Electromagnetic fields produced by incubators influence heart rate variability in newborns

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ABSTRACT

Background: Incubators are largely used to preserve preterm and sick babies from postnatal stressors, but their motors produce high electromagnetic fields (EMFs). Newborns are chronically exposed to these EMFs, but no studies about their effects on the fragile developing neonatal structure exist.

Aim: To verify whether the exposure to incubator motor electric power may alter autonomous nervous system activity in newborns.

Material and methods: Heart rate variability (HRV) of 43 newborns in incubators was studied. The study group comprised 27 newborns whose HRV was studied throughout three 5-minute periods: with incubator motor on, off, and on again, respectively. Mean HRV values obtained during each period were compared. The control group comprised 16 newborns with constantly unrecordable EMF and exposed to changes in background noise, similar to those provoked by the incubator motor.

Results: Mean (SD) total power and the high-frequency (HF) component of HRV increased significantly (from 87.1 (76.2) ms^2 to 183.6 (168.5) ms^2) and the mean low-frequency (LF)/HF ratio decreased significantly (from 2.0 (0.5) to 1.5 (0.6)) when the incubator motor was turned off. Basal values (HF = 107.1 (118.1) ms^2 and LF/HF = 1.9 (0.6)) were restored when incubators were turned on again. The LF spectral component of HRV showed a statistically significant change only in the second phase of the experiment. Changes in background noise did not provoke any significant change in HRV.

Conclusion: EMFs produced by incubators influence newborns' HRV, showing an influence on their autonomous nervous system. More research is needed to assess possible long-term consequences, since premature newborns may be exposed to these high EMFs for months.

One of the main concerns about people in contact with electric devices is their exposure to electromagnetic fields (EMFs). Concern arose when evidence was given that EMFs can alter some neurological or clinical measures in the population: for instance, research disclosed that EMFs produced by cell phones could alter EEG brain activity in humans,[1] and several epidemiological studies have found an association between exposure to EMFs and health effects, including childhood leukaemia and adult brain cancer. Experts strongly disagree about whether this association is causal and, if so, how strong it is[2]; however, in 2001, an expert group of the International Agency for Research on Cancer (an institution belonging to the WHO) reviewed reports on the carcinogenicity of EMFs. Weighting the evidence from cellular, animal and human studies (especially from epidemiological studies on childhood leukaemia), they classified these fields as "possibly carcinogenic to humans".[3]

Additionally, recent research has concluded that occupational exposure to a 50 Hz EMF could influence the neurovegetative regulation of the cardiovascular system,[4 5] and studies suggest a precautionary attitude toward the exposure of infants to EMFs.[6] Despite of this, newborns and especially premature babies may have to be kept for months in neonatal incubators, at an age when developing tissues may be more susceptible to environmental influences; and in incubators they are exposed continuously to a high level EMF produced by an electric motor which is close to baby's body, and whose function is to warm and circulate the air which surrounds the baby.

In a previous paper we reported EMF levels in common neonatal incubators, finding levels of magnetic flux density well over 10 mG at mattress level.[7] These values were similar to those found in two previous studies on EMFs in infant incubators,[8 9] though higher than values recorded in two other reports.[10 11] Nevertheless, as far as we know, no studies of the effects of an incubator-generated EMF on the newborns' autonomic nervous system (ANS) have ever been performed, though development of the ANS has been correlated with the risk of developing arrhythmias[12] and sudden infant death syndrome.[13 14]

Our study aimed to assess whether EMFs to which newborns are exposed in incubators influence physiological variables. We concentred on heart rate variability (HRV), since it is easy to assess and it has been shown to be altered by an EMF in adults: occupational exposure to EMF may be a risk factor for life-threatening cardiac arrhythmias and myocardial infarction[15 16]; Tabor *et al* found that an EMF of 200–300 mG affected HRV,[17] and Sastre *et al* showed that nocturnal exposure to intermittent 200 mG magnetic fields significantly reduced HRV.[18] Bortkiewicz *et al* subsequently showed that occupational exposure to an EMF of 200–300 mG increased the risk of a decrease in HRV and sympathetic dominance, both risk factors for cardiac arrhythmias.[19]

HRV represents variations in instantaneous heart rate and is considered to be a marker of cardiac ANS activity. Spectral analysis shows various frequency components of HRV: the low-frequency (0.04–0.15 Hz) component (LF) is modulated by both the sympathetic nervous system and the parasympathetic nervous system, and the high-frequency (0.15–0.4 Hz) component (HF) is mainly modulated by the parasympathetic nervous system. The LF/HF ratio in HRV is used to assess a predominant shift in the sympatho-parasympathetic balance,[20] which has been hypothesised to be correlated with sudden infant death.[21]

We want to assess whether EMFs produced by incubators alter newborns' sympatho-vagal balance.

MATERIALS AND METHODS

We studied 43 newborns in Siena hospital, between March and August 2007, during their stay in incubators. Exclusion criteria were major malformations, intraventricular haemorrhage greater than grade II, seizures, bradycardia (basal heart rate <100/min) and tachycardia (basal heart rate >180/min). We performed two separate experiments. The first (experiment 1) assessed whether the EMF produced by incubators could alter newborns' HRV. The second experiment (experiment 2) was begun after the positive results of experiment 1 and assessed whether HRV changes were due to the EMF or to changes in noise which, as well as EMF, was produced by the incubator motor. Different newborns took part in the two experiments. All babies were in quiet wakefulness, active sleep or quiet sleep; no baby was in active wakefulness or crying.

Experiment 1

We studied 27 babies confined to neonatal incubators for clinical reasons. Table 1 shows details of the babies studied. Before applying the electrodes, an EMF recorder (EMDEX Lite, Enertech, Campbell, CA, USA) measuring 4.7″×2.4″×1.0″ (11.9×6.1×2.2 cm) was placed in the incubator on the mattress close to the baby's chest, so that it was possible to see the display from the outside. The detection range of the EMDEX Lite is 0.1–700 mG/40–1000 Hz. EMF levels were recorded by an observer in each period. We recorded 15-minute ECGs of the babies in supine position at least 1 hour after feeding. No baby was on assisted ventilation. A commercially available imaging system (Cardioline, Prima Holter; Remco, Vignate-Milano, Italy) was used. Five electrodes were gently applied to the babies' thorax; after a 5-minute interval the 15-minute ECG was recorded.

After 5 minutes of recording (recording period 1), the motor of the incubator was turned off for 5 minutes (recording period 2) and then was turned on again, recording for another 5 minutes (recording period 3).

Experiment 2

To assess whether any changes in HRV might be due not to changes in the EMF but to changes in background noise (due to the arrest of the incubator fan), we studied 16 newborns (mean (SD) postmenstrual age 34.1 (2.4) weeks) with the same inclusion criteria used for experiment 1. We measured HRV in a 15 minute period during which we turned the incubator motor off and reproduced close to the baby's head a noise of the same intensity and features (48–50 dB, frequency range: 20–20 000 Hz) as that of the fan background noise.[22] To reproduce the noise we used a recorder (Sony TCM-40DV) put in the incubator at 10 cm from the head of the baby, and reproduced two 5-minute periods of noise (recording periods 1a and 3a, respectively), separated by a 5-minute silence period (recording period 2a).

We recorded the values of babies' skin temperature at the beginning and at the end of the experiments, using the electronic thermometer of the incubators applied on the thorax.

We also studied whether HRV changes might be due to changes in vibrations (and not by EMF) produced by turning the motor on and off. We used a triaxial ICP accelerometer (PCB Piezotronics, USA) (sensitivity 10 mV/ms^2) to measure vibrations according with the standard ISO 2631-1[23 24] at the mattress level when the motor was on and off. The signals from the accelerometer were simultaneously acquired by a digital spectrum analyser (Soundbook, Sinus, Germany) with four acquisition channels. We measured the vibration levels at six points of the incubator mattress: two points on the axial line of the mattress, two points on a line at 10 cm to the right of the axial line and two points on a line at 10 cm to the left of the axial line.

This study was approved by the Siena Hospital ethics board. Informed consent was obtained from the babies' parents.

Data analysis

Each ECG signal is usually acquired at a frequency of 250 samples/second. Detection of the QRS complex and measurement of the R–R interval were performed automatically, using the R-wave peak as a reference point. Premature beats, missed beats and artefacts were identified visually using an interactive graphic interface, and evaluated by the operator. An R–R tachogram, consisting of a discrete series of successive R–R intervals as a function of the number of recognised QRS complexes, was obtained. HRV was evaluated by a frequency and time domain analysis.

Analysis of the frequency domain

The algorithm used to analyse the tachogram in the frequency domain was a spectral method (fast Fourier transform). According to Task Force of the European Society of Cardiology and the North American Society of Pacing Electrophysiology[20] three main spectral components can be distinguished in a spectrum calculated from R–R tachograms of 5 minutes: (*a*) a very low-frequency component (<0.04 Hz); (*b*) a low-frequency component (range 0.04–0.15 Hz); and (*c*) a high-frequency component (range 0.15–0.4 Hz). Measurements of the LF and HF power components as well as total power were made in absolute power units (ms^2). The ratio of high to low frequency was calculated, as an expression of sympatho-vagal balance.

Table 1 Characteristics of the babies studied

Experiment	Male/female	Gestational age Median (range)	Postmenstrual age Median (range)
1	16/11	30 (25–33)	34 (30–38)
2	9/7	31 (24–36)	35 (31–38)

Table 2 Mean (SD) low-frequency (LF) and high-frequency (HF) heart rate variability during three recording periods: P1 (baseline registration with incubator motor on); P2 (5-minute registration with incubator motor off), P3 (5-minute registration with incubator motor on again)

	HF* Median (range)	LF/HF* Median (range)	Total power* Median (range)	Skin temperature Median (range)
P1	54 (7–250)	2.0 (0.5–2.0)	484 (81–2209)	36.6 (36.1–36.8)
P2	140 (16–619)	1.5 (0.3–2.9)	1024 (144–3696)	36.7 (36.0–36.9)
P3	84 (10–623)	2.5 (1.8–3.5)	676 (100–3969)	36.5 (36.3–36.9)

*p<0.05.

Statistical analysis

We analysed data, comparing spectral HRV parameters (mean total power, LF, HF and LF/HF) by the Wilcoxon matched-pairs signed-ranks test, by means of GraphPad Instat 3.05 software.

RESULTS

All babies in our study had been fed within 1 hour and were in quiet wakefulness, active sleep or quiet sleep. No baby was in active wakefulness or crying. Only two babies during experiment 1 cried and for this reason were excluded from the study. All babies were examined in the afternoon. In experiment 1, the mean (SD) EMF intensity was 8.9 (2.2) mG, 0.7 (0.7) mG and 8.6 (2.0) mG for recording periods 1, 2 and 3, respectively. Total power (expression of total HRV) and the HF component (expression of vagal activity) significantly increased when the incubators were turned off ($p<0.05$), and the LF/HF ratio decreased, suggesting that the EMF may cause sympathetic imbalance (table 2). Base values were restored when the incubators were turned on again (table 2), with a significant increase in LF/HF and a significant decrease in total power and HF component with respect to period 2 ($p<0.05$). LF mean values increased but not at a significant extent from period 1 to 2, but from period 2 to 3 their decrease was significant ($p = 0.03$). Mean skin temperature before the experiment was not statistically different from the temperature after the experiment.

During experiment 2 (table 3), no significant changes in HRV components were noticed when the HRV during noisy periods was compared with the HRV of silent periods.

The values of experiment 2 were not significantly different from those recorded in phase 2 of experiment 1, when the incubator was off.

Measurement of the vibrations produced by the motor showed that their spectral components (1–80 Hz) are in a range (0.004–0.008 m/s^2) which is below the threshold of human perception (0.01–0.02 m/s^2).

DISCUSSION

Our study showed that an EMF present in neonatal incubators can alter HRV in newborns, though other studies,[25 26] with some exceptions,[19] did not find similar effects in adults. We excluded the possibility that these changes might be due either to skin temperature variations (which did not vary significantly throughout the test) or to changes in background noise (see experiment 2). We also excluded the possibility that these changes might be due to changes in background vibrations produced by the incubator motor because we showed that the level of vibrations produced by the motor is below the human perception threshold. The decrease in EMF determined by turning the incubator off caused a significant change in HRV and in sympatho-vagal balance, which returned suddenly to basal levels when the motor was turned on again. In particular, EMF caused a reduction in HRV and an increase in LF/HF ratio, an expression of sympathetic dominance.

This is noteworthy for several clinical reasons:

- A reduced HRV is a powerful and independent predictor of adverse prognosis in patients with heart disease and in the general population,[27] and the proarrhythmic role exerted by transient or persistent alterations in sympathetic and vagal control mechanisms is well known.[27] Specifically, sympathetic hyperactivity favours the onset of life-threatening cardiac arrhythmias, whereas vagal activation usually exerts relatively protective antifibrillation effects.[28]
- The LF/HF ratio is higher in preterm infants than in adults[29]; but this may be influenced by the electromagnetic environment, leading to the need for new studies on babies not exposed to an EMF.
- General criteria require that human physiological variables should never be influenced by external sources whose consequences are still unknown. An ecologically safe environment (ie, where involuntary influences on human organisms are not exerted by the equipment) should always be guaranteed, especially for premature infants whose tissues are made up of developing immature cells, particularly affected by external chemical and physical pollutants.
- Neonatal incubators are noisy[22 30 31]: the presence of a high EMF is another factor that new engineering of incubators worth considering.
- The question as to whether exposure to an EMF can cause leukaemia[32] remains unanswered and controversial. Nevertheless, results of increasingly sophisticated studies and two pooled analyses reported that the risks of leukaemia doubled in children exposed to fields >4 mG during the year before diagnosis, compared with children exposed to fields <1 mG.[33 34] These values are considerably lower than those recorded in our incubators; more studies are needed before a definite link between leukaemia or other human diseases and EMF exposure is cofirmed. This subject remains highly controversial.

In recent papers we showed that an increase in the distance between the motor and the mattress,[8] or the use of ferromagnetic panels,[35] decreased the level of EMF exposure and that even caregivers should be concerned about the risks of EMF, since they are exposed to peaks of >10 mG when close to the incubators.[36] In the incubators we analysed, the EMF values were within ICNIRP guidelines,[37] but were considerably higher than those recommended for computer monitor magnetic field emissions[38] and even higher than those recorded in the proximity of HT lines (10 mG at 40 m from the line)[39] and domestic video screens.[40]

These observations suggest that newborns should be one case in which a policy of prudent avoidance of an EMF is warranted, perhaps because no study has so far excluded the possibility of negative consequences of their chronic exposition to a high EMF in incubators.[41]

International recommendations and laws set levels to safeguard the health of workers exposed to EMFs: newborns should be worthy of similar protection, and follow-up programmes of formerly premature babies should include the study of sympathetic activity development.

Table 3 Mean (SD) low-frequency (LF) and high-frequency (HF) heart rate variability during three 5-minute recording periods: P1 (reproduced noise); P2 (silence); P3 (reproduced noise)

	HF Median (range)	LF/HF Median (range)	Total power Median (range)	Skin temperature Median (range)
P1	164.5 (10–896)	1.2 (0.7–2.1)	900 (64–3481)	36.55 (36.3–37)
P2	140.5 (9–1035)	1.3 (0.8–2.2)	841 (64–384)	*
P3	88.5 (4–1013)	1.2 (0.8–2.0)	600 (36–3721)	36.7 (36.3–36.8)

*This value of skin temperature was not recordable because the incubator and its thermometer were off during the experiment. So temperature was recorded only at the beginning of phase 1 and at the end of phase 3.
No significant difference was noticed between periods.

Competing interests: None.

Ethics approval: Approved by the Siena Hospital ethics board.

What is already known on this topic

- Newborns are exposed to high electromagnetic fields when in incubators.
- Electromagnetic fields are supposed to provoke health consequences in humans.

What this study adds

- Electromagnetic fields generated by incubators can alter heart rate variability in newborns. This is a sign of an influx of electromagnetic fields into the newborns' autonomic system.
- This factor should be considered when designing incubators.

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