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SHORT REPORT

Computer analysis of maternal–fetal heart rate recordings during labor in relation with maternal–fetal attachment and prediction of newborn acidemia

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Abstract

Objective: To assess combined maternal (MHR) and fetal heart rate (FHR) recordings during labor, in relation with maternal–fetal attachment and prediction of newborn acidemia.
Study design: Fifty-nine simultaneous MHR and FHR recordings were acquired in the final minutes of labor. Computer analysis followed the FIGO guidelines with estimation of MHR and FHR baselines, accelerations, decelerations, short- (STV) and long-term variabilities. MHR and FHR characteristics, their differences and correlations were assessed in relation to labor progression and to newborn umbilical artery blood (UAB) pH lower than 7.15 and 7.20. To assess prediction of acidemia, areas under ROC curves (auROC) were calculated.
Results: Progression of labor was associated with a significant increase in MHR accelerations and FHR decelerations both in the non-acidemic and acidemic fetuses ($p < 0.01$). At the same time there was an increase in MHR–FHR correlations and differences in accelerations and decelerations in acidemic fetuses. The auROC ranged between 0.50 for FHR accelerations and 0.77 for MHR baseline plus FHR STV.
Conclusions: MHR and FHR respond differently during labor with signs of increased maternal–fetal attachment during labor progression in acidemic fetuses. Combined MHR–FHR analysis may help to improve prediction of newborn acidemia compared with FHR analysis alone.

Keywords

Attachment, cardiotocography, computer analysis, fetal heart rate, FIGO guidelines, maternal heart rate, prediction

History

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Introduction

There is scarce information about maternal (MHR) and fetal heart rate (FHR) interaction during labor and research has mainly focused on the misidentification of MHR as FHR [1,2].

Some studies have assessed the relationship between maternal pathological conditions and neonatal mother–infant attachment [3], as well as the underlying physiopathological pathways [4], keeping in mind the importance of this for the future development of the child [5]. There is also evidence of increased heart rate variability correlation between mother and child immediately after pre-operation [6]. However, to our knowledge, these aspects have never been assessed in relation to labor progression. Moreover, combined analysis of MHR and FHR recordings [1] in the prediction of newborn acidemia has also never been explored.

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In this study, we explore the evolution of simultaneous MHR and FHR recordings during labor in relation to the maternal–fetal attachment concept [3,4] and the prediction of newborn acidemia.

Material and methods

The study followed the Helsinki Declaration, was approved by the local Ethics Committee and all women gave their informed consent to participate.

Fifty-nine 100 min simultaneous MHR and FHR recordings, with good signal quality, consecutively acquired by the same researcher, were obtained from uneventful singleton pregnancies, with fetuses in cephalic presentation, until a maximum of 10 min before a vaginal delivery or 30 min before a caesarean birth. As the study was exploratory from its outset, implying the implementation of a MHR–FHR monitoring protocol not used in clinical practice, and limited resources to do it, a pragmatic population selection was adopted based on a previous study on FHR analysis alone [7].

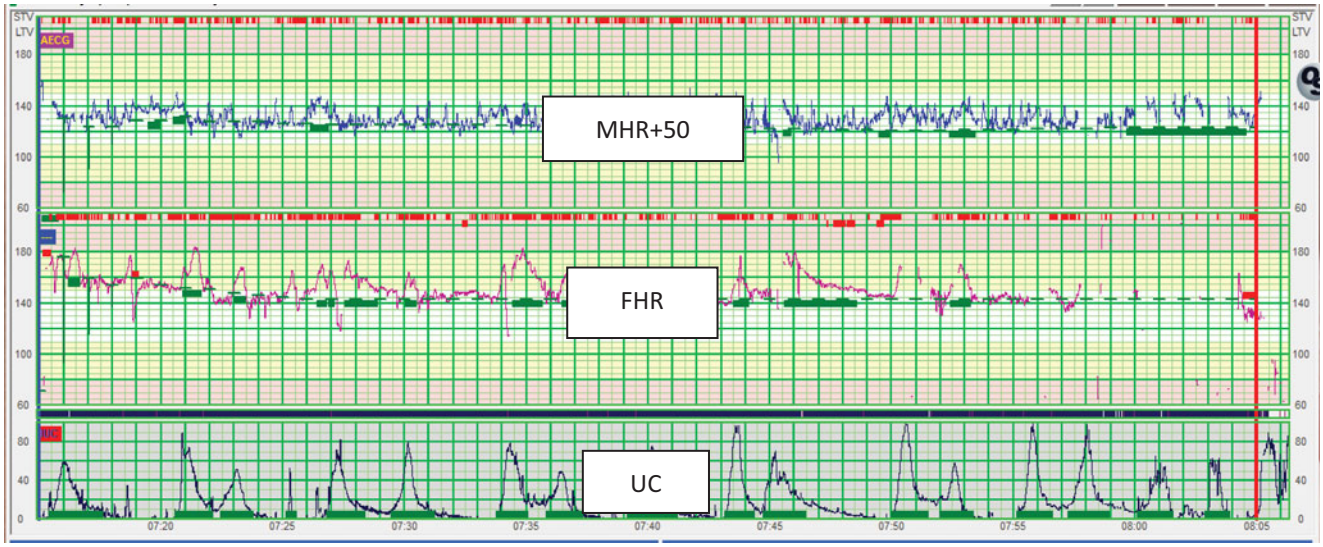

Figure 1. Example of a computer analysis of a simultaneous maternal (MHR), fetal heart rate (FHR) and uterine contraction (UC) recording, as displayed by the Omniview-SisPorto system. MHR is displayed plus 50 beats per minute (MHR + 50). Accelerations and UC are depicted with green bars underneath and deceleration with red bars on top, in colour prints, or just gray bars, in black and white prints. For further explanations please see text and reference [1].

For acquisition and analysis of MHR and FHR signals a specially conceived system, following the FIGO guidelines [8], was used, based on the Omniview-SisPorto® system (Speculum, Lisbon, Portugal) described in detail elsewhere [1]. In short, MHR signals were obtained *via* an electrocardiography (ECG) sensor connected to the maternal thorax, while for the FHR signals an ultrasound sensor was placed on the maternal abdomen [1]. Both MHR and FHR sensors were connected to a conventional STAN® 31 fetal monitor (Neoventa Medical, Gothemburg, Sweden) coupled to the Omniview-SisPorto® system. Computer analysis (Figure 1) included the estimation of signal loss (SL), abnormal short-term variability (STV), baseline, abnormal long-term variability (LTV), accelerations, decelerations and uterine contractions. STV was determined as the difference between two adjacent MHR beats and considered abnormal when lower than 1 beat per minute (bpm). MHR and FHR baselines were estimated using complex algorithms based on histogram and STV analysis. Accelerations and decelerations were detected as sharp deviations above or below baselines, with at least 15 bpm amplitude and 15 s duration. LTV was estimated, in segments not displaying accelerations or decelerations, as the difference between the highest and lowest values in a sliding window of one minute and was classified as abnormal when under 5 bpm [1,8].

FHR baseline has been associated with the intrinsic fetal cardiac chronotropic activity, under basal, central and autonomic, nervous system activities, while STV and LTV reflect the continuous, basal and active, balance between the mentioned nervous activities; accelerations are associated with fetal behavioural states and sympathetic activity and decelerations with parasympathetic activity, generally elicited by chemo or baroreceptor stimulation [8]. MHR baseline, STV, LTV, accelerations and decelerations may be observed in similar situations, as the ones described for FHR, but, to our knowledge, these MHR variables have only been scarcely assessed before [1,9].

Table 1. Main maternal and fetal characteristics of the studied population in relation to the newborn umbilical artery blood pH ≥7.20 or <7.20 (non-acidemic and acidemic fetuses, respectively).

	Non-acidemic fetuses $n = 45$	Acidemic fetuses $n = 14$	p
Maternal data			
Age (years) mean (sd)	27 (5)	27 (6)	0.680
Multipara n (%)	13 (29)	3 (21)	0.738
Gestational age (weeks) mean (sd)	39 (1)	39 (1)	0.119
Delivery: n (%)			1.000
Vaginal	32 (71)	10 (71)	
Operative vaginal	8 (18)	3 (21)	
Cesarean section	5 (11)	1 (7)	
Epidural analgesia n (%)	43 (96)	14 (100)	1.000
Newborn data			
Birthweight (g) mean (sd)	3241 (340)	3200 (292)	0.682
1 min Apgar score med (min–max)	9 (9–7)	9 (8–10)	0.143
5 min Apgar score med (min–max)	10 (9–10)	10 (9–10)	0.563
Umbilical artery blood pH mean (sd)	7.276 (0.044)	7.146 (0.052)	**<0.001**
Male gender n (%)	27 (60)	7 (50)	0.508

p Values under 0.05 are presented in bold.

Individual MHR and FHR characteristics, their differences and correlations were assessed in relation to labor progression and to the newborn umbilical artery blood (UAB) pH.

The main maternal and fetal characteristics were described using means and standard deviations, medians and ranges or frequencies, as appropriate (Table 1). Mann–Whitney tests, t-tests or Chi-square tests were used to compare the non-acidemic with acidemic fetuses (Tables 1 and 2) and paired sample t-tests or Wilcoxon rank signed tests to compare the first and the last 50 recording minutes (Table 2). Mean differences between FHR and MHR values were presented with 95% confidence intervals and MHR–FHR correlations were calculated using the Pearson or Spearman correlation

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Table 2. Maternal (MHR) and fetal heart rate (FHR) variables, during the last two periods of 50 min of labor, in fetuses delivered with umbilical artery blood pH ≥7.20 (non-acidemic) and <7.20 (acidemic).

	First 50 min				Last 50 min					
	MHR		FHR		MHR		FHR			
	Non-acidemic	Acidemic	Non-acidemic	Acidemic	Non-acidemic	Acidemic	Non-acidemic	Acidemic	*p* First versus Last Minutes	*p* Non-acidemic versus acidemic
Baseline mean (sd)	132 (14)	128 (10)	142 (9)	137 (12)	135 (13)	129 (11)	140 (10)	139 (15)		
Accelerations total med (m–M)	8 (0–31)	7 (1–22)	5 (0–24)	5 (0–17)	11 (0–34)	14 (2–23)	5 (0–21)	4.5 (1–22)	1,2	
Decelerations total med (m–M)	0 (0–2)	0 (0–20)	3 (0–18)	4 (0–10)	0 (0–8)	0 (0–3)	5.5 (0–16)	5.5 (3–20)	3	
STV < 1 mean (sd)	32 (12)	26 (10)	48 (10)	40 (8)	31 (10)	26 (10)	44 (11)	37 (8)	3	b,d
LTV < 5 med (m–M)	0 (0–78)	0 (0–0)	5 (0–28)	0 (0–29)	0 (0–25)	0 (0–0)	1.5 (0–21)	1.5 (0–9)	3	b
Accelerations med (m–M)										
10 min S1 (FCM1 or FCF1)	1 (0–7)	1 (0–5)	1 (0–6)	1 (0–6)	1 (0–8)	1 (0–4)	1 (0–6)	1 (0–6)		
10 min S2 (FCM2 or FCF2)	2 (0–6)	0 (0–3)	0.5 (0–7)	1.5 (0–6)	2 (0–7)	1.5 (0–7)	0.5 (0–6)	1 (0–4)	2	a
10 min S3 (FCM3 or FCF3)	1 (0–6)	2 (0–4)	0 (0–6)	1 (0–5)	2 (0–8)	3.5 (0–6)	1 (0–5)	0.5 (0–4)	1	
10 min S4 (FCM4 or FCF4)	2 (0–9)	1.5 (0–7)	1 (0–6)	0.5 (0–4)	2 (0–8)	3 (0–6)	0 (0–6)	1 (0–4)	1	
10 min S5 (FCM5 or FCF5)	2 (0–7)	1.5 (0–6)	0 (0–4)	0.5 (0–6)	3 (0–7)	3.5 (1–6)	0 (0–5)	0.5 (0–5)	1,2	
Decelerations med (m–M)										
10 min S1 (FCM1 or FCF1)	0 (0–2)	0 (0–1)	0 (0–5)	0 (0–4)	0 (0–5)	0 (0–1)	0 (0–3)	1 (0–3)		
10 min S2 (FCM2 or FCF2)	0 (0–1)	0 (0–0)	–	–	0 (0–3)	0 (0–1)	0 (0–4)	1 (0–3)		
10 min S3 (FCM3 or FCF3)	0 (0–1)	0 (0–0)	0 (0–6)	1 (0–3)	0 (0–1)	0 (0–2)	1 (0–6)	1 (0–8)	3	b
10 min S4 (FCM4 or FCF4)	0 (0–1)	0 (0–0)	0 (0–5)	0 (0–2)	0 (0–2)	0 (0–1)	1 (0–5)	1.5 (0–5)	4	
10 min S5 (FCM5 or FCF5)	0 (0–1)	0 (0–0)	1 (0–7)	1 (0–3)	0 (0–1)	0 (0–1)	2 (0–5)	1 (0–3)	3	

Means (standard deviations) or medians (minimum–maximum) are presented as appropriate.
[a]Significant *p* value for $MHR_{acidemic}$ versus $MHR_{non\text{-}acidemic}$ (first 50 min).
[b]Significant *p* value for $MHR_{acidemic}$ versus $MHR_{non\text{-}acidemic}$ (last 50 min).
[c]Significant *p* value for $FHR_{acidemic}$ versus $FHR_{non\text{-}acidemic}$ (first 50 min).
[d]Significant *p* value for $FHR_{acidemic}$ versus $FHR_{non\text{-}acidemic}$ (last 50 min).
[e]Significant *p* value for $MHR_{first\ 50\,min}$ versus $MHR_{last\ 50\,min}$ (non-acidemic).
[f]Significant *p* value for $MHR_{first\ 50\,min}$ versus $MHR_{last\ 50\,min}$ (acidemic).
[g]Significant *p* value for $FHR_{first\ 50\,min}$ versus $FHR_{last\ 50\,min}$ (non-acidemic).
[h]Significant *p* value for $FHR_{first\ 50\,min}$ versus $FHR_{last\ 50\,min}$ (acidemic).

J Matern Fetal Neonatal Med, Early Online: 1–5

Table 3. Mean differences and correlations (with 95% confidence intervals) between maternal (MHR) and fetal heart rate (FHR) variables, during the last two 50-min periods of labor, in fetuses delivered with umbilical artery blood pH ≥7.20 (non-acidemic) and <7.20 (acidemic).

	First 50 min				Last 50 min			
	Mean MHR–FHR		r FHR, MHR		Mean MHR–FHR		r FHR, MHR	
	Non-acidemic	Acidemic	Non-acidemic	Acidemic	Non-acidemic	Acidemic	Non-acidemic	Acidemic
Baseline	**−9 [−15, −4]**	**−9 [−16, −1]**	−0.01 [−0.30, 0.26]	0.26 [−0.15, 0.65]	−5 [−11, 0]	−9 [−22, 3]	0.01 [−0.27, 0.28]	−0.40 [−0.84, 0.44]
Accelerations total	**3 [1,5]**	1 [−3, 5]	0.13 [−0.16, 0.42]	0.12 [−0.50, 0.76]	**6 [3,9]**	**6 [3,10]**	0.09 [−0.19, 0.39]	**0.58 [0.10, 0.89]**
Decelerations total	**−4 [−5, −2]**	−3 [−7, 1]	0.13 [−0.13, 0.38]	−0.30 [−0.67, 0.15]	**−5 [−6, −4]**	**−6 [−9, −4]**	0.38 [−0.12, 0.60]	**0.55 [0.14, 0.90]**
STV < 1	**−16 [−20, −11]**	**−14 [−21, −7]**	−0.05 [−0.34, 0.28]	0.08 [−0.38, 0.55]	**−13 [−18, −8]**	**−11 [−18, −4]**	−0.09 [−0.36, 0.21]	0.09 [−0.69, 0.71]
LTV < 5	−4 [−8, 0]	−3 [−8, 1]	−0.02 [−0.23, 0.19]	–	−2 [−5, 0]	**−2 [−4, −1]**	−0.02 [−0.29, 0.25]	–
Accelerations								
10 min S1	0.0 [−0.7, 0.6]	0.4 [−0.6, 1.4]	−0.01 [−0.33, 0.29]	0.21 [−0.40, 0.71]	−0.1 [−0.8, 0.6]	−0.1 [−1.5, 1.2]	−0.03 [−0.34, 0.30]	−0.10 [−0.63, 0.49]
10 min S2	**−0.9 [−1.5, −0.2]**	0.6 [−0.5, 1.8]	**0.35 [0.09, 0.61]**	0.05 [−0.48, 0.61]	**−1.0 [−1.8, −0.2]**	−1.1 [−2.2, 0.1]	0.02 [−0.28, 0.29]	0.22 [−0.34, 0.73]
10 min S3	**−0.7 [−1.4, −0.1]**	−0.6 [−1.8, 0.7]	**0.30 [0.01, 0.55]**	−0.13 [−0.71, 0.51]	**−1.2 [−1.9, −0.5]**	**−1.4 [−2.8, −0.1]**	0.25 [−0.05, 0.52]	0.39 [−0.25, 0.82]
10 min S4	−0.6 [−1.3, 0.1]	−0.8 [−2.5, 0.8]	0.11 [−0.18, 0.41]	−0.37 [−0.76, 0.14]	**−1.6 [−2.3, −1.0]**	**−1.5 [−2.5, −0.4]**	0.13 [−0.14, 0.41]	**0.58 [0.18, 0.84]**
10 min S5	**−1.0 [−1.7, −0.4]**	−0.6 [−1.9, 0.7]	0.09 [−0.21, 0.41]	0.27 [−0.28, 0.75]	**−2.3 [−3.1, −1.5]**	**−2.4 [−3.6, −1.3]**	−0.21 [−0.50, 0.09]	0.13 [−0.47, 0.70]

Results different from zero with statistical significance are presented in bold.

Table 4. Areas under the ROC curves (auROC) for prediction of umbilical artery blood pH <7.20, considering the last 50 min of FHR and MHR recordings.

	auROC [95%CI]
Univariate analysis	
FHR	
Baseline	0.51 [0.30, 0.71]
Accelerations	0.50 [0.33, 0.67]
Decelerations	0.53 [0.36, 0.69]
STV < 1	**0.71 [0.55, 0.86]**
LTV < 5	0.51 [0.35, 0.67]
MHR	
Baseline	0.63 [0.46, 0.79]
Accelerations	0.57 [0.40, 0.73]
Decelerations	0.51 [0.34, 0.68]
STV < 1	0.65 [0.48, 0.82]
LTV < 5	0.58 [0.42, 0.74]
Bivariate analysis	
FHR baseline and STV < 1	**0.71 [0.56, 0.86]**
MHR baseline and STV < 1	**0.68 [0.51, 0.85]**
MHR and FHR accelerations	0.53 [0.35, 0.70]
MHR and FHR decelerations	0.54 [0.39, 0.69]
FHR and MHR STV < 1	**0.77 [0.63, 0.92]**
MHR baseline and FHR STV < 1	**0.77 [0.63, 0.90]**

The highest auROC are presented in bold.

coefficients with 95% confidence intervals (Table 3). To assess the prediction of acidemia, areas under ROC curves (auROC) with 95% confidence intervals were calculated, using uni- and bivariate logistic regression, considering the FHR or/and MHR baselines, accelerations, decelerations, STV < 1 and LTV < 5, obtained during the last 50 recording minutes (Table 4). Statistical significance was set at p values <0.05.

Given the small number of cases with low UAB pH values, we considered the relatively high, but still clinically significant, UAB pH thresholds of 7.20 and 7.15 [10].

Results

In Table 1, the main maternal and fetal characteristics of the studied population are presented, comprising fetuses born with UAB pH > or <7.20, which were statistically similar, except in the mean UAB pH. Similar results were obtained considering UAB pH <7.15, but only six cases presented an UAB pH below that value.

In Tables 2 and 3, the individual MHR and FHR characteristics, their differences and correlations are presented, in relation to labor progression and to newborn UAB pH > or <7.20.

Progression of labor was associated with a significant increase of MHR accelerations and FHR decelerations, both in the non-acidemic and acidemic fetuses, as well as to a decrease in FHR STV (Table 2). At the same time, in the non-acidemic fetuses, there was a decrease of statistically significant MHR–FHR correlations, regarding the number of accelerations, as well as an increase in the number of significant differences from zero (Table 3). On the other hand, in the acidemic fetuses, there was a modest, but significant, increase in the number of MHR–FHR correlations, regarding the number of accelerations (from $r = 0.12$, $p > 0.05$ to $r = 0.58$, $p < 0.05$) and decelerations (from $r = -0.30$,

$p > 0.05$ to $r = 0.55$, $p < 0.05$), as well as of increase in the number of significant differences from zero (Table 3). Similar results were obtained considering UAB pH <7.15, but with less situations attaining statistical significance, in relation with the lower number of cases under the UAB pH threshold.

In the last 50 min of labor, the auROC for MHF and FHR features in the prediction of newborn acidemia ranged from 0.50 (95% CI: 0.33–0.67) for FHR accelerations to 0.77 (95% CI: 0.63–0.90) for MHR baseline plus FHR STV < 1 (Table 4), considering the UAB pH threshold of 7.20, and from 0.51 (95% CI: 0.30–0.73) for FHR LTV < 5 to 0.70 (95% CI: 0.45–0.96) for MHR baseline plus FHR STV <1, considering the UAB pH threshold of 7.15.

Comment

In this study, the interaction between MHR and FHR recordings during labor was analysed for the first time in relation to labor progress and prediction of newborn acidemia.

Progression of labor was associated to a significant increase of MHR accelerations and FHR decelerations, as well as to a decrease in FHR STV, both in the non-acidemic and acidemic fetuses. This is consistent with previous reports pertaining to pregnancies with normal outcomes [1,9], as well as with isolated reports on FHR [7,11]. To our knowledge, there are no similar reports pertaining to the acidemic fetuses.

Progression of labor was also associated, in the non-acidemic fetuses, to a decrease in the number of significant MHR–FHR correlations regarding the number of accelerations and with an increase in the number of significant differences from zero (Table 3). On the other hand, in the acidemic fetuses, there was an increase in the number of significant MHR–FHR correlations, regarding both the number of accelerations and decelerations, as well as of increase in the number of significant differences from zero (Table 3). This suggests that during progression of labor in the non-acidemic fetuses, the mother and the fetus react to physiological stimulus with different amplitudes while keeping their autonomy, whereas situations of fetal acidemia the fetus tends to loose its autonomy, evidencing signs of more intense maternal–fetal attachment. To our knowledge, this finding has not been previously reported, but is consistent with the increased mother–infant attachment observed in stressful maternal–fetal and mother–infant situations [3–6]. This is also consistent with an increased secretion of oxytocin as labor progresses, one of the hormones that has been linked with mother–infant attachment, namely during breastfeeding [4,5]. This suggests that maternal–fetal attachment may be a way to protect fetuses that are born acidemic and one that may be important to consider for subsequent child survival and future development [5].

The capacity of isolated FHR or MHR analysis to predict newborn acidemia was relatively limited and similar with the ones reported in other studies on this topic using FHR analysis alone [7,11], but combined analysis of MHR and FHR may improve it (Table 4). If these results are confirmed in larger studies, they may signify that combined analysis will be the way forward for intrapartum monitoring. To our knowledge, there are no other studies evaluating combined MHR and FHR analysis in this context.

The results of this study need to be interpreted with caution as they pertain to a small number of fetuses with a mildly low UAB pH [10]. Further studies are necessary to confirm these findings, perhaps using easier ways of simultaneous MHR–FHR recording, namely oximetry for MHR and internal electrocardiography for FHR, or transabdominal ECG for the extraction of MHR and FHR signals [12].

Declaration of interest

Diogo Ayres de Campos and João Bernardes have been involved in the development of Omniview-SisPorto system. Royalties are fully converted to institutional research funds.

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