of such fabrics were so far tested in a laboratory environment using methods including anechoic chamber with aperture. However, their benefits in real situations have yet to be established.

The aim of the present study was to accomplish this task with experiments on prenatal rats. The consequences of suppressing the level of EM field exposure at a common cell phone frequency with EMSF on fetal kidney by postmortem evaluations after birth were investigated.

MATERIALS and METHODS

Experimental animals and induction of pregnancy

The study was approved by the Local Ethics Committee for Animal Experiments of Adnan Menderes University, Aydin, Turkey (no.: 64583101/2016/76, date: 04/18/2016).

The experiments were conducted using Wistar albino rats at 12–14 weeks old and weighing 220–270 g at the beginning. After the adaptation period of 2 weeks, a pair of male and female rats was placed in the same cage to induce pregnancy. The first day of pregnancy was detected by smear test performed in the morning. A total of nine rats with confirmed pregnancies on the same day were randomly selected and subjected to the procedures including EM field exposure and protection with a textile fabric, as described below. The rats were kept at 22±2 °C room temperature, 40%–50% humidity environment, 12-hour light–dark cycle, and had access to water and standard pellet.

Groups

The pregnant rats (n=9) were equally and randomly divided into three experimental groups: sham control (G1, n=3), EM field-exposed (G2, n=3), and EM field-exposed and protected (G3, n=3). The sham control rats were placed in Plexiglass cages, one rat per cage, kept in our housing facility, and subjected to normal ambient EM radiation. The remaining six rats were removed from the animal facility on a daily basis, subjected to EM field irradiation all together at the same time and same duration, and returned back to the facility. The exposures were conducted in a large room with no EM interference (except the ambient EM noise) from its surroundings. They lasted 60 min and held in the morning (starting at around 10 am) throughout the pregnancy (19–21 days, until birth).

EM Field Irradiation Setup

The setup consisted of a specifically designed Plexiglass platform assembled with six separate plastic rat holders positioned radially in a hexagonal formation, similar to the arrangement shown in Figure 1 and described in a previous study (5). EM field was created by the electronic transmitter unit depicted in Figure 2 (10). Linear antenna of the unit was inserted through a hole (3 cm in diameter) drilled at the center of the platform. The device was operated at 900 MHz (~200 mV/m at the head region), as it has been the carrier frequency of a common cell phone service provider in Turkey and many other countries.

The rats from both groups G2 and G3 were strained in the tubes with heads closer, but approximately 10 cm away from the center. This configuration allowed exposing all six animals to the same field at the same time. Additionally, the setup included an EMSF, shaped as a curtain and placed between the antenna and the rats in group G3. In this configuration, G3 rats were protected from the EM field, but those in the G2 group were remained fully exposed to it.

The electric field was measured from the rat head, trunk, and tail regions during the application at an interval of 6 min for 1 h. The mean electric field value was determined as 6.9 mV/m.

Textile Fabric and EM Shielding Characteristics

Several fabrics with special knitting and weaving methods have been manufactured by the Textile Engineering Department at Erciyes University, Turkey. Treading materials in these fabrics were embedded with polyester/metal wires to form a mesh or irregular nonwoven structures. The EM shielding characteristics of the fabrics were determined over a broad bandwidth with a range of 30 MHz–10 GHz by the radio frequency measurements in specially isolated rooms. This work was described in detail in a previous study (3). Among the available fabrics, the one shown in Figure 3 was selected as it achieved the highest EMF attenuation of 80 dB at approximately 900 MHz. This particular fiber was produced by needling technique of cut polyamide fibers coated with a special alloy, prepared with nano technology and silver content, and was in the form of a nonwoven surface. The polarization of the EM field interacts with the regular mesh structure of the fabric. Randomly oriented fibers minimize this interaction and thus constitute another reason for the selection of this particular fabric.

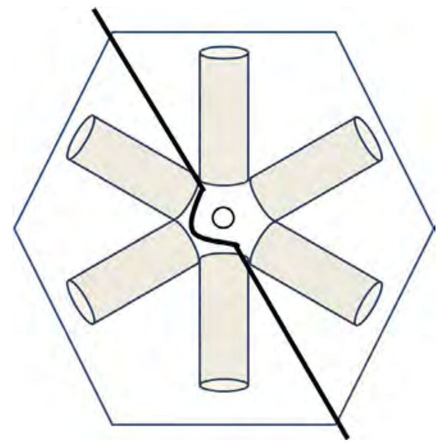

Figure 1. Experimental setup for exposing the rats to EM field. The antenna of the transmitter was inserted through the middle circle. Thick-dark line denotes EM field shielding fabric. Rats in holders below the fabric are protected from EM radiation

Figure 2. Transmitter (rf generator) operating at 900 MHz

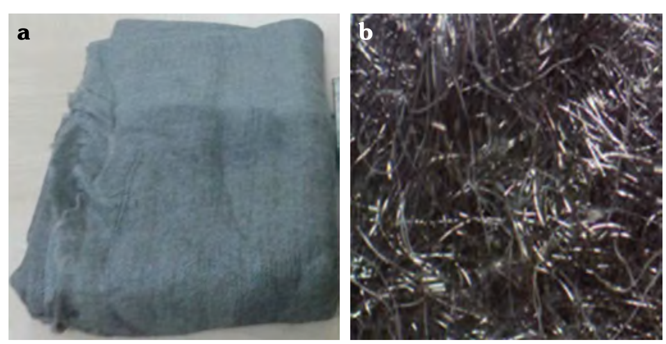

Figure 3. a, b. (a) EM field shielding fabric. (b) Microscopic view

Histopathological Analysis

After birth, a total of 24 newborn siblings (8 from each group) re-

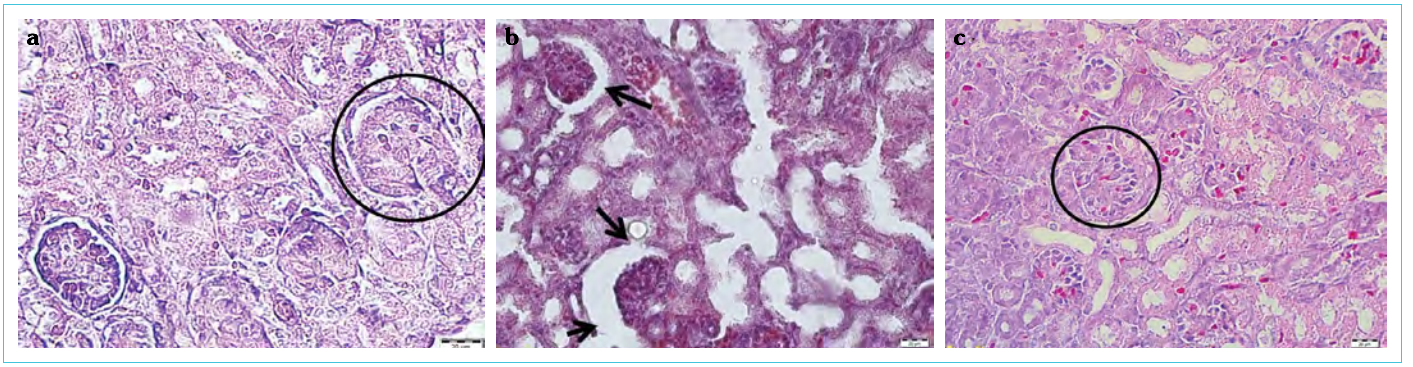

Figure 4. a–c. Bowman capsule and glomeruli (×40, H&E stain). (a) Sham control group. (b) EM field-exposed group, (→) damaged section of Bowman capsule. (c) EM field-exposed and protected group

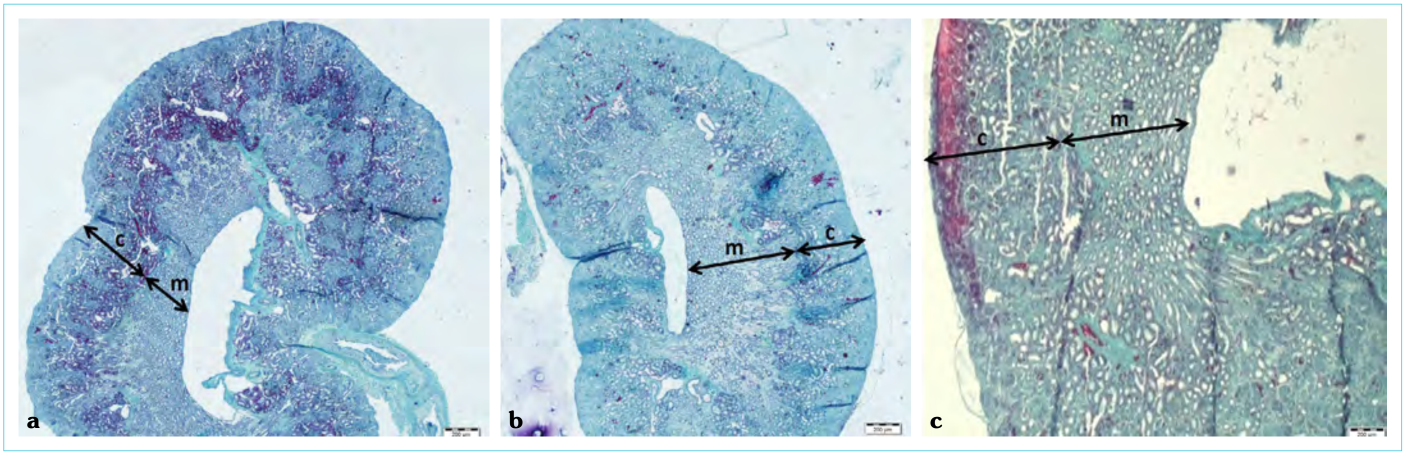

Figure 5. a–c. Visualization of cortex (c) and medulla (m) thicknesses (×4, Masson's trichrome stain). (a) Sham control group. (b) EM field-exposed group. (c) EM field-exposed and protected group

c: Cortex; m: Medulla

gardless of their genders were sacrificed under anesthesia using 10 mg/100 mg ketamine and 50 mg/mL xylazine (0.25 mg/100 mg body weight), and their organs were removed. The current study focused on the kidneys only, as it was the interest of previous publications. The kidney tissues were fixed in a solution containing 10% formalin.

Following the routine paraffin embedding procedure, it was determined that a newborn kidney can be approximately sectioned from a block into 300 slides of each 5 μm thick. Based on this, we obtained neighboring three sections of each 5 μm thick at every 150 μm interval using hematoxylin and eosin (H&E) dye, Masson's trichrome (MT) stain, and periodic acid–Schiff (PAS) dye. The whole kidney was sufficiently covered by 10 slides only for each staining. The representative slides were then examined under light microscope (11). The histological evaluation involved structures including Bowman capsule, glomerular structure, basal membrane integrity, and proximal tubule basement membrane. The changes were measured histometrically and expressed in μm.

Statistical Analysis

Data were analyzed using IBM SPSS 20.0 (IBM Corp., Armonk, NY, USA) for statistical analysis. Histopathological data and quantitative measurements from a total of 24 kidneys of newborns from nine mother rats were gathered under each group, and inter- and intra-group comparisons were made statistically using parametric and nonparametric measurements whenever possible to determine the significant differences. Parametric data were expressed as mean±standard deviation. Nonparametric data were expressed as median (25^{th}–75^{th} percentiles). Kolmogorov–Smirnov test was used to determine whether the variables were compatible with the normal distribution. ANOVA test was used to compare the groups. Tukey test was used depending on the homogeneity of variances within the groups for pairwise comparison. Kruskal–Wallis test was used to classify the differences between the groups. Bonferroni corrected post-hoc test was used for pairwise comparisons. A p value <0.05 was considered as statistically significant.

RESULTS

All nine pregnant rats survived the experimental procedures without a loss or significant complication. The rats were held and maintained with ease in the platform. Once the EM radiation started, the rats showed signs of agitation and discomfort, especially those in the unprotected group G2. After removal from the holder, these rats also exhibited aggressive behaviors for an extended time period.

Postmortem analysis revealed certain changes in the characteristics of newborn kidney tissue. The extent of the changes in the Bowman capsule was exhibited in the H&E stained slides (Fig. 4).

Table 1. Quantitative histopathology-based measurements from the kidneys in experimental groups

	Control (n=8)	EM field-exposed (n=8)	EM field-exposed and protected (n=8)	p
Basal membrane absence (%)	%8 (2–10)	%32 (27–37)*	%16 (13–18)	0.000
Proximal tubule internal diameter (μm)	15.01±2.56	29.94±4.42*	23.43±6.35	0.000
Glomeruli diameter (μm)	68.40±9.03	63.71±3.85	69.03±6.45	0.470
Bowman capsule size (μm)	73.71±5.92	83.65±4.83*	81.49±7.72	0.003
Cortex thickness (μm)	261.13±4.10	284.57±10.93*	262.40±14.01	0.000
Medulla thickness (μm)	594.25±23.48	732.61±20.46*	625.89±85.35	0.000

*Denotes statistically significant difference ($p<0.05$)

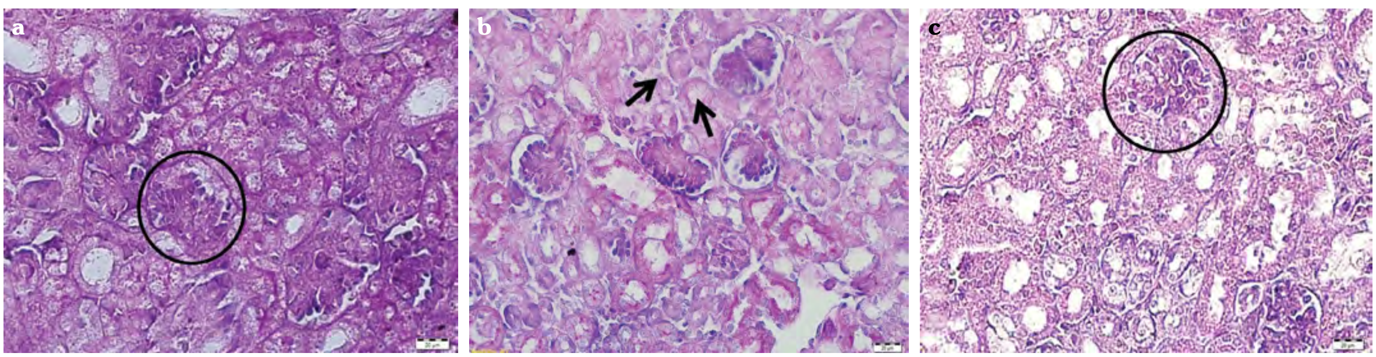

Figure 6. a–c. Overview of basement membrane structure change in all groups by PAS staining (×40). (a) Sham control group. (b) EM field-exposed group, (→) damaged section of Bowman capsule. (c) EM field-exposed and protected group

Ten capsules per slide were randomly selected. The diameters of all capsules (a total of 100 per kidney and 800 per group) were measured two times and then averaged. Glomeruli were also measured similarly.

MT staining depicted the connective tissue in the kidneys (Fig. 5). The thicknesses of the cortex and medulla were recorded from 10 different radial orientations and then averaged (10 per slice, 10 slices per kidney, and 8 kidneys). The average measurements are listed in Table 1.

PAS staining in the constructs allowed examining the integrity of the basement membrane structures (Fig. 6). Proximal tubules were divided into four equal quadrants, the sections around the membrane layer were identified, and their percentages per total area of the tubule were evaluated. The absence of any degeneration in the basal membrane was assigned as 0%, and half the fraction of the degenerated case was evaluated as 50%. The inner diameter of the tubules was measured twice and averaged in the cross-sectional plane. The cubic epithelial cells inside the tubules were also examined, and structural changes were determined. The degree of the damage to the Bowman capsule and the extent of Bowman's range are quantified in Table 1.

Overall data indicated that the kidney structure and morphology of the prenatal rats were greatly affected by exposure to EMF. Glomerular basement membrane continuity was interrupted. The diameters of the Bowman capsule and the proximal tubule were increased. Both cortex and medulla thickened. However, these effects were significantly lesser in the kidneys placed behind the fabric.

DISCUSSION

Public awareness and health concerns on the potential risks of radio frequency/microwave radiation emissions from widespread use of wireless communication devices have been addressed by experimental studies in the past. Efforts have been spent for mainly understanding the effects of EM radiation on biological tissues using histopathological and biochemical methods (12–16). The subsequent work focused on developing countermeasures with approaches based on available chemical agents to protect the biological tissue against exposure. Traditionally, metals and alloys have been employed for EM shielding; however, these materials are heavy and expensive and may be subject to thermal expansion and metal oxidation associated with their use. Thus, advanced materials for textile shielding are introduced due to their desirable properties of flexibility, lightweight, and effectiveness (17, 18).

Consequences of long-term EM field exposure were initially evaluated at low frequency (5 Hz for 5 min a day for 6 months) with follow-up measurements involving oxidative stress markers and zinc levels in plasma and testicular and renal tissues (19). Zinc supplements were suggested for reducing the EM field-induced damage to the testicular and kidney tissues. Similar studies extended the frequency to 900 MHz band as it has been a common carrier in cell phone communication. Such exposure is noted to cause a significant decrease in total antioxidant capacity in the brain, liver, and kidney (20). In a study at 900 MHz electromagnetic field on postnatal days 22–59, in the EM field group, pathologies, such as dilatation and vacuolization in the distal and proximal tubules, degeneration in the glomeruli, and an increase in cells tending to apoptosis, were observed in the kidney tissue. Additionally, EM field group samples exhibited glomerular capillary degeneration with capillary basement membranes (21). In a recent study, the effects of kidney growth on pre- and postnatal male rats exposed to 2.45 GHz electromagnetic field were examined, and tubular degeneration was observed in the kidneys (5). In another study, male rats were exposed to 2100 MHz electromagnetic field, and a large number of positively stained renal tubular epithelial cells were observed with deterioration of the brush border of renal tubules (22). When the effects on female rats exposed to 900 MHz EM field continuously during mid–late adolescence were examined, bleeding in the glomerulus, vacuolization and irregularity in the proximal and distal tubular epithelium, diffuse intracapsular epithelium, diffuse glomerular degeneration and edema, rarely degeneration in Bowman capsules, hemorrhage, tubular nucleus localization and morphology, and cortex edema in the medullary region were observed (23). The evidences by other studies indicated that caffeic acid phenethyl ester, melatonin, and omega-3 treatments prevent renal and heart failures by alleviating the oxidative tissue damage via free radical cleansing, lipid peroxidation, and antioxidant properties (24–27). These results were particularly important as individuals carry cell phones in waistbands, which are anatomically located nearby the kidneys.

The offspring of rats exposed to EM field for 1 h a day during pregnancy exhibited a higher apoptotic index, higher DNA oxidation levels, and lower sperm motility and viability when examined on day 60 of postpartum (25). Insulin release was modified in rats when irradiated with 900 MHz EM field for 6 h daily for 7 days (28). In these rats, damage was observed in Langerhans islet cells with mild to severe inflammation in the liver portal areas, and these changes were closely related to exposure time. In a recent proteomic analysis on the testicular tissue excised from rats allowed to move freely within the 900 MHz EM field for 30 days, the findings suggested increased testicular proteins associated with reproductive damage and carcinogenic risk in adults (29).

With these reports on tissue degradation associated with EM field in mind, alternative measures have been developed to prevent the direct interaction of the EM field with the biological tissue using EMSFs. To the best of our knowledge, this is the first study aimed at determining the degree of tissue protection achieved with the implementation of a fabric. Our results based on the morphometric analysis indicated that prenatal kidney deteriorated in intrauterine life. This finding was in agreement with a previous study (11). However, the fabric was able to reduce the level of renal tissue destruction significantly.

The limitation of our study is that the long-term power of the fabric protection could have been further confirmed if the mothers and some siblings were kept alive for an extended period of time.

EMSF potentially protects the prenatal kidney during development against the harmful effects of EM radiation of mobile devices at 900 MHz when the fabric was worn during pregnancy. The effects are likely to extend to the other organs and frequencies, as well as the age of maturity, but remains to be seen in future investigations.

Acknowledgements: The authors thank Prof. Dr. Hüseyin Gazi Örtlek for generously providing the EMFS fabric used in the study.

Ethics Committee Approval: The study was approved by the Local Ethics Committee for Animal Experiments of Adnan Menderes University, Aydin, Turkey (no.: 64583101/2016/76, date: 04/18/2016).

Peer-review: Externally peer-reviewed.

Author Contributions: AGS, SK, AMT performed the literature search, experiments, histology, data analysis and interpretation. NA provided the EMF device as a critical resource and helped with data interpretation and review. MB conceptualized and supervised the overall study and its design, interpreted the data and wrote the paper.

Conflict of Interest: The authors declare that they have no conflict of interest.

Financial Disclosure: This work was supported by the Adnan Menderes University Institutional Office of Scientific Research Projects under grant TPF-15042.

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