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Development and evaluation of an algorithm for computer analysis of maternal heart rate during labor

Paula Pinto [a,b], João Bernardes [b,c,d,*], Cristina Costa-Santos [b,d], Célia Amorim-Costa [b,e], Maria Silva [a], Diogo Ayres-de-Campos [b,c,e]

[a] *Nélio Mendonça Hospital, Funchal, Portugal*
[b] *School of Medicine, University of Porto, Portugal*
[c] *São João Hospital Porto, Portugal*
[d] *CINTESIS – Centre for Research in Technologies and Health Information Systems, Porto, Portugal*
[e] *INEB – Institute of Biomedical Engineering, Porto, Portugal*

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ABSTRACT

Background: Maternal heart rate (MHR) recordings are morphologically similar and sometimes coincident with fetal heart rate (FHR) recordings and may be useful for maternal–fetal monitoring if appropriately interpreted. However, similarly to FHR, visual interpretation of MHR features may be poorly reproducible.
Methods: A computer algorithm for on-line MHR analysis was developed based on a previously existing version for FHR analysis. Inter-observer and computer-observer agreement and reliability were assessed in 40 one-hour recordings obtained from 20 women during the last 2 h of labor. Agreement and reliability were evaluated for the detection of basal MHR, long-term variability (LTV), accelerations and decelerations, using proportions of agreement (PA) and Kappa statistic (K), with 95% confidence intervals (95% CI). Changes in MHR characteristics between the first and the second hour of the tracings were also evaluated.
Results: There was a statistically significant inter-observer and computer-observer agreement and reliability in estimation of basal MHR, accelerations, decelerations and LTV, with PA values ranging from 0.72 (95% CI: 0.62–0.79) to 1.00 (95% CI: 0.99–1.00), and K values ranging from 0.44 (95% CI: 0.28–0.60) to 0.89 (95% CI: 0.82–0.96). Moreover, basal MHR, number of accelerations and LTV were significantly higher in the last hour of labor, when compared to the initial hour.
Discussion: The developed algorithm for on-line computer analysis of MHR recordings provided good to excellent computer-observer agreement and reliability. Moreover, it allowed an objective detection of MHR changes associated with labor progression, providing more information about the interpretation of maternal–fetal monitoring during labor.

1. Introduction

Maternal heart rate (MHR) can be misinterpreted as that of the fetus, a problem that is still common and important during labor [1–6], both when external (ultrasound) or internal (electrocardiographic) fetal heart rate (FHR) recording methods are used [7]. This may have an important clinical impact as in a recent case series of 41 twin deliveries, where the second twin was born acidemic, 10% of the cases of MHR monitoring were missed by visual analysis [6].

There is also recent evidence that MHR evaluation during pregnancy and in labor may provide useful pathophysiological information on the maternal–fetal clinical state, namely in assessment of hypertensive pregnancy conditions [8,9], gestational diabetes [10], pre-term and term labor diagnosis [11] or labor analgesia [12].

However, it seems that visual analysis of MHR recordings is subject to poor observer agreement and reliability [13], as with FHR analysis [14,15], explaining why some authors report MHR decelerations during labor [16] while others report accelerations [17]. Moreover, visual analysis may not be sufficiently precise to allow an understanding of the complexity of maternal–fetal pathophysiological interactions [18–20]. Computer analysis could help to overcome the limitations and subjectivity of visual analysis [13], to identify MHR recordings misinterpreted as that of the fetus

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[*] Correspondence to: Departamento de Obstetrícia e Ginecologia, Faculdade de Medicina da Universidade do Porto, Al. Hernâni Monteiro, 4200-319 Porto, Portugal. Tel.: +351 961043547.
E-mail address: jbernardes59@gmail.com (J. Bernardes).

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[1–6] and to improve monitoring of the overall maternal–fetal condition.

In this paper, we describe the development of a new algorithm for computer analysis of MHR during labor, based on an existing and tested model for FHR analysis [21–25], following the evidence that MHR recordings are morphologically similar and sometimes coincident with FHR recordings [17]. To our knowledge, no other computer algorithms have been developed for combined on-line analysis of MHR and FHR during labor.

2. 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. Forty simultaneous recordings of MHR and FHR were obtained from 20 women in the last two hours of labor. The average maternal age was 28.7 (SD: 4.9) years and the average gestational age 39.2 (SD:0.9) weeks. Thirteen women were nulliparous, two underwent a cesarean section and all but one were under epidural analgesia. The average one and five minute Apgar scores were, respectively, 9.4 (SD:0.5) and 9.9 (SD:0.3), and the average umbilical artery blood pH was 7.23 (SD:0.8).

For acquisition of the MHR and FHR signals a conventional STAN® 31 fetal monitor (Neoventa Medical, Gothemburg, Sweden) was used. The STAN® 31 fetal monitor has two sockets for heart rate acquisition, one for an electrocardiography sensor and another for an ultrasound sensor. MHR was acquired with an electrocardiography sensor connected to three electrodes on the maternal thorax, while FHR was acquired with an ultrasound sensor placed in the abdomen (as usually performed in clinical practice), both connected to the STAN® 31 fetal monitor (Neoventa Medical, Gothemburg, Sweden). This monitor was connected, *via* a standard computer cable to the Omniview-SisPorto® system for computer analysis of FHR tracings (Speculum, Lisbon, Portugal), using a RS232 or RS485 protocol and a computer program developed in Visual Basic, running under a Microsoft Windows environment [22,23].

Computer analysis of MHR recordings was performed using a specifically developed algorithm (Fig. 1), based on the Omniview-SisPorto® algorithms for FHR analysis, also following the FIGO guidelines for fetal monitoring [23,26]. In short, MHR signals conveyed from the fetal monitor at 4 Hz, underwent a scale conversion obtained by adding 50 beats/min (bpm) to the original MHR values, except when these values were equal to zero. After that, they were subjected to a pre-processing algorithm, for removal of noise and calculation of signal loss and signal quality. Short-term variability (STV) was determined as the difference between two adjacent MHR beats and considered abnormal when lower than 1 bpm. After that, basal MHR was estimated, using a complex algorithm based on histogram and STV analysis [21,22,27]. Accelerations and decelerations were subsequently detected as MHR deviations, above or below baseline, with at least 15 bpm amplitude and 15 s duration. Finally, 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 <5 bpm [21,22,27] (Figs. 1 and 2).

Visual analysis of basal MHR, long-term variability (LTV), accelerations and decelerations was also performed by three expert clinicians with a special interest in the field. Experts analyzed tracings independently and with no knowledge of each other's or the computer's evaluation. For visual analysis, the FIGO guidelines were closely followed [26] with the needed scale adaptations (Figs. 2 and 3). In short, basal MHR was defined as the mean of the lowest stable segment(s) lasting at least 2 min, preferably with a LTV less than 15 bpm and a mean value within 60–100 bpm. LTV was defined as the difference, in bpm, between the highest peak and lowest trough, in a 1-min segment of baseline oscillations. Accelerations and decelerations were defined as transient increases or decreases in MHR, in relation to the baseline, of at least 15 bpm of amplitude and lasting 15 s or more [26].

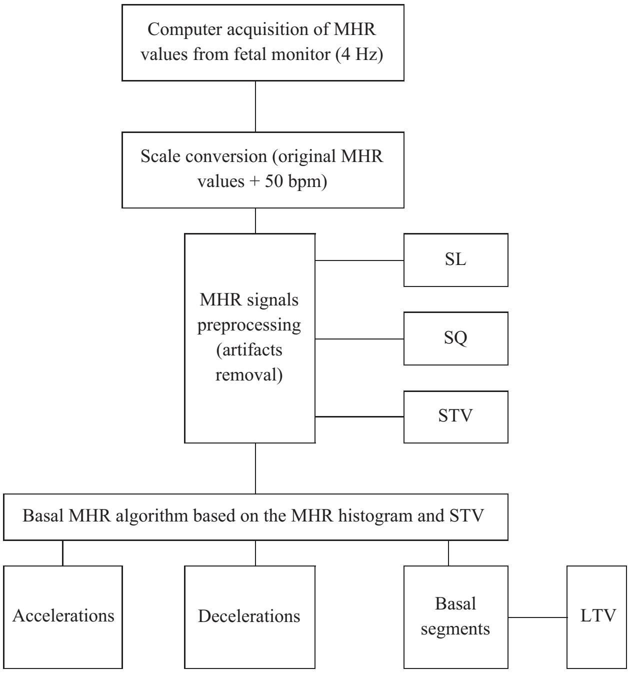

Fig. 1. Schematic representation of the novel maternal heart rate (MHR) processing algorithm. SL: signal loss; SQ: signal quality; STV: short-term variability; and LTV: long-term variability.

Agreement, reliability and correlation among experts and between the majority of experts and the computer were assessed in one hour segments for basal MHR and LTV, and in 10 min segments for accelerations and decelerations, with the proportions of agreement (PA), Light's Kappa statistic (K), calculated with 95% bootstrap confidence intervals (95% CI) [28,29], and the Kendall's tau correlation coefficient, respectively (Tables 1 and 2, and Fig. 3).

For each MHR segment, three trials of agreement, reliability and correlation among experts (1 *versus* 2, 1 *versus* 3 and 2 *versus* 3) and one trial between the majority of experts and the computer were considered. For assessment of agreement and reliability in basal MHR estimation, concordant evaluations were considered when the difference in estimations was equal to or less than 5 bpm [30]. LTV was categorized as normal (1), when ≥ 5 bpm, and abnormal (0) when inferior to this. Accelerations and decelerations were categorized as sporadic (0–1/10 min) or repetitive ($>1/10$ min). For a better explanation of the procedure a case-example is provided in Table 1 and Fig. 3. Experts 1, 2 and 3 assigned basal MHR as 90, 90 and 100 beats/min (bpm), respectively; there was agreement between experts 1 *versus* 2 (in the 90–94 bpm category) and disagreement between observers 1 *versus* 3 and 2 *versus* 3 (in the 90–94 and 100–104 bpm categories). On the other hand, the majority of experts and the computer assigned basal MHR as 90 and 92 bpm, respectively; there was agreement between them (both in the 90–94 bpm category). Experts 1, 2, 3 and their majority, as well as the computer, assigned LTV as normal (category 1); there was agreement between experts 1 *versus* 2, 1 *versus* 3 and 2 *versus* 3, as well as between the experts majority *versus* the computer. Experts 1, 2, 3 and their majority, as well as the computer, assigned all accelerations as repetitive and all decelerations as sporadic (except in the 10 min segment number 3, where expert 2 assigned repetitive decelerations); there was agreement between experts 1 *versus* 2, 1 *versus* 3 and 2 *versus* 3, as well as between the experts majority *versus* the computer (except