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Short-term Heart Rate Dynamics of Women During Labor

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Abstract— **We studied 10 minutes segments of heartbeat interval fluctuations from 18 young women in labor with normal outcome of pregnancy. Data of each studied case were classified into two distinct groups. One group involving segments where the uterine activity was observable (three or more contractions in ten minutes), and the other group of reference having segments with fewer uterine activity or not presenting contractions at all. For comparison, we also included segments collected during the last trimester of gestation prior to labor from a third group of women. Corresponding RR interval series were analyzed to estimate RR_{mean}, RMSSD, α_1, $\alpha_{1(MAG)}$ and $\alpha_{1(SIGN)}$ parameters. No significant differences among groups were identified in RMSSD, α_1 and $\alpha_{1(MAG)}$. Nevertheless, $\alpha_{1(SIGN)}$ did present significant differences in comparison with the last trimester results ($p<0.007$), revealing a subtle change in the temporal organization of maternal RR series during labor. Results of these parameters then suggest that during labor, despite preserving a concomitant non-linear influence, the maternal short-term autonomic cardiac regulation behaves with less antagonism.**

I. INTRODUCTION

Labor and childbirth imply a muscular work and both suppose a great physical effort, with an important metabolic activity [1],[2]. Given that the uterine contractions compress the intrauterine vessels and the placenta, driving the maternal blood toward the inferior vena cava, the venous return increases considerably with the subsequent augment in most cases of heart rate, cardiac output and mean arterial pressure [3],[4],[5],[6].

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The question of how such hemodynamic conditions of labor are presumably driven by dynamic autonomic adaptations, and moreover the actual role of the autonomic nervous system in pregnancy, become of interest and still remain to be fully elucidated [7].

The autonomic condition of pregnant women prior to labor has been mainly assessed by quantifying the spectral power, or by assessing the structure of irregularity of the heartbeat fluctuations through the use of scaling exponents [4],[8],[9],[10],[11],[12].

In fact, some authors have identified autonomic pregnancy changes in the heartbeat fluctuations, which have been associated in general with responses to undertake the aortocaval compression of late gestation [13]. Yeh et al. have reported that the heartbeat fluctuations of late pregnant women involve lower magnitude and increased short-term fractal scaling exponent α_1, as compared with data collected 3 months after delivery, which return to show similar values of non-pregnant controls [11].

But, as studied by Peña et al., a lack of significant changes in the scaling exponents α_1 and $\alpha_{1(SIGN)}$ in pregnant women along gestation [12], provides evidence that the short-term cardiac dynamics is not compromised throughout pregnancy. Furthermore, changes in $\alpha_{1(MAG)}$ were also found so implying that the complexity of the mechanisms involved in regulating heart rate of pregnant women does appear to increase from mid-pregnancy [12].

These findings rise the need of identifying whether labor provoke short-term dynamic changes of the maternal heartbeat fluctuations, which could provide insights regarding the regulatory adaptations needed to achieve the hemodynamic conditions demanded by labor and childbirth. One would infer that the autonomic adaptations to fulfill labor's hemodynamic requirements should then become reflected in the behavior of heartbeat fluctuations.

This study assesses the appropriateness of using scaling parameters to analyze heartbeat fluctuations obtained from women in labor, particularly regarding their scaling linearity and nonlinearity. Accordingly, we evaluate the short-term RR fluctuations registered from women in the third term of pregnancy and during labor (with or without the presence of uterine contraction) to potentially identify dynamic changes of RR fluctuations at these stages or conditions.

II. METHODOLOGY

Once obtained informed consent, we collected 10 minutes segments of ECG from 18 women in labor at semi-Fowler position, mean age of 25±5 years, without any complication and with normal outcome of pregnancy, mean APGAR (5 minutes) 9±0.7 points. Labor was considered by the following clinical criteria: presence of regular contractions as well as effacement and cervix dilatation [2]. Oxytocin was administered to all cases to regularize uterine activity in accordance with the procedures adopted by CIMIGen[1]. Data of each studied case were classified into two distinct groups; one group (SYNC) involving segments where the uterine activity was observable (three or more contractions in ten minutes), and the other group of reference with fewer uterine activity or not presenting contractions at all (CON). For comparison, we also included segments collected during the last trimester of gestation from a third group of 18 women (TRD) not showing any clinical manifestation of the initiation of labor at the semi-Fowler position (9:00 AM to 12:00 PM). Approval was provided as part of the ongoing research between our institution and CIMIGen.

For data acquisition we used a Monica AN24 device to collect raw abdominal ECG recordings. Sampling frequency was 900 Hz. Required segments were delineated visually by using device's software, which displays values of maternal and fetal heart rate among ECG derived uterine activity signal (Fig. 1). To ensure the proper selection of the segments involving contractions, we decided to identify unequivocal increases of the maternal heart rate because it was assumed that during well-established frequent contractions the hemodynamic adjustments should clearly involve a compensation of cardiac output [3],[4],[5],[14]. Given that body movements can modify the heartbeat dynamics, segments were only selected in case of showing none or few maternal gross events.

Raw maternal ECGs were then processed using previous validated algorithms to generate RR fluctuations series corresponding to SYNC, CON and TRD segments [15]. All series consisted of 600 samples (spanning 5 to 10 minutes duration). Some of these series had to be reconditioned by a filtering approach that has been tested in previous studies to exclude for ectopic beats and artifacts [16].

The mean value of RR fluctuations (RR_{mean}) as well as the conventional RMSSD parameter, which quantifies high frequency fluctuations [17], were calculated for all series.

The scaling parameters of series were evaluated by applying detrended fluctuation analysis (DFA) and the magnitude and sign analyses (MSA). The DFA provided the scaling exponent α_1 as detailed elsewhere [18].

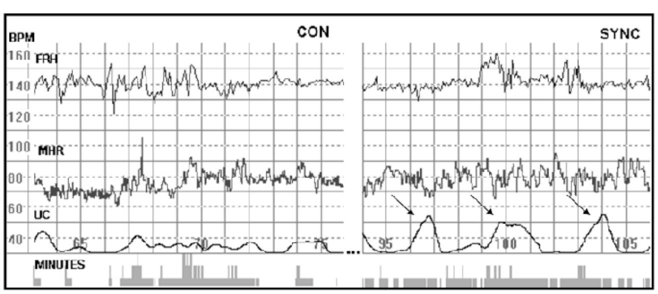

Fig. 1. Visual inspection of maternal (M) and fetal (F) heart rate (HR) traces during labor including CON and SYNC segments. Also depicted is an ECG derived uterine activity signal (UC) and vertical marks from an accelerometer to suggest the presence of maternal gross movements, which both were used as references to help identifying and selecting such segments (see text for a detailed description). Arrows indicate the manifestation of well-established frequent contractions.

[1] Maternal and Childhood Research Center, Mexico City.

Accordingly, the RR fluctuations series were integrated by:

$$Y(k) = \sum_{i=1}^{k}[\mathrm{RR}(i) - \mathrm{RR}_{\mathrm{ave}}] \quad (1)$$

where $Y(k)$ is the k-th value of the resulting integration (k=1,2,…,L), RR(i) is the i-th RR interval, and RR_{ave} are the mean RR values of the RR series. Next, the integrated series were divided into segments having equal number of n segments. The local trends Y_n were obtained for all segments by a least-squared line fit and subtracted from $Y(k)$ to reduce the nonstationary artifacts. The average root-mean-square fluctuations, $F(n)$, were calculated:

$$F(n) = \sqrt{\frac{1}{L}\sum_{k=1}^{L}[Y(k) - Y_n(k)]^2} \quad (2)$$

The relationships on a double-log graph between $F(n)$ and time scales n were approximated by a linear model $F(n) \sim n^{\alpha 1}$, so providing the scaling exponent α_1 as the slope of the plot covering the short-term range of n from 4 to 11 intervals (in accordance with Peña et al. [12]). The scaling exponent may vary from 0.5 (uncorrelated fluctuations, white noise) to 1.5 (smoother fluctuations). A value near 1 indicates the existence of fractal-like correlations. Nonlinearity and time ordering were assessed by MSA as follows [19],[20]. Original RR sequences were processed to obtain series of increments by taking the differences between adjacent intervals ($RR_{i+1}-RR_i$). These series (ΔRR) were decomposed into magnitude $|\Delta RR|$ and sign series sign(ΔRR). After subtracting their respective means, magnitude and sign series were integrated and DFA was again applied as described above. The slope of $F(n)/n$ covering the range from 4 to 11 intervals then provided magnitude and sign scaling exponents ($\alpha_{1(MAG)}$ and $\alpha_{1(SIGN)}$, respectively). Positive correlations in magnitude series (i.e. finding $\alpha_{1(MAG)} > 0.5$) are considered as reliable markers of nonlinear properties [20]. The $\alpha_{1(SIGN)}$ exponent provides information about the temporal organization of the original series in relation to how series' increments alternate, indicating if a positive or negative increment is more likely to occur given a current increment [19],[20].

Having verified equal variance and normality, statistical differences of RR_{mean}, RMSSD, α_1, $\alpha_{1(MAG)}$ and $\alpha_{1(SIGN)}$ between CON and SYNC segments were evaluated by a paired t-test. Differences of same parameters between CON and TRD segments (or SYNC and TRD) were evaluated by a t-test for independent measures. Significance was considered by $p<0.05$ for the paired t-test, and by $p<0.025$ for the independent comparisons.

III. RESULTS

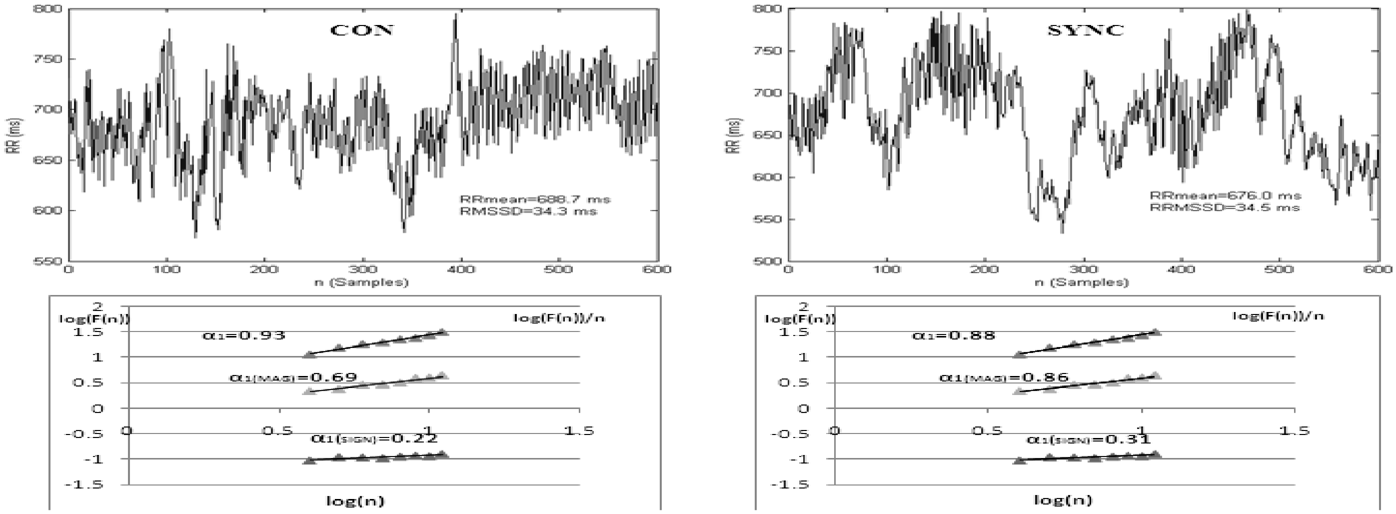

Fig. 2. Typical data of woman heartbeat fluctuations during labor for CON (left) and SYNC (right) segments. Corresponding log-log *–F(n)* vs *n*– and -*F(n)/n* vs. *n*– relationships are shown below the time series. Values of the parameters RR_{mean}, RMSSD, α_1, $\alpha_{1(MAG)}$ and $\alpha_{1(SIGN)}$ calculated for these series are depicted as well.

Fig. 2 shows typical results of the analysis of heartbeat fluctuations for a woman during labor including CON (left) and SYNC (right) segments. Whereas the raw RR series are presented at figure's top, the log-log *–F(n)* vs *n*– and -*F(n)/n* vs *n*– relationships, providing the α_1, $\alpha_{1(MAG)}$ and $\alpha_{1(SIGN)}$ from a linear best-fit of the *n* range 4 to 11, are depicted below. Also included are the results for the RR_{mean} and RMSSD parameters. Notice an apparent increased heart rate (i.e. lower RR values) owing to the presence of regular uterine contractions during the SYNC segment. Yet all RMSSD, α_1, $\alpha_{1(MAG)}$ and $\alpha_{1(SIGN)}$ parameters maintain similar values for both segments regardless of such contractions.

Table I summarizes principal findings for all studied parameters in relation with CON, SYNC and TRD segments. Whereas the RR_{mean} was the only parameter showing significant differences between CON and SYNC segments, a condition in accordance with our proposed experimental design for the selection of segments, $\alpha_{1(SIGN)}$ was the only scaling parameter showing a dynamic effect of labor on heartbeat fluctuations as identified by significant differences between TRD and CON segments.

TABLE I
MEAN VALUES (± SD) OF THE PARAMETERS RR_{MEAN}, RMSSD, α_1, $\alpha_{1(MAG)}$ AND $\alpha_{1(SIGN)}$

	Labor (CON)	Labor (SYNC)	TRD
RR_{mean} (ms)	676±108	629.5±105*	711±81++
RMSSD (ms)	35±14	30±13	28±15
α_1	1.12±0.24	1.14±0.26	1.00±0.22
$\alpha_{1(MAG)}$	0.72±0.10	0.74±0.13	0.70±0.14
$\alpha_{1(SIGN)}$	0.36±0.20	0.39±0.17	0.16±0.20**

Calculated from segments of heartbeat fluctuations of women (*N*=18) during labor CON or SYNC, and prior to labor TRD. Statistical differences are indicated by symbols.
* $p<0.03$, between CON and SYNC
** $p<0.007$, between CON and TRD as well as SYNC and TRD.
++ $p<0.014$, between SYNC and TRD.

IV. DISCUSSION

Among linear and nonlinear scaling measures, the main finding of this contribution is the identification of subtle but significant dynamic changes in the directionality of maternal heartbeat fluctuations during labor, as suggested by the parameter $\alpha_{1(SIGN)}$ regardless of the presence of uterine contractions (Table I). Accordingly, such fluctuations at labor intriguingly show weaker anticorrelations in comparison with the stronger anticorrelated behavior of the data collected before labor at the third trimester (0.36 ± 0.2 vs. 0.16 ± 0.2, respectively). Following our previous results, an stronger anticorrelated condition of maternal heartbeat fluctuations seems to be maintained, in fact, along three terms of gestation [12].

The physiological cause of finding weaker anticorrelated dynamics needs to be elucidated. Yet one may speculate that the autonomic regulation, expressed by the sympathetic and parasympathetic interplay, becomes less antagonistic during labor. In any case, given that changes in directionality from strongly to weakly anticorrelated heartbeat fluctuations have been identified in pathological but also in sleep induced and aging conditions [19],[21],[22], the meaning of both behaviors and their transition regarding the cardiovascular short-term regulation remains elusive. However, we think that finding a dynamic feature that shows changes at labor in comparison with previous stages of gestation becomes of potential interest as a hallmark to be explored in further studies. This is specially so with respect to what is already been evidenced for oxytocine, which besides the uterine and other well-known influences also seems to embrace functional effects as a cardiovascular modulating peptide [23].

Despite the presence of different mean heart rate, another finding of our study is that no significant changes in the α_1 or RMSSD of maternal heartbeat fluctuations were introduced by the uterine activity or by labor itself (Table I). Actually, α_1 and RMSDD showed similar values to previous antenatal results [12]. This was also the case for $\alpha_{1(MAG)}$, which presented no significant differences regardless of the uterine activity and in comparison with the results of data collected prior to labor (Table I). Thus, according to the dynamic meaning of these parameters, the short-term heartbeat fluctuations maintain irregular fractal-like ($\alpha_1 \approx 1$) and nonlinear ($\alpha_{1(MAG)} > 0.5$) dynamics despite the increased hemodynamic demands of labor. Using the interpretation adopted in our previous study [12], both dynamical conditions can then be considered as evidence that the cardiovascular regulation does not become restricted. By the contrary, during normal labor in the absence of major complications, this short-term regulation behaves with a concomitant nonlinear dynamics that may provide stable and adaptive capabilities [24].

Finally, regarding the magnitude and sign analyses, our results are of particularly interest because, notwithstanding a strong correlation and that either α_1 and $\alpha_{1(SIGN)}$ reflect linear scaling properties [19],[20],[12], our study illustrates that both parameters, as well as $\alpha_{1(MAG)}$, may be needed to complement the characterization of time series, so all providing value insights about the underlying dynamics. This consideration could also be supported by the fact that static or magnitude parameters, such as the RMSSD analyzed here, do not appear to show marked changes in relation to labor or even the specific presence uterine activity.

Our study may be limited by the fact that contractions during labor seem to have introduced minimal increments in heart rate (see Fig. 1), contrary to those presented in other studies [4]. These increments were significant though (see Table I). In any case, the potential manifestation of changes in the scaling parameters relative to the specific intensity of UC remains to be elucidated.

V. CONCLUSION

This study seems to confirm the suitability of scaling parameters to analyze heartbeat fluctuations obtained from women during labor. The lack of change in the scaling exponents α_1 and $\alpha_{1(MAG)}$ in pregnant women during labor, provides further evidence that the dynamics of short-term cardiac regulation is not compromised at the end of gestation. Yet $\alpha_{1(SIGN)}$ does present significant differences in comparison with the last trimester data that reveal a subtle change in the temporal organization of maternal RR series during labor. Results of these parameters then suggest that during labor, despite preserving a concomitant non-linear influence, the maternal sympathetic/parasympathetic regulation behaves with less antagonism.

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