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Electronic fetal monitoring: benefits, concerns and possible prospects

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Diagnosis of pathological fetal status using the processing of cardiac signals is based on the registration and evaluation of parameters of heart rhythm changes. Non-invasive fetal electrocardiography (FECG) is a prospective method of studying its functional state. This method makes it possible to obtain the characteristics of the primary electrophysiological processes occurring in the fetal myocardium. It is known that the introduction of electronic fetal monitoring led to a significant increase in the level of abdominal delivery.
The objective: **to test the hypothesis regarding the possible influence of FECG parameters on the delivery method.**
Materials and methods. **A total of 39 women between 24 and 38 weeks of pregnancy, between October 1, 2022 and October 1, 2024, were examined.**
FECG recording was performed using the "Cardiolab Baby Card" equipment (SRC "KHAI-Medica", Kharkiv, Ukraine) in the abdominal abduction for 30–60 minutes. The following HRV indicators were studied:
– STV (short term variations);
– LTV (long term variations);
– AC / DC (acceleration capacity / deceleration capacity);
– SI (stress index; SI = AMo (%) / (2 × Mo × Var), Var = NNmax – NNmin, where AMo is most often the value of the NN interval in the highest column on the histogram).
AC / DC and SI indicators were determined both in the fetus and in the mother. The women were followed up and the delivery date, weight, body length, head circumference and Apgar score of the newborns were studied.
Results. **Maternal and fetal HRV, term of delivery, neonatal anthropometric data, and Apgar score were not significantly different among women according to mode of delivery. The study of the linear correlation among the obtained characteristics of the examined contingent of women made it possible to establish certain regularities. This work revealed a moderately strong correlation between the fetal HRV indicators obtained on the basis of the analysis of phase-rectified signals – AC / DC and the Apgar score. The results of the multivariate regression analysis of the model with the way of delivery did not establish any relationship with the indicators of HRV of the mother and fetus, the term of delivery, anthropometric parameters and Apgar score, determined in the work. Among other data obtained by logistic regression, it was worth noting the presence of a strong relationship between:**
– the Apgar score and the weight of the newborn (p = 0.04);
– the Apgar score and the head circumference (p = 0.04);
– as well as trends towards relationships correlation in pairs of maternal AC vs weight (p = 0.05);
– maternal AC vs fetal body length (p = 0.05);
– fetal SI vs delivery term (p = 0.05).
Logistic regression data give a hope for the prospect of further studies of the role of the maternal AC in the diagnosis of fetal growth restriction, as well as the fetal SI as a marker of neurological maturation and a criterion of the state of the fetus.
Conclusions. **Electronic monitoring based on non-invasive FECG had no influence on the choice of the mode of delivery, which allows us to consider the prospect of creating systems for remote fetal monitoring.**
Keywords: *heart rate variability, fetal distress, cesarean section, non-invasive fetal electrocardiography.*

Електронний моніторинг плода: користь, побоювання та можливі перспективи

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Діагностика патологічних станів плода на основі кардіосигналів базується на реєстрації та оцінці параметрів змін серцевого ритму. Неінвазивна електрокардіографія плода (ЕКГП) є перспективним методом дослідження його функціонального стану. Цей метод дає змогу отримувати характеристики первинних електрофізіологічних процесів, що відбуваються в міокарді плода. Відомо, що впровадження електронного моніторингу плода сприяло значному підвищенню рівня абдомінального розродження.
Мета дослідження: перевірка гіпотези щодо можливого впливу параметрів ЕКГП на вибір методу розродження.
Матеріали та методи. Здійснено обстеження 39 жінок із терміном вагітності від 24 до 38 тижнів у період із 1 жовтня 2022 до 1 жовтня 2024 р.
Реєстрацію ЕКГП проводили за допомогою обладнання «Cardiolab Baby Card» (НТЦ «ХАІ-МЕДИКА», м. Харків, Украї-

на) в абдомінальному відведенні протягом 30–60 хв. Досліджували такі показники варіабельності серцевого ритму (ВСР):
– STV (short term variations) – короткотривалі варіації;
– LTV (long term variations) – довготривалі варіації;
– AC / DC (acceleration capacity / deceleration capacity) – схильність до прискорення/уповільнення серцевого ритму;
– SI (stress index) – стресовий індекс (SI = AMo (%) / (2 × Mo × Var), Var = NNmax – NNmin, де AMo – найчастіше значення NN-інтервалу в найвищому стовпчику гістограми).

Показники AC / DC і SI визначали як у плода, так і у матері. Після обстеження проводили подальше спостереження за жінками та аналізували термін пологів, масу й довжину тіла, окружність голівки новонароджених та їхню оцінку за шкалою Апгар.

Результати. Показники ВСР у матері й плода, термін пологів, антропометричні дані новонароджених та їхня оцінка за шкалою Апгар не мали вірогідної різниці відповідно до способу розродження. Аналіз лінійної кореляції серед отриманих характеристик обстеженого контингенту жінок дозволив виявити певні закономірності. Встановлено помірний кореляційний зв'язок між показниками ВСР плода, отриманими на основі аналізу фазово-випрямлених сигналів (AC / DC), та оцінкою стану новонародженого за шкалою Апгар на першій хвилині життя.

Результати багатофакторного регресійного аналізу не виявили зв'язку між показниками ВСР матері та плода, терміном розродження, антропометричними параметрами новонароджених й оцінкою за шкалою Апгар. Однак логістичний регресійний аналіз виявив кореляції:
– між оцінкою за шкалою Апгар і масою тіла новонародженого (p = 0,04);
– між оцінкою за шкалою Апгар та окружністю голівки новонародженого (p = 0,04);
– тенденцію до взаємозв'язку між AC у матері та масою тіла новонародженого (p = 0,05);
– між AC у матері та довжиною тіла плода (p = 0,05);
– між SI у плода й терміном пологів (p = 0,05).

Отримані дані логістичної регресії свідчать про перспективність подальших досліджень ролі AC матері в діагностиці затримки росту плода, а також SI у плода як маркера неврологічного дозрівання та критерію оцінки його стану.

Висновки. Електронний моніторинг на основі неінвазивної ЕКГП не впливав на вибір методу розродження, що дозволяє розглядати перспективу створення систем дистанційного спостереження за станом плода.

Ключові слова: *варіабельність серцевого ритму, дистрес плода, кесарів розтин, неінвазивна електрокардіографія плода.*

The diagnosis of pathological fetal conditions through the study of cardiac signals is based on the registration and assessment of heart rate variability parameters. Noninvasive fetal electrocardiography (FECG) is a promising method for studying the functional state of the fetus [1]. This method allows for the characterization of the primary electrophysiological processes occurring in the fetal myocardium. Despite certain technological challenges, such as the low amplitude of FECG peaks and the low signal-to-noise ratio, there are significant practical advances in its use [2]. Heart rate variability (HRV) reflects the impact of autonomic nervous regulation on the hemodynamic system. Currently, FECG is used in scientific research to assess both HRV and morphological parameters of the PQRST complex. Importantly, FECG also enables long-term remote fetal monitoring due to the development of telecommunications systems based on the Internet [3].

The non-stress test is one of the primary methods in modern perinatology. The appearance of accelerations in the fetal heart rate in response to fetal movements is associated with "neurological maturation" after 26 weeks of gestation [4]. Back in the early 1980s, it was proven that the result of a non-stress test has no predictive value regarding the condition of the newborn [5]. Moreover, it is known that widespread use of fetal electronic monitoring has led to a significant increase in cesarean section rates [6].

The objective: to test the hypothesis regarding the potential impact of FECG parameters on the method of delivery.

MATERIALS AND METHODS

A total of 39 women, with gestational ages ranging from 24 to 38 weeks. Among them, 28 (71.80%) patients had spontaneous vaginal deliveries, and 11 (28.20%) underwent cesarean section. The indications for cesareans were: obstructed delivery (45.50%), fetal distress (27.30%), breech presentation (18.20%), and contructed pelvis (9.00%). The current of gestation was uneventful. However, preterm birth at 35 and 36 weeks occurred in 2 cases (5.10%). Selection was randomized. The study excluded patients with genetic anomalies or fetal malformation, multiple pregnancies, infectious diseases, or severe gestational or extragenital pathology requiring urgent abdominal delivery. All women underwent mandatory examinations in accordance with the current regulations of the Ministry of Health of Ukraine (order No. 1437 dated 09.08.2022). The study was conducted within the framework of the research project in cooperation with the Department of Obstetrics and Gynaecology No. 3 of Kharkiv National Medical University, the Department of Obstetrics and Gynaecology of the Zaporizhzhia State Medical and Pharmaceutical University, and National Aerospace University "Kharkiv Aviation Institute". It was held at Kharkiv Municipal Perinatal Center during the period from 1.10.2022 till 1.10.2024. All patients were informed about the study methodology, objectives, and conditions.

FECG registration was carried out using the "Cardiolab Baby Card" (Scientific and Research Center "KhAI MEDICA", Kharkiv, Ukraine) equipment in the abdominal lead for 30–60 minutes. The following HRV indicators were studied: STV (short-term variations), LTV (long-term variations), AC / DC (acceleration capacity / deceleration capacity), SI (stress index; SI = AMo (%) / (2 × Mo × Var); Var = NNmax – NNmin, where AMo is the most frequent NN interval in the tallest histogram column). AC / DC and SI indicators were assessed for both the fetus and the mother [7, 8]. The women were followed up, and data on delivery term, newborn weight, body length, head circumference, and Apgar scores were collected.

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS for Windows, version 25.0, Chicago, Illinois, USA). Results were presented as mean values with standard deviations for continuous variables and as percentages for categorical data. The nor-

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mality of continuous variable distribution was assessed using skewness values and histograms.

An independent t-test was used to compare continuous variables with normal distribution, while non-normally distributed variables were analyzed using the Mann–Whitney U test. The chi-square test (or Fisher's exact test) was used to compare categorical variables. Depending on distribution, Spearman or Pearson correlation analysis was applied to assess associations between continuous variables. Multivariate studies were conducted using logistic regression analysis with an input model. A p-value of less than 0.05 was considered statistically significant.

RESULTS AND DISCUSSION

The average age of the participants was 24.10 ± 5.80 years, and the mean gestational age at FECG registration was 30.15 ± 5.34 weeks. Fetal growth restriction (FGR) was diagnosed in 9 (23.10%) patients. There were no significant differences in maternal and fetal HRV indicators, delivery term, newborn anthropometric data, or Apgar scores depending on the method of delivery (Table 1).

Further analysis revealed correlations between the studied parameters (Table 2). A strong correlation was found between maternal HRV indicators: AC vs DC ($r = 0.96$; $p < 0.001$), AC vs SI ($r = –0.78$; $p < 0.001$), DC vs SI ($r = –0.83$; $p < 0.001$). Similarly, significant correlations were observed among fetal HRV indicators: AC vs DC ($r = 0.86$; $p < 0.001$), AC vs SI ($r = –0.65$; $p < 0.001$), AC vs STV ($r = 0.85$; $p < 0.001$), DC vs SI ($r = –0.63$; $p < 0.001$), DC vs STV ($r = 0.9$; $p < 0.001$), DC vs LTV ($r = 0.84$; $p < 0.001$). Additionally, a strong correlation was found between delivery term and newborn anthropometric parameters and Apgar scores: delivery term vs weight ($r = 0.85$; $p < 0.001$), delivery term vs body length ($r = 0.83$; $p < 0.001$), delivery term vs head circumference ($r = 0.68$; $p < 0.001$), and weight vs Apgar score ($r = 0.68$; $p < 0.001$).

Moderate correlations were observed between fetal AC / DC indicators and Apgar scores: AC vs Apgar score ($r = 0.34$; $p = 0.034$), DC vs Apgar score ($r = 0.37$; $p = 0.019$).

The results of the multivariate regression analysis of the model with the method of delivery did not reveal any association between the studied maternal and fetal

Table 1

Maternal and fetal HRV indicators, delivery term, anthropometric data, and Apgar scores of the examined group of women

Indicator, units	Methods of childbirth	Quantity	Minimum	Maximum	Mean ± standard deviation
AC maternal, ms	physiological childbirth	28	4.25	14.82	8.53 ± 2.90
	CS	11	4.44	9.91	8.05 ± 1.72, p = 0.61
DC maternal, ms	physiological childbirth	28	4.73	17.13	8.65 ± 3.04
	CS	11	4.53	11.49	8.21 ± 1.86, p = 0.66
AC of the fetus, ms	physiological childbirth	28	0.77	3.71	1.88 ± 0.63
	CS	11	1.33	2.73	1.77 ± 0.45, p = 0.60
DC of the fetus, ms	physiological childbirth	28	0.78	4.00	2.26 ± 0.80
	CS	11	1.33	3.46	2.01 ± 0.59, p = 0.35
SI maternal	physiological childbirth	28	48.00	457.00	177.18 ± 107.66
	CS	11	102.00	283.00	169.73 ± 57.52, p = 0.83
SI of the fetus	physiological childbirth	28	251.00	3102.00	1036.00 ± 633.08
	CS	11	448.00	2401.00	1065.91 ± 550.80, p = 0.89
STV, ms	physiological childbirth	28	1.20	13.00	6.90 ± 2.91
	CS	11	4.40	12.30	6.58 ± 2.25, p = 0.74
LTV, ms	physiological childbirth	28	9.30	71.00	35.51 ± 14.09
	CS	11	23.50	52.10	34.45 ± 9.52, p = 0.82
The term of childbirth, weeks	physiological childbirth	28	26.00	41.00	36.64 ± 3.55
	CS	11	30.00	40.00	36.09 ± 3.45, p = 0.66
Weight, gram	physiological childbirth	28	410.00	4000.00	2770.71 ± 897.20
	CS	11	820.00	5530.00	2971.82 ± 1449.32, p = 0.60
Body length, cm	physiological childbirth	28	27.00	58.00	48.54 ± 7.67
	CS	11	34.00	62.00	48.45 ± 9.76, p = 0.98
Head circumference, cm	physiological childbirth	28	19.00	36.00	32.61 ± 4.32
	CS	11	26.00	38.00	32.09 ± 3.96, p = 0.73
Apgar score on 1st minute	physiological childbirth	28	6.00	9.00	7.43 ± 2.33
	CS	11	5.00	9.00	6.73 ± 1.27, p = 0.35

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Table 2

Indicators of linear correlation between the studied parameters

Indicator, unit	r, p	AC maternal	DC maternal	AC of the fetus	DC of the fetus	SI maternal	SI of the fetus	STV	LTV	The term of childbirth	Weight	Body length	Head circumference	Apgar score
AC maternal, ms	r	1.00	0.96	0.02	–0.01	–0.78	0.09	–0.17	–0.18	–0.02	–0.21	–0.15	–0.16	–0.08
	p	–	< 0.001	0.89	0.95	< 0.001	0.52	0.30	0.28	0.91	0.20	0.35	0.33	0.64
DC maternal, ms	r	0.96	1.00	0.01	–0.02	–0.83	0.08	–0.16	–0.18	–0.04	–0.18	–0.13	–0.12	–0.07
	p	< 0.001	–	0.95	0.89	< 0.001	0.64	0.33	0.29	0.79	0.29	0.43	0.46	0.66
AC of the fetus, ms	r	0.02	0.01	1.00	0.86	–0.16	–0.65	0.85	0.84	0.22	0.06	0.16	0.23	0.34
	p	0.891	0.948	–	< 0.001	0.33	< 0.001	< 0.001	< 0.001	0.18	0.72	0.32	0.16	0.034
DC of the fetus, ms	r	–0.01	–0.02	0.86	1.00	–0.14	–0.63	0.90	0.84	0.20	0.05	0.15	0.21	0.37
	p	0.953	0.888	< 0.001	–	0.38	< 0.001	< 0.001	< 0.001	0.23	0.75	0.36	0.21	0.02
SI maternal	r	–0.78	–0.83	–0.16	–0.14	1.00	–0.07	0.01	0.07	0.04	0.04	0.07	–0.02	–0.03
	p	< 0.001	< 0.001	0.33	0.38	–	0.66	0.93	0.67	0.81	0.79	0.69	0.90	0.87
SI of the fetus	r	0.09	0.08	–0.65	–0.63	–0.07	1.00	–0.73	–0.80	–0.10	0.07	–0.09	–0.14	–0.24
	p	0.57	0.64	< 0.001	< 0.001	0.66	–	< 0.001	< 0.001	0.54	0.68	0.57	0.38	0.14
STV, ms	r	–0.17	–0.16	0.85	0.9	0.01	–0.73	1.00	0.96	0.1	0.02	0.14	0.20	0.28
	p	0.30	0.33	< 0.001	< 0.001	0.931	< 0.001	–	< 0.001	0.53	0.91	0.39	0.22	0.09
LTV, ms	r	–0.18	–0.18	0.84	0.84	0.07	–0.8	0.96	1.00	0.06	–0.03	0.10	0.16	0.23
	p	0.28	0.29	< 0.001	< 0.001	0.67	< 0.001	< 0.001	–	0.69	0.86	0.55	0.32	0.16
The term of childbirth, weeks	r	–0.02	–0.04	0.22	0.20	0.04	–0.10	0.10	0.06	1.00	0.85	0.83	0.68	0.73
	p	0.92	0.79	0.18	0.23	0.81	0.54	0.53	0.69	–	< 0.001	< 0.001	< 0.001	< 0.001
Weight, gram	r	–0.21	–0.18	0.06	0.05	0.04	0.07	0.02	–0.03	0.85	1.00	0.92	0.84	0.68
	p	0.20	0.29	0.72	0.75	0.79	0.68	0.91	0.86	< 0.001	–	< 0.001	< 0.001	< 0.001
Body length, cm	r	–0.15	–0.13	0.16	0.15	0.07	–0.09	0.14	0.10	0.83	0.92	1.00	0.85	0.74
	p	0.35	0.43	0.32	0.36	0.69	0.57	0.39	0.55	< 0.001	< 0.001	–	< 0.001	< 0.001
Head circumference, cm	r	–0.16	–0.12	0.23	0.21	–0.02	–0.14	0.20	0.16	0.68	0.84	0.85	1.00	0.72
	p	0.32	0.46	0.16	0.21	0.90	0.38	0.22	0.32	< 0.001	< 0.001	< 0.001	–	< 0.001
Apgar score on 1st minute	r	–0.08	–0.07	0.34	0.37	–0.03	–0.24	0.28	0.23	0.73	0.68	0.74	0.72	1.00
	p	0.64	0.66	0.03	0.02	0.87	0.14	0.09	0.16	< 0.001	< 0.001	< 0.001	< 0.001	–

HRV indicators, the delivery term, anthropometric parameters, or the Apgar score of the newborn (Table 3). Among other data obtained through logistic regression, a significant correlation was found between the Apgar score and newborn weight (p = 0.04), the Apgar score and head circumference (p = 0.04), and there was a trend towards correlation in the pairs: maternal AC vs weight (p = 0.05), maternal AC vs fetal body length (p = 0.05), fetal SI vs delivery term (p = 0.05). Data on the potential dependency between HRV indicators, which have a common nature, have no theoretical or practical significance.

The choice of delivery method remains a significant issue in modern obstetrics, especially with the substantial increase in cesarean section rates. The nonspecific nature of antenatal electronic fetal monitoring data, concerning the normal or compromised state of the fetus, and the multifactorial nature of decelerations during labor, have contributed to the increased rate of false-positive diagnoses of fetal distress [9]. This study identified a moderate correlation between fetal HRV indicators derived from phase-rectified signal analysis – AC / DC – and the Apgar score. Currently, there are some results from the implementation of acceleration and deceleration capacity indicators in diagnosing fetal distress [10]. Thus, the problem in diagnosing fetal distress lies in selecting the correct criteria to assess the fetal condition. In our study, no correlation was found between fetal electronic monitoring parameters and the method of delivery. This indicates that the appropriate diagnostics can help exclude or minimize false-positive results of fetal distress.

The logistic regression data provide hope for future research on the role of maternal AC in diagnosing FGR, as well as fetal SI as a marker of neurological maturation and a criterion for fetal condition. The role of maternal autonomic nervous regulation in ensuring ergotropic and trophotropic reactions of the fetus has been known for

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Table 3

Logistic regression model for delivery method

Variable	Coefficient B	Standard error	Z (the No. of standard deviations from the mean of a given distribution)	p	Correlation chances	95% trustworthy interval
Constant	–20.79	16.65	1.25	0.21	0	0–137489.89
AC maternal	–0.24	0.63	0.37	0.71	0.79	0.23–2.72
DC maternal	0.34	0.64	0.54	0.59	1.41	0.4–4.89
AC of the fetus	–0.43	1.97	0.22	0.82	0.65	0.01–31.01
DC of the fetus	3.34	2.04	1.64	0.10	28.28	0.52–1532.67
SI maternal	0	0.01	0.53	0.59	1.00	0.99–1.02
SI of the fetus	0	0	0.69	0.49	1.00	1.00–1.00
STV	–0.78	0.74	1.06	0.28	0.46	0.11–1.95
LTV	–0.02	0.12	0.17	0.86	0.98	0.78–1.23
The term of childbirth	0.30	0.44	0.67	0.50	1.34	0.56–3.20
Weight	0	0	1.6	0.11	1.00	0.99–1.00
Body length	0.17	0.25	0.66	0.50	1.18	0.72–1.93
Head circumference	0.26	0.42	0.62	0.53	1.30	0.57–2.94
Apgar score	0.04	0.55	0.07	0.94	1.04	0.35–3.05

quite some time [11, 12]. The association between fetal HRV indicators and newborn biometric parameters is also well-documented [13]. The use of HRV indicators for FGR screening has been proposed [14, 15], though reliable criteria for establishing a system of remote monitoring of fetal nutritional and digestive disorders based on HRV data are still lacking [16, 17].

Synchronization of maternal and fetal heart activity and HRV indicators is characteristic of physiological pregnancy [18, 19]. The placenta acts as an intermediary in hemodynamic processes within the fetoplacental system. This study found no correlation between maternal and fetal HRV indicators, likely due to the high rate of placental dysfunction (FGR) in the examined cohort. Placental dysfunction impairs the transmission of maternal hemodynamic oscillations – maternal HRV – to the fetus [20, 21]. Adverse perinatal outcomes are associated with the impact of maternal inflammation mediators and oxidative stress on the fetal autonomic nervous system [22]. Remote monitoring based on non-invasive FECG allows for long-term recordings and assessment of maternal and fetal HRV parameters [23]. The advantages of FECG over ultrasound fetal assessment methods should also be highlighted. FECG is completely neutral due to the absence of any impact on the fetus, and it is cost-effective and requires no specially trained personnel for its use, which is particularly important in wartime conditions in Ukraine [24, 25].

Among the limitations of this study are the small sample size and the single-center design.

CONCLUSIONS

Electronic monitoring using non-invasive FECG did not influence the choice of delivery method, supporting the potential for developing remote fetal monitoring systems.

Conflict of interest. The authors declare no conflict of interest.

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