



Radiofrequency exposure in the Neonatal Medium Care Unit

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ABSTRACT

The aims of this study were to characterize electromagnetic fields of radiofrequency (RF-EMF) levels generated in a Neonatal Medium Care Unit and to analyze RF-EMF levels inside unit's incubators. Spot and long-term measurements were made with a dosimeter. The spot measurement mean was 1.51 ± 0.48 V/m. Higher values were found in the proximity to the window and to the incubator evaluated. Mean field strength for the entire period of 17 h was $0.81 (\pm 0.07)$ V/m and the maximum value was 1.58 V/m for long-term RF-EMF measurements in the incubator. Values found during the night period were higher than those found during the day period. It is important to consider RF-EMF exposure levels in neonatal care units, due to some evidence of adverse health effects found in children and adults. Characterization of RF-EMF exposure may be important to further investigate the mechanisms and underlying effects of electromagnetic fields (EMF) on infant health. A prudent avoidance strategy should be adopted because newborns are at a vulnerable stage of development and the actual impact of EMF on premature infants is unknown.

1. Introduction

Advances in technology have had a significant impact on the field of medical applications. Medical applications use electromagnetic fields in the radiofrequency range (RF-EMF), in fact, most applications which emit EMF are in the frequency range above 100 kHz up to some GHz. The usual frequencies that are allowed for medical, industrial, and scientific, applications are similar to most industrial sources (Carranza et al., 2011). These are the frequency bands and sources used by the Global System for Mobile Communication (GSM) including the Industrial Medical and Scientific (IMS) band 2400 (2400, 2400–2483.5 MHz). Sources of exposure are apparatus used for electronic health records, biological monitoring and clinical treatment and diagnosis. RF-EMF sources of exposure are wireless communication systems (Calvente et al., 2015), incubator motors, transport incubators, radiant warmers and syringe pump systems. Besides, sources of different non-ionizing radiation of extremely low frequency and low frequency electromagnetic fields (ELF-EMF, LF-EMF), and optical radiation are mechanic ventilators, systems for monitoring of vital parameters, oxygen therapy devices, medical aspirators for secretions, portable wireless devices like tablets and laptop computers, and

phototherapy lights for the treatment of hyperbilirubinaemia and skin diseases, respectively. The increasing use of electromagnetic fields (EMFs) frequency range from 0 Hz to 300 GHz, has resulted in some concerns regarding their biological effects on human health. Adverse and beneficial biological effects of EMFs have been described in laboratory animal (Riminesi et al., 2004) but the biological mechanism of such effects remains unclear. Biological effects depend not only on the distance to the source and size of the object but also on environmental parameters. For example, at lower frequencies of radiation (< 100 kHz) many biological effects are quantified in terms of current density in tissue and this parameter is most often used as a dosimetric quantity. At higher frequencies, several interactions are due to the rate of energy deposition per unit mass (Specific Absorption Rate, SAR) and SAR is therefore used as the dosimetric quantity. The high temperatures resulting from exposure to RF-EMF should also be taken into consideration (Kesari et al., 2013; Saunders et al., 2005).

Few studies have investigated the possible adverse health effects of RF-EMF exposure in children, who may be more vulnerable than adults to EMF (Kheifets et al., 2005a, 2005b; Schüz, 2005). However, it is important to state the special susceptibility of embryo, fetus and child during the development critical periods, because during these

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stages several feature, conducts and specific abilities are acquired (Artigas-Pallarés et al., 2011). Postnatal changes are characterized by slower growth and maturation of existing organ systems, particularly the central nervous system (CNS). Massive neuron proliferation, differentiation, and connections in the CNS are remarkably vulnerable. This allows a high capacity to acquire, assimilate, learn and remember some quick information without any big effort (Kheifets et al., 2005a, 2005b; Pinto, 2008). The development of the CNS is particularly susceptible to raised temperatures. A reduction in brain size, which results in a smaller head, is one of the most sensitive markers of heat-induced developmental abnormalities and can be correlated with heat-induced behavioral deficits (Saunders et al., 2005). Moreover, the lower bone density and lesser amount of fluid in the brains of children vs. adults may result in a deeper penetration of larger amounts of RF-EMF into the brain (Christ et al., 2010). Kane has suggested that exposure of the human embryo, fetus, and newborn to RF-EMF, an acknowledged environmental toxin under many exposure conditions, may be associated with an increased incidence of autism (Kane, 2004). Nevertheless, evidence that children are indeed more vulnerable to this exposure remains scant (Otto and von Möhrendahl, 2007; Leung et al., 2011), and some studies have shown that effects in children did not differ from those in healthy adults (van Rongen et al., 2009; Croft et al., 2010; Segalowitz et al., 2010; Feychting, 2011; Valentini et al., 2011; Loughran et al., 2013). Studies that analyzed exposure to EMF in premature infants are mainly focused on ELF-EMF (ELF: frequency range 0 Hz to 300 kHz; in scientific literature, the exposure assessment to fields from 5 Hz to 100 kHz is often referred to as ELF). Exposure to EMFs in incubators may modify the heart rate variability as well as other biological rhythms especially sensitive during perinatal period, thus having an impact on the autonomous nervous system, in newborns (Bellieni et al., 2008). In this sense, we consider highly vulnerable REM (Rapid Eye Movement) and No-REM sleep rhythms and also the acquisition of a melatonin circadian rhythm that takes place at the age of 6–8 months. This affects the autonomous nervous system in newborns and also in several functions related to maturation and neuronal plasticity. Some authors have found an association between exposure to ELF-EMF and low birth weight, and increased risk of spontaneous preterm birth and small for gestational age infants (de Vocht et al., 2014a, 2014b). Exposure to RF-EMF has also been related to higher risk of childhood leukemia (Calvente et al., 2010), neurodegenerative diseases (Kesari et al., 2013), behavioral problems (Divan et al., 2008; Thomas et al., 2010; Divan et al., 2012; Guxens et al., 2013; Huang et al., 2013; Calvente et al., 2016), and psychosocial risk (Sansone et al., 2013; Schoeni et al., 2015). Other studies found a negative impact on sleep-dependent performance improvement after exposure to RF-EMF, supporting its involvement in sleep-wake regulation (Lustenberger et al., 2013, 2015). Čermáková emphasizes the need to take a special care of newborns kept in incubators even if only the sub-reference values are detected. Babies in an incubator have much smaller dimensions, higher electric conductivity and may trigger another mechanism of response to ELF-EMF than those indicated in that paper (Čermáková, 2003). In the Neonatal Intensive Care Unit (NICU) babies spend their first hours or days of life in an incubator or in a radiant warmer. Modern incubators use the most advanced technology to provide thermal stability to low birth weight and sick newborns, thus improving their chances of survival (Antonucci et al., 2009). Incubators are enclosed cots made of transparent material with a padded mattress that is heated by convection, an external air filter, and sophisticated systems to monitor weight, breathing, heart and brain activity. The motor of incubators uses radiofrequency energy to operate and the lamps used in phototherapy are also sources of EMF (Bellieni et al., 2012). Like all electrical instruments, incubator motors are a source of EMFs radiating on its surrounding (Bellieni et al., 2005). The technological progress made in the development of more comfortable and safe infant incubators does not guarantee by itself an optimum microenvironment for premature and at risk neonates NICU.

In fact, conventional noxious NICU environments and practices, including exposure to bright lights, high sound levels, and frequent noxious interventions, may negatively influence the development of the neonatal brain (Antonucci et al., 2009; Darcy et al., 2008). Premature infants are especially vulnerable to environmental exposure. Compared with term infants, premature infants have many physiological limitations, often experience CNS immaturity, and have an increased need for intensive care. These factors make preterm infants much more susceptible to the possible negative effects of the NICU environment (Darcy et al., 2008). Research reports indicate that RF-EMF exposure levels, typically encountered from some commercial products (a broad range of commercial RF-EMF energy product applications including, most notably, broadcast FM radio transmitters, radar, television, public service mobile communication transceivers, microwave ovens, and cellular phones) may induce alterations of biological processes or damage to the genome (Maes et al., 1993; Lai et al., 1996; Phillips et al., 1998; Luukonen et al., 2009). The review published by Juutilainen et al. analyses papers dealing with the biological effects of RF-EMF (Juutilainen et al., 2011). Considering several experimental models, different biological endpoints have been examined including genotoxic and non-genotoxic effects, gene and protein expression, carcinotoxicity and nervous system effects in animals and humans. Although the majority of studies reported no evidence of health effects, some studies reported effects on the human CNS but no consistent evidence has been found for carcinogenic or genotoxic effects. These authors and other studies emphasize that there are no biological or biophysical mechanisms that can explain such effects (Juutilainen et al., 2011; SCENIHR, 2013, 2015). Bellieni et al. analyze as to reduce the high ELF-EMF to which newborns are exposed in incubators and to which caregivers are exposed when working near the incubators (Bellieni et al., 2005). The impact of these EMFs on the enhanced sensitivity of the developing body is still largely unknown (Bellieni et al., 2005). The difficulty in making direct measurements of exposure to EMFs has needed to create measurement models. In this sense, Li et al. developed realistic anatomical models to evaluate human exposure to RF-EMF. Infants have significant physical and anatomical differences compared to other age groups. Investigating the effect of EMF exposure on infants is of particular importance, especially because their CNS undergoes rapid development (Li et al., 2015), and premature infants often stay in NICU for months. In addition, their results revealed that the safety limits prescribed by International Commission for Non-Ionizing Radiation Protection (ICNIRP) guidelines might not be conservative for exposure of infants to RF-EMF (Li et al., 2015; Antonucci et al., 2009). Besides current safety levels to EMFs are based on short-term or immediate effects, and it is important to consider that cancer and other diseases can have a long latency period (Calvente et al., 2010). Furthermore, there are few published data reporting the effects of EMF exposure on newborns in incubators, being the impact of EMF on infant health still unclear (Antonucci et al., 2009). Most of the scientific literature published on this topic is based on ELF-EMF exposure, as previously mentioned. Preterm or term newborns placed in incubators are considered an at risk group of particular interest because they are exposed to EMF from birth as they are surrounded by electrical equipment and general environment (multiple cellular phones, devices communicating wirelessly, and more traditional sources of exposure such as the radio) at the NICU. Some of these neonates have to stay at the NICU for a long time, growing in an EMF environment (Lai Thomas and Bearer Cynthia, 2008). There has been little research on the correlation between EMF exposures during the early phases of human development. In this respect more attention should be given to the exposure of developing embryos, fetuses, and young child to environmental toxins of all kinds because of their greater fragility and susceptibility. Fetuses and babies have a high number of stem cells which are responsible for the formation of the fetal nervous system (Franco et al., 2012). Stem cells are very sensitive to toxic effects. Thus, exposure of the fetus to EMF can increase the risk

of growth retardation and birth defects (Leeka et al., 2005). Other authors reported negative effects associated to RF-EMF exposure in human stem cells (Czyz et al., 2004; Belyaev et al., 2010). Fetuses and babies have an underdeveloped immune system and any insults, in particular physical and chemical agents, can result in harmful effects. In this sense, some authors have reported on the RF-EMF effects on immune system by stimulation of various allergic and inflammatory responses, as well as effects on tissue repair processes (Johansson, 2009).

Moreover, RF-EMF signals can generate unwanted electromagnetic interference in electro-medical equipment. These signals can interfere with the normal operation and with the recording of clinical data, which might result in misdiagnosis or incorrect treatments for patients (Carranza et al., 2011). The National Quality Forum (NQF) has published an update on security practice to improve health assistance (NQF, 2010). NQF endorsed 34 safe practices to be implemented at the NICU to create and maintain a safe culture; improving hospital leadership, and promoting patient involvement in safety). Thus, the aims of this study were to characterize the general environment RF-EMF levels generated in the Neonatal Medium Care Unit located into NICU and to analyze RF-EMF levels inside the incubators of this Unit.

2. Materials and methods

2.1. Study area

The design of the study was cross-sectional. Measurements of RF-EMF levels were performed in the general environment of the Neonatal Medium Care Unit (NMCU) of the Pediatric Unit of the San Cecilio University Hospital (Granada, Southern Spain). The NMCU can accommodate six to eight newborns monthly. This study was performed on an incubator C2000 (Dräger, Germany). RF-EMF energy is emitted while incubator motors are running. In addition, hospital staff uses cell phones in the facility during the working time, including the night shift.

Our NMCU is divided into the following areas: the green area, where incubators are located, and the red, blue and white area reserved for breastfeeding. The green area has four exterior windows with metal frames at 107 centimeter above the floor and an interior window with metal frame at 86 cm above the floor to the hallway (see Fig. 1).

2.2. Sources of exposure

In hospitals, the number of sources of exposure to RF-EMF has increased as a result of the development in wireless technologies. Wireless technologies have also had a huge influence in medical applications (wireless biomonitoring and portable wireless devices like tablets and laptop computers). Different frequency bands and sources are used by the GSM, including the IMS band 2400 (2400, 2400–2483.5 MHz) (Calvente et al., 2015). In the NICU, the infant incubator is a biomedical device which provides warmth, humidity and oxygen to babies in a controlled environment. Incubator C2000 (Dräger, Germany) uses energy of RF-EMF for internal functioning; bands ISM 150–80 MHz and 80–2.5 GHz. The C2000 is intended for use in the electromagnetic environment in which radiated RF-EMF disturbances are controlled. The customer of the C2000 can help prevent electromagnetic interference by maintaining a minimum distance between portable and mobile RF-EMF Communications Equipment and the C2000 as recommended, according to the maximum output power of the communications equipment. Underneath the baby there is an air-blown electric heating and humidification system which moves heated humidified air through the incubator chamber. The field measured in the incubator (according other studies) is originated by the fan and blower motor and the electric heating coils. Furthermore, phototherapy lights also produce radiant heat inside the incubator; therefore infants in incubators would require more diligent monitoring.

Babies in incubators are often connected to a ventilator; oxygen saturation monitor, IV pump of the umbilical artery catheter, electrocardiogram and blood pressure monitor, and bilirubin lights, baby warmer and temperature monitor might be placed overhead. Other devices for clinical treatment and diagnosis use electric power sources. The frequency distribution of the electric field is in the range 30 MHz to 3 GHz. It is worth considering the electromagnetic environment in the Unit created by staff's cell phones, Bluetooth technology and the phone and radio antennas around the hospital.

2.3. Equipment

Measurements were made with an ExpoM RF dosimeter (ExpoM, Zürich, Schweiz). Table 1 shows its technical specifications (available at http://www.fieldsatwork.ch/uploads/Downloads/ExpoM_RF_Fact_Sheet-EN.pdf. http://www.fieldsatwork.ch/uploads/Downloads/ExpoM_RF_Manual-EN_v2.1.pdf). Band-selective measurements allow for a detailed differentiation of the different electromagnetic field sources. This dosimeter separately measures frequency ranges. The 16 predefined frequency bands covered by this device include all major wireless communication and broadcasting services and any RF-EMF activity outside these bands is not detected. The minimum sampling period was 0.5 s. ExpoM uses true-RMS (root mean square) detection method and a three axis isotropic antenna. Uncertainty in the separate bands can add up to 6 dB (factor of 2). This approach ensures

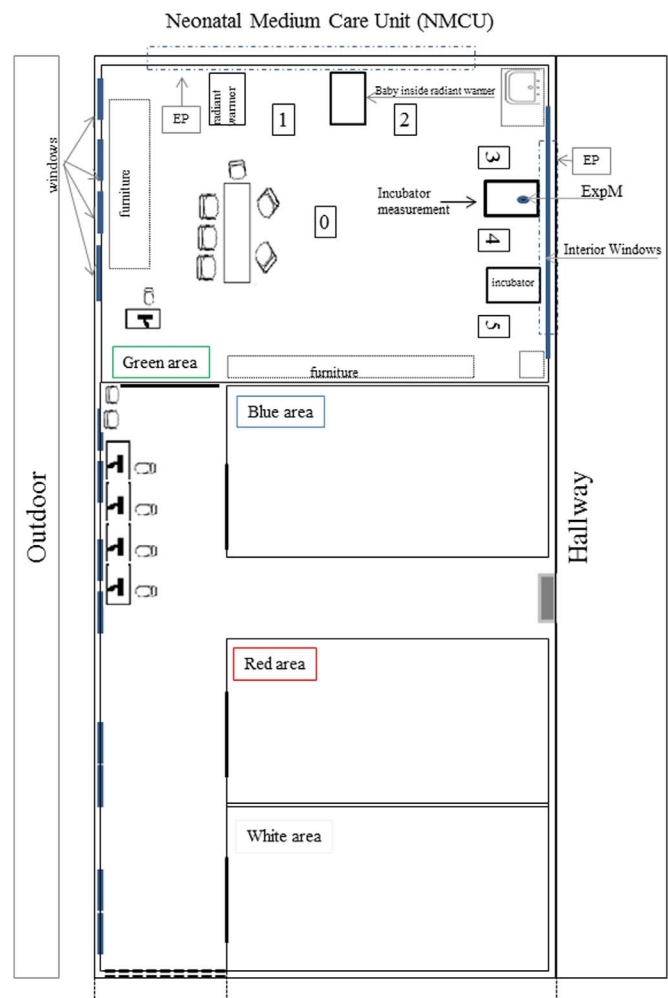


Fig. 1. Distribution of incubators and radiant warmer in the measurement area (Green area). Spot measurement points (0-5), and incubator long-term measurement. ExpoM: Exposimeter. EP: Electric panel. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

Table 1

Technical specifications: RF measurement and other parameters.

Detection method	True-RMS, 0.3 s integration time for each band
Sample interval	User-selectable; from 3 to 6000 s in steps of 0.5 s
Uncertainty	Random distribution of direction of incoming RF (when you move the ExpoM): 10% (1 dB) Other case: 6 dB (factor of 2).
Antenna	Three axis isotropic antenna
Crosstalk	Typically between –40 and –60 dB
Field measured	Field strength; 16 frequency bands
Unit	All field values are expressed in Volts per meter (V/m).
Dynamic range	0.005–5 V/m – Low detection limit

modulation-insensitive measurements, allowing for meaningful cross-standard field value comparisons. ExpoM generates a file with the date and time, sequence number, field strength, among other information. The last field shows the resulting total field strength computed from all band measurements. All field values are expressed in Volts per meter (V/m). The dynamic range of measurements is 0.005–5 V/m – Low detection limit.

2.4. Measurement procedure

Spot and long-term measurements were made in May 2015 during a standard working day at the main area of the NMCU (green area). The dimensions of this area are 7.5 m × 5.04 m. Fig. 1 shows the distribution of incubators and radiant warmer. Spot measurements were performed with the cell phones of the NMCU staff in the flight mode. All the values recorded at each single measurement point were subsequently averaged over the measurement time in order to obtain a single value for each point. The sampling interval selected was 4 s.

2.5. Spot measurements: survey study with portable exposimeter

Several measurement points were considered within the green zone according to the distribution of incubators, radiant warmer, medical electronic equipment, furniture and NMCU staff. Measurements were taken at three heights (1.10 m, 1.50 m, and 1.70 m) in order to get the maximum field value and estimate the background levels in the center of the area (point 0). In addition, this area is part of a healthcare facility and therefore is intended for occupational use. Thus, we found interesting to develop a method especially designed for the working environment involving measurements at different heights made in the center of this area. Measurements at points 1, 2, 3, 4 and 5 were performed at 1.10 m, which is the mean height of the incubators and radiant warmer when the baby is inside (see Fig. 1). These measurements made near the incubator and radiant warmer are of greater interest because this area is generally occupied by healthcare personnel and parents and this is the typical distribution in the NMCU. The mean and the median were calculated from the values recorded. Spot measurements were made during daytime.

2.6. Long-term measurements

2.6.1. Incubator

Long-term RF-EMF measurements were also made with an ExpoM RF dosimeter. Expo M was positioned in the area of the incubator where rests the baby's head (see Fig. 1). The exposimeter operated in continuous acquisition mode. The sampling interval selected was 4 s over a total of 17 h/day. All the values recorded were subsequently averaged over the measurement time. The ambient air temperature was held at 23–24 °C. The air temperature of the incubator was set at 38 °C.

2.7. Statistical analyses

Descriptive statistics of spot and long-term measurements (true-

Table 2

Spot measurements at the Neonatal Medium Care Unit GREEN Area.

Point	Height (m)	Broad band result (V/m)	
		Mean ± standard deviation	Median
0 (center)	1.10	1.52 ± 0.07	1.53
	1.50	1.66 ± 0.10	1.64
	1.70	1.63 ± 0.08	1.60
1	1.10	1.36 ± 0.08	1.39
2		1.10 ± 0.05	1.10
3		1.05 ± 0.06	1.06
4		1.60 ± 0.08	1.61
5		2.49 ± 0.14	2.54

RF Measurements: Electric field strength broad band results at selected points (0–5) in the Neonatal Medium Care Unit (NMCU) green area at the Pediatric Unit of San Cecilio University Hospital (Granada, Southern Spain) environment.

RMS field strength) were obtained for the NMCU. Arithmetic mean, standard deviation, percentiles, minimum values, maximum values and RMS for two minutes per band at each point and total field strengths were computed. All the values recorded were averaged over the measurement time accordingly. Microsoft Excel 2010 was used for data analyses.

3. Results

All recorded values (spot and long-term RF-EMF measurements) were well below International Commission on Non-Ionizing Radiation Protection reference levels (ICNIRP, 1998).

3.1. Spot measurements to RF-EMF

Table 2 shows the mean and the median of all values measured (height 1.10 m): 1.51 ± 0.48 V/m and 1.41, respectively for the total points. The maximum value obtained was 1.66 V/m at a height of 1.50 m (point 0). In addition, the field strength of the FM band was above the rest of the bands (Fig. 2). At average height of 1.10 m, higher values were found for points 0, 4 and 5 (1.52, 1.60 and 2.49 V/m, respectively), probably due to their proximity to the window and to the incubator evaluated. It is worth mentioning that a volumetric infusion pumps and pulse oximeter are attached to this incubator. The median of the measured values was similar to the mean obtained for every one of them (Table 2).

3.2. Long-term measurements RF-EMF Incubator

Mean (SD) field strength for the entire period of 17 h was $0.81 (\pm 0.07)$ V/m and the maximum value was 1.58 V/m. Values found during the night period were higher than those found during the day period, except for the maximum value, which was found during the day period. Mean field strength of the day period was 1.1 lower than the night period. Median and arithmetical mean values were similar for the day period and the night period although slightly higher at night (Table 3). The higher field strength values from the 16 frequency bands corresponded to the FM band (frequency range 87.5–108 MHz) and the GSM900 DL band (frequency range 925–960 MHz) (Fig. 3). The field strength value for the FM band at night was 1.12 higher than that found during the day.

When RF measurements were analyzed by band, half the values were within the typical dynamic range (0.003–5 V/m), except for LTE 800 (UL, DL), DECT, UMTS UL, ISM 2.4, LTE 2600 (UL, DL), and ISM 5.8 GHz bands that were below the dynamic range. The FM Radio band features the highest level of RF-EMF with 0.79 V/m, followed by the DVB-T and GSM900 DL bands with 0.11 V/m each (Table 4).

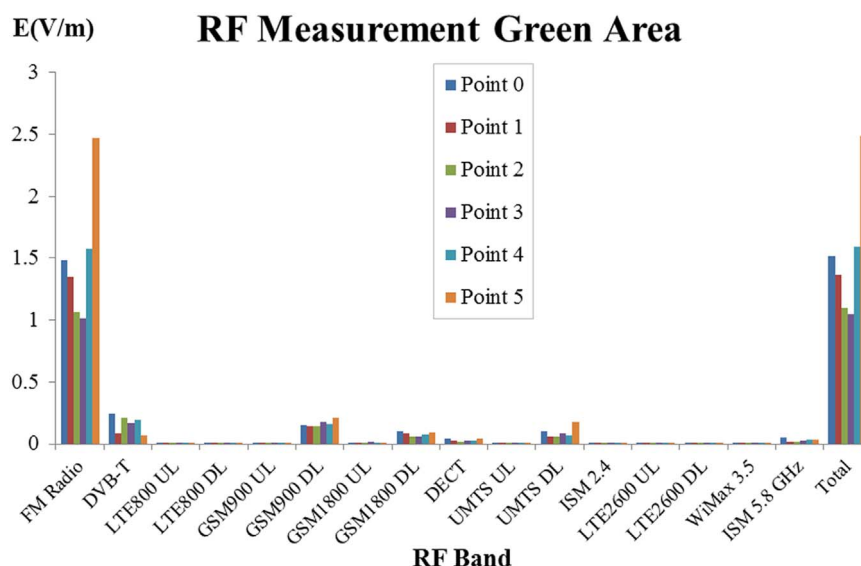


Fig. 2. RF measurements at the green area: Measured field strength (16 frequency bands) in the Neonatal Medium Care Unit (NMCU) at the Pediatric Unit of the San Cecilio University Hospital (Granada, Southern Spain). Mean value obtained from spot measurement point (0-5) during 2 min and at 1.10 m (mean height).

Table 3

Electric Field strength measurements in the incubator (RF).

	AM $\pm$ SD	Median	Min	p25	p75	Max
Total period (12:12–5:21) h	0.81 $\pm$ 0.07	0.82	0.52	0.76	0.87	1.58
Day period (12:12–22:00) h	0.78 $\pm$ 0.08	0.78	0.52	0.72	0.83	1.58
Night period (22:00–5:21) h	0.85 $\pm$ 0.04	0.87	0.62	0.82	0.88	1.41

Radiofrequency (RF) Measurement in the incubator: Mean value during day, night and total period in the incubator. Neonatal Medium Care Unit (NMCU) at the Pediatric Unit of the San Cecilio University Hospital (Granada, Southern Spain).

Field values are expressed in Volts per meter (V/m)

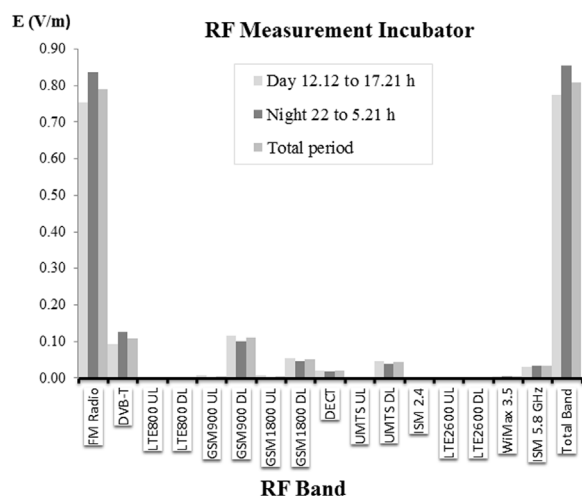


Fig. 3. Measured field strength (16 frequency bands). Mean value during day, night and total period in the incubator. Neonatal Unit of San Cecilio Hospital (Granada, Spain).

4. Discussion

Our results show that environmental values of RF-EMF in the NMCU were higher than these found within the incubator evaluated despite the fact that all the measurements in the incubator were made with all electronic devices switched on. In addition, there were differences between day and night levels, with the FM Radio band having the highest frequency range (87.5–108 MHz) of the 16 frequency bands. Differences between day and night may be due to the potential cumulative environmental effects, which are caused by the

Table 4

RF Measurements by band in the incubator (12:12 h to 5:21 h period).

Band name	Frequency range (MHz)	E (V/m)	Typical dynamic range (V/m)
FM Radio	87.5–108	0.790	0.020 5
DVB-T	470–790	0.107	0.005 5
LTE800 UL	791–821	0.001	0.005 5
LTE800 DL	832–862	0.001	0.005 5
GSM900 UL	880–915	0.005	0.005 5
GSM900 DL	925–960	0.109	0.005 5
GSM1800 UL	1710–1755	0.005	0.005 5
GSM1800 DL	1805–1880	0.051	0.005 5
DECT	1880–1900	0.019	0.005 5
UMTS UL	1920–1980	0.002	0.003 5
UMTS DL	2110–2170	0.042	0.003 5
ISM 2.4	2400–2485	0.002	0.005 5
LTE2600 UL	2500–2570	0.001	0.003 5
LTE2600 DL	2620–2690	0.001	0.003 5
WiMax 3.5	3400–3600	0.005	0.003 3
ISM 5.8 GHz	5150–5875	0.032	0.05 5
Total		0.810	

Radiofrequency (RF) Measurement in the incubator: Measured field strength (16 frequency bands). Neonatal Medium Care Unit (NMCU) at the Pediatric Unit of the San Cecilio University Hospital (Granada, Southern Spain).

combined influence of an increase of incubator device switched on and the time of exposure. In addition, high value of ELF-EMF might lead to overestimations of the frequency range of RF-EMF. Another potential source of RF-EMF might be that staff has more time to use their cell phones while sitting in the unit during the night shift. Besides the medical devices can generate EMF that disrupts the radio environment of hospital areas. It is also possible that in certain areas of a healthcare center, high-frequency signals could be detected as a result of pollution caused by radio-electric commercial or communications systems with common use bands (walkie-talkies, ham radio, or broadcasts of security forces and civil protection), in addition to those received by mobile operator base stations (Carranza et al., 2011). Exposure depends strongly on absorption and reflection by obstacles, which in turn depend on the frequency and angle of incidence of the wave and on the material, thickness, and coating/sheathing of the obstacle (Calvente et al., 2015).

We found variability in the environmental values of RF-EMF related to the distribution of the measurement points in the NMCU green area. Moreover, the values obtained for the incubator were 1.88

times lower than the environmental values found for the green zone.

There are only a few papers on exposure of newborns in incubators to EMF where the only source considered is the motor that generates these emissions and these studies measure low frequency exposures (Bellieni et al., 2005). To our knowledge, this is the first study that analyzes the levels of RF-EMF exposure in a neonatal unit.

Some studies on RF-EMF and ELF-EMF have reported biological and adverse health effects to the fetus and young children even when exposure levels are still well within the current legal levels in many countries. It has been reported that brain development is highly sensitive to EMF exposure (including RF-EMF) in the prenatal period (Hardell and Sage, 2007). This study has reported changes in the brain and nervous system function under some conditions of RF-EMF exposure and alerts about the unknown biological consequences of prolonged EMF exposures to children. In addition, several studies have described adverse health effects at levels below safety standards including deficits in verbal expression/comprehension and behavioral problems in children; however, most of the neurobehavioral functioning tasks were not affected (Kane, 2004; Schoeni et al., 2015; Calvente et al., 2016).

Studies that analyzed the association between exposure to RF-EMF and incidence of leukemia show a statistically significant relationship that is a function of the distance to the radio/station transmitters (Calvente et al., 2010). However, Söderberg et al., in a case-control study, found little evidence that exposure to ELF-EMF inside infant incubators is associated with increased risk of childhood leukemia (Söderberg et al., 2002).

Little is known about the biological effects of the exposure to RF-EMF in premature infants or about the human vulnerability at this stage of development. Studies from the Danish National Birth Cohort found a positive and dose-dependent relation between cell phone use by mothers during pregnancy and behavioral problems in their offspring (Divan et al., 2008, 2012; Sudan et al., 2013). However, this association was not supported by other authors (Guxens et al., 2013). Infant incubators do not guarantee by themselves an optimum micro-environment for premature babies and may negatively influence the development of these infants (Antonucci et al., 2009). Lustenberger et al., in a randomized, double-blind, crossover design, explored possible mechanisms to explain how RF-EMF (900 MHz) affect cortical activity during sleep and whether such effects on the cortical activity during sleep interact with sleep-dependent skill changes. They showed that RF-EMF exposure resulted in an increased slow-wave activity (SWA) towards the end of the sleep period and in a reduced sleep-dependent motor skill improvement. Furthermore, Lustenberger et al. provide first evidence that the increased SWA results from a direct induction of sleep slow waves by RF-EMF pulses (Lustenberger et al., 2013). Other authors suggest that the possible effects on circadian rhythms should also be considered (Bellieni et al., 2012). Nevertheless, adverse effects associated to RF-EMF exposure are not central to this paper and we only provide a summary of such effects. The World Health Organization (WHO) principle of preliminary precaution should always be applied, even for low frequencies.

Finally, a problem that is worth considering is the EMF interference with medical equipment that arises from the widespread use of cell phones, radios, Wi-Fi and several medical applications that work in the RF range, especially in critical care areas of hospitals. Tan and Hinberg found a wide range of threshold levels and a wide variety of failure modes. Therefore, they strongly recommended that use of portable telecommunication devices should be limited in hospitals and should not be used in intensive care units, among other areas (Tan and Hinberg, 1994). (Carranza et al., 2011) concluded that “special protective measures should be taken against electromagnetic interferences by incoming radio waves”.

Mobile and portable communication equipment should be used no closer to any part of the incubator than the recommended separation distance, calculated from the equation applicable to the frequency of

the transmitter. However, there is no policy of prohibition and the use of cell phones is common in intensive care areas. The consequences of exposure in infants' health deserve further research, in particular regarding the impact that RF-EMF and ELF-EMF may have on the maturational aspects of infants. The use of incubators with better shielded electrical components, moved away from the mattress, the use of shielded fan motors and relocation of the incubator motor away from the infant are measures that will help reduce EMF exposure. In addition, NICU limitation of the use of cell phones and non-medical devices (portable wireless devices, like tablets and laptop computers) in hospital areas with dedicated meeting areas in the unit. It would be advisable to establish policies and protocols for each individual unit regarding EMF levels in order to minimize exposure in those areas. This recommendation should be seen as an interim precautionary limit that is intended to guide preventive actions in the face of scientific uncertainty.

5. Conclusions

All of the recorded RF-EMF measurements (both spot and long-term) were well below the ICNIRP reference levels. Nevertheless, the increasing uses of RF-EMF used in wireless technologies as well as the number of devices that emit RF-EMF energy operate suggest an urgent need for more research in this field. In particular, it is important to consider RF-EMF exposure levels in sensitive environments such as neonatal care units since premature infants are especially vulnerable to environmental insults compared with term infants.

The health effects of RF-EMF exposure on infants are not well known. However several studies have shown some health effects even below ICNIRP safety standards. Besides, it is worth mentioning, that these standards were based on measurements made on adults. Thus, characterization not only to ELF-EMF exposure but also to RF-EMF exposure may be important to further investigate the mechanisms and underlying effects of EMF. The WHO principle of preliminary precaution should always be applied especially in infants, even in the case of low frequencies. In our opinion, it is advisable to adopt a prudent avoidance strategy primarily because newborns are at a vulnerable stage of development and the actual impact of EMF on premature infants is unknown. Further research should help point the way to specific risk-management and prevention regulations in such relevant health care facilities. Current risk assessments cannot exclude that RF-EMF might have adverse health effects due to the remaining gaps in knowledge, but especially due to the impossibility to prove a non-effect, mainly in premature babies where there is a lack of data. For all of these reasons and given the absence of studies in preterm infants, it seems necessary to evaluate exposure to EMFs at earlier and earlier ages and discuss the potential effects.

Conflicts of interest

The authors declare no conflicts of interest.

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