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REVIEW



Electromagnetic fields in neonatal incubators: the reasons for an alert

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ABSTRACT

Background: Neonatal incubators are important tools for sick newborns in the first few days of life. Nevertheless, their electric engine, often very close to the newborn's body, emits electromagnetic fields (EMF) to which newborns are exposed. Aim of this paper is to review the available literature on EMF exposure in incubators, and the effects of such exposures on newborns that have been investigated.

Methods: We carried out a systematic review of studies about EMF emissions produced by incubators, using Medline and Embase databases from 1993 to 2017.

Results: We retrieved 15 papers that described the EMF exposure in incubators and their biological effects on babies. EMF levels in incubators appear to be between 2 and 100 mG, depending on the distance of the mattress from the electric engine. In some cases, they exceed this range. These values interfere with melatonin production or with vagal tone. Even caregivers are exposed to high EMF, above 200 mG, when working at close contact with the incubators.

Conclusion: EMF have been described as potentially hazardous for human health, and values reported in this review are an alert to prevent babies' and caregivers' exposure when close to the incubators. A precautionary approach should be adopted in future incubator design, to prevent high exposures of newborns in incubators and of caregivers as well.

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Introduction

Many babies, for being born prematurely or for being sick, should be cared for in electronic incubators. A modern neonatal incubator is a device with a rigid enclosure aimed to contain a baby and provided with utilities to control its inner environment; in particular, it provides a safe and warm environment where the temperature and humidity may be controlled, and oxygen may be supplied when necessary. However, infant incubators also have some hidden disadvantages (e.g. noises or excessive lights for phototherapy) that should be carefully considered; among these, the emission of electromagnetic fields (EMF) [1].

Like all electrical instruments, the motors of neonatal incubators produce EMFs. An electromagnetic field is a physical field produced by electrically charged objects. It is the combination of an electric field and a magnetic field. The electric field is produced by stationary charges, and the magnetic field by moving charges (currents). It is a continuous field, propagated in a wavelike manner. Human exposure to EMF is due to many different sources such as

high-voltage transmission lines, MRI scanners or PC and mobile telephones, represents one of the most common and fastest growing environmental hazards, and its levels will continue to increase as technology advances [2–4]. According to their wavelength, EMFs are classified into high (HF), low (LF), very high (VHF) or very low (VLF). EMF are measured in Gauss (G) or in Tesla (T) units; 1 T = 10,000 G.

EMF produced by incubators decrease with the distance from their source, but they are high close to it, so both babies in incubators and caregivers close to it, are exposed to EMF.

We performed this review, to highlight the available literature concerning babies' exposure to EMF in neonatal incubators, and its possible consequences on infants' and caregivers' health.

Materials and methods

A PubMed search from Medline and Embase was undertaken to identify studies assessing either infants' exposure to EMF in incubators or the consequences of this exposure, using the following key words:

“electromagnetic fields”, “EMFs”, “infant incubator”, “neonatal intensive care unit” and “magnetic flux density”. To be included, studies should report EMF data expressed in mG or μT . Articles from 1993 throughout 2017 were reviewed. The date of our last search was May 2017.

Results

We retrieved 15 studies [4–18] that fulfilled the inclusion criteria. We excluded one study [18] for data being expressed in V/m units.

Measurements (Table 1)

Several studies assessed EMF values to which newborns are exposed in incubators [5–11]. Riminesi et al. [5] and Aasen et al. [6] described magnetic flux density (MFD) distribution in a NICU and inside the incubators, finding EMF values approximately 100 times higher than in residencies. Bearer et al. [7] measured the EMF

at regular intervals on the center line of the incubator, in two models of isolettes (C-86 and C-100 Air-Shields®) with the fan and heater on, and with the fan and heater off. When the heater and the fan are on and EMF exceed 100 mG in the C86 isolette and 25 mG in C-100 isolettes.

Bellieni et al. [8] showed levels of magnetic flux density at mattress level well over 10 mG at mattress level, up to 88.4 mG in common incubators and up to 357.0 mG in a transport incubator. The study carried out by Ramstad et al. [9] showed that a substantial reduction in field levels can be obtained by moving the source of the electromagnetic fields away from the infant.

The type of skeleton of the incubator seems important, with EMF values radically dropped if the skeleton is made of plastic instead than of iron [19].

As previously suggested, the distance is crucial to reduce infant exposure and can be decreased by raising the mattress, adding a thicker mattress or lowering the electrical components. Bellieni et al. [10] measured

Table 1. Studies on EMF measurement [5–14], concerning infants' exposure.

Incubator, reference	Measurements		Measurements after increasing the distance from engine
	a. Site of measurement	b. Instrument	
Air-Shields®	a. Center line of mattress		126*
ISOLETTE C100	b. Not specified		27
Air-Shields® ISOLETTE C86			
[4]			
Air-Shields® ISOLETTE C100 2E	a. 5 × 5 cm grid		13.5
DRAGER® ISOLETTE 8000	b. EMDEX-II		14.4
[6]			
OHMEDA® OHIO	a. 10–15 cm above the infant's head		10–100
CARE PLUS	b. EMDEX II		
[27]			
ISOLETTE C100	a. 5 × 5 cm grid		5–15
[9]	b. EMDEX-II		
OHMEDA® OHIO CARE PLUS	a. 6 cm × 6 cm grid		88.4
ATOM® V850TR	b. EMDEX Lite		357
ATOM® V2100G			30.4
OHMEDA® OMNIBED GIRAFFE			4.9
[12]			
TYPES NOT REPORTED	a. Within the incubator		500 mG if the incubator has an iron skeleton and 0.1 mG, if the incubator has a plastic skeleton
[19]	b. Magnetometer EFA 300		
BABYTHERM® 8000 OIWS	a. In contact with the cradle plane during the measure, and the electrical centre of the probe was about 1.5 cm above it		50
BABYTHERM® 8010 OIWS			750
INCUBATIR 8000 IC			17
[5]	b. EMDEX II		
OHMEDA® GIRAFFE OMNIBED	a. In contact with the cradle plane during the measure, and the electrical centre of the probe was about 1.5 cm above it.		12.7
OHMEDA® OHIO INFANT WARMER			1.7
[17]	b. EMDEX II		
			EMF measured outside and surrounding the closed incubator in standby mode adjacent to the control
			Panel: 280 mG. Values above 2 mG at 2 feet away.
			Humidifier: 390 mG. Values exceed 2 mG at 18 in. away

EMF at mattress level in three neonatal incubators with and without ferromagnetic panels between the electric motor and the mattress, revealing that the use of the ferromagnetic panels significantly reduced EMF exposure not only for infants but also for their caregivers.

Calvente et al. reported their values in V/m instead than in milliGauss: they found EMF of $0.81 (\pm 0.07)$ 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 [11].

Three papers described caregivers' exposure to EMF. Bellieni et al. [12] applied an EMF detector to the nurses during a 24-h period and reported that during their stay close to the incubators, the EMF exceeded 10–20 mG. Passi et al. [13] measured the EMF all around the electrical tools of an incubator, where nurses and doctors work, and showed that these fields exceed 200 mG. Paul et al. [14] reported that EMF at 5 cm from the front (defined by the nurses' usual work area) of the NICU devices ranged from less than 10 to 1140 mG. The percentage of time when subjects were exposed to magnetic fields of 4 mG or greater ranged from 5.8% to 15.6% for the NICU nurses, 0.4–2.9% for five of the comparison group nurses, and was 9.4% for one of the normal newborn nurses.

Biological effects

The exposure to high electromagnetic fields can interfere with the infant's heart rate variability (HRV) altering the autonomous nervous system activity [15]. HRV of 27 newborns was studied throughout three 5-min periods: (1) with incubator motor on, (2) with incubator off and (3) with incubator on again, respectively. Mean HRV values obtained during the three described period were compared. The control group comprised 16 newborns but exposed to no source of ELF-EMF; they were exposed to changes in background noise similar to those provoked by the incubator motor (to reproduce the conditions of the first cohort). Mean total power and the high-frequency (HF) component of HRV increased significantly and the mean LF/HF ratio decreased significantly when the incubator motor was turned off. When incubators were turned on again, basal values were restored. On the contrary, changes in background noise did not provoke any significant change in HRV. Also Passi et al. [11] showed that incubator-generated EMF influence heart rate variability.

A study [16] examined 28 babies (study group), who had spent at least 48-h in common incubators with the presence of significant ELF-EMF exposure.

Measurements of mean 6-hydroxy-melatonin-sulfate (6OH-MS) urine excretion were recorded at the end of their stay in the incubators, and compared with their mean 6OH-MS excretion 48 h after having been put in cribs, where EMFs are below the detectable limit (<0.1 mG). Mean 6OH-MS values were, respectively, 5.34 ± 4.6 and 7.68 ± 5.1 ng 6 Ohms/mg creatinine when babies were exposed to ELF-EMF in incubators, and after having been put in the crib. These changes were compared with a control group of 27 babies, who were not exposed to EMF neither before the first nor before the second sampling. In this group, mean 6 Ohms values were 5.91 ± 5.41 versus 6.17 ± 3.94 ng 6 Ohms/mg creatinine, respectively, in the first and in the second sample. A significant increase ($p = .026$) soon after being removed from incubators, was demonstrated in newborns of the study group but not in the controls ($p = .679$).

A possible correlation between infants exposure to EMFs in incubators and increased risk of childhood leukemia has been hypothesized, but with scarce evidence [17]. These authors identified all children with leukemia born in Sweden between 1973 and 1989 from the National Cancer Registry (1,700,000 infants, of which 726 cases were eligible for the study). They retrieved information about treatment in infant incubators from medical records and made measurements of EMF in the incubators for each incubator model used in the hospitals. The exposure of each child combined with the length of the treatment in an infant incubator with the EMF values of the incubator models. In particular, the authors divided the exposure of each child into highly exposed and moderately exposed with the cut point at 6 mG the infants were also divided into "unexposed", (<30 h), and "exposed" (30 h). For acute lymphoblastic leukemia the risk resulted being close to unity for all exposure definitions (0.9, with a confidence interval of 0.6–1.3); for acute myeloid leukemia, there was a slightly elevated risk ($RR = 1.8$) but with no indication of dose response and a wide confidence interval of 0.5–6.

Nurses exposed to EMF in neonatal intensive care units are reported to be prone to develop cancer [4,14], but no statistical data are available on this evidence.

Discussion

EMF values were below those of ICNIRP recommendations [18] in the incubators analyzed in this review, nevertheless they were considerably higher than the values recommended by two guidelines for computer monitors magnetic field emissions for adults, namely

MPR II and TCO. They were even higher than those recorded in the proximity of High Tension lines (10 mG at 40 m from the line) or domestic video screens (maximum values of 0.091 mG) [20,21] that have raised much concern in public opinion and among EMF experts who found a link between exposure to low-intensity EMF and tumors [22]; for instance Ahlbom et al. [23] indicate an almost two-fold risk for subjects exposed to more than 4 mG while other authors [24] give a safety limit of 2 mG, and the exposure to 200 mG EMF was found to reduce the normal variability of heart rate [25] and exposure to EMF alters sleep by inhibiting the production of melatonin [26]. A possible association between the extremely low-frequency EMF exposure and the occurrence of leukemia or other diseases has been postulated [19], and both light and EMFs can alter pineal function with long-term risk of breast cancer [27], so guidelines have been made to limit adults' exposure to EMF, since there has been much concern about the possible effects of EMF on human health, mainly about those generated by high-tension lines and mobile telephones [26] and several studies reported adverse health effects of EMFs even at levels below safety standards [28–31].

Nonetheless, neonates, for their intrinsic fragility, small size and high water content that increases electric conductivity should receive a higher standard of attention for EMF exposure.

Just two studies [9,11] on EMF exposure in neonatal incubators were available beyond the year 2004, despite new equipment and new incubators have been introduced in the market. This fact highlights a lack of interest towards this topic; a similar alarm raised in relation to adult health would not be similarly neglected.

The studies fail to determine how much energy was absorbed, and where absorption actually occurred in the newborn body. Organ-specific dosimetry is necessary to help to establish causality.

The absence of an established mechanism by which magnetic fields could produce health effects makes it difficult to identify the definitive metric for assessing exposure [32,33].

Nonetheless, infants requiring incubators obviously have other comorbidities such as prematurity and are obviously exposed to multiple sources of electromagnetic field; thus the reported EMF are only one source of possible iatrogenic pathology that preterm babies can go through.

Conclusion

Modern incubators meet the reference levels specified in Council Recommendation 1999/519/EC, according to

ICNIRP 98 guidelines, but those values are developed on adult human models, while newborns have much smaller dimensions and higher electric conductivity [34], thus, a precautionary principle should be used. This principle is already used for adults' EMF exposure.

In this light, future incubators should be conceived following better criteria about EMF emissions, redesigning the incubator components. This review has shown that this can be attained by using incubators with a plastic rather than a metallic skeleton, increasing the distance mattress-engine and using ferroabsorbing panels to shield the baby.

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Disclosure statement

The authors declare no conflicts of interest.

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