

Heart Rate Variability Analysis for the Prediction of Hypotension during Spinal Anesthesia in Programmed Cesarean Surgery and its Relation with Fetal Cord Acid-base Equilibrium

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Abstract

In this paper the ability of linear and nonlinear heart rate variability (HRV) indices to predict hypotension during spinal anesthesia in programmed cesarean is studied, as well as their relation with fetal cord values. A database consisting of the ECG recordings of 40 pregnant women is analyzed. Recordings include the following positions: lateral decubitus (LD), supine decubitus (SD), sitting position (SP) and recovery from Valsalva maneuver (RV).

Classical temporal, spectral and non-linear HRV indices were calculated. Univariate analysis shows significant hypotension association: maternal age, gestational age, sample (SampEn) and approximate entropy (ApEn) in SD, the difference in SampEn, ApEn and correlation dimension (D_2) values between positions SD and LD, and the difference in total power between SD and SP. Data from fetal cord study show that hypotension is associated with an increase in arterial lactic acid. The difference in SampEn, ApEn and D_2 values between SD and LD are associated with venous lactic acid. A logistic regression model was used for the prediction of hypotension reaching balanced accuracy of 89.7%.

1. Introduction

Heart rate variability (HRV) allows non-invasive assessment of autonomic nervous system (ANS) [1] although the exact contribution of its two branches (sympathetic and parasympathetic) is a matter of debate and research [2]. Several HRV indices allow the assessment of the impact that some pathologies have on ANS risk stratification, and short term response to drugs (hypotension and hemody-

namical instability with general or spinal anesthesia [3]). The former applications, as well as its potential clinical use, make analysis of HRV especially interesting.

Spinal anesthesia is the elective technique in cesarean intervention, despite its high rate of hemodynamic instability and clinical hypotension (>60%) in habitual practice without pharmacological prevention [4]. Repercussion of these hypotension events on the mother and the fetus makes the prediction of this clinical situation especially relevant.

Clinical data and HRV indices have been studied in pregnant women for hypotension risk prediction after spinal anesthesia for cesarean section. Predictive value has been reported for linear (ratio between power in low and high frequency bands, LF/HF [5]) and nonlinear (peak correlation dimension [6] and approximate entropy [7]) parameters.

The objective of this work is to analyze linear and nonlinear HRV indices, obtained from women programmed for elective cesarean just before the surgery and the previous day, and their association with hypotension and with data from pH fetal cord, which is an index of placental hypoperfusion and fetal distress [8]; and to calculate, by logistic regression, a prediction model with studied indices.

2. Materials and methods

Database: The database consists of 40 pregnant women programmed for cesarean intervention at the University Hospital Miguel Servet, Zaragoza, Spain, after giving their informed consent. Exclusion criteria were urgent surgery, uterine contractions and maternal or fetal pathology.

Two-lead ECGs were acquired for each subject the

evening before the surgery, after admission, and just before the surgery in the Surgery Area, with a sampling frequency of 1000 Hz (Biopac Data Acquisition MP System). A protocol was designed to enhance ANS alterations. Firstly, the subject was at lateral decubitus (minimum stress position) for 7 minutes (LD); then at supine decubitus (hemodynamic stress caused by aorto-cava compression) for other 7 minutes (SD); in the sitting position for 7 minutes (SP); finally, a Valsalva maneuver of 15 s is performed, and at least one minute of recovery (RV) is recorded.

HRV indices: Linear HRV indices included classical temporal and spectral indices. Time domain indices: mean heart rate (HRM), standard deviation of normal-to-normal intervals (SDNN), the squared root of the mean squared differences of successive NN intervals (RMSSD), the standard deviation of differences between adjacent NN intervals (SDSD) and the proportion of interval differences of successive NN intervals greater than 20 and 50 ms (pNN20 and pNN50, respectively), were calculated from the R-R interval series [1].

Frequency domain indices were obtained from the power spectral density of the modulating signal with information related to activity of the ANS obtained from the integral pulse frequency modulation model [9]. Then, absolute and normalized powers were computed in the following bands: very low frequency (VLF, 0.015-0.04 Hz), low frequency (LF, 0.04-0.15 Hz), high frequency (HF, 0.15-0.4 Hz.) and total power, TP, as the addition of both LF and HF bands frequency content. Besides classical bands, an extended HF band (HF_{EXT}), which ranges from 0.15 Hz to the Nyquist limit [10], is considered in order to assure the inclusion of respiratory frequency, which in pregnant women can exceed 0.4 Hz.

Non-linear HRV indices included Approximate Entropy (ApEn), Sample Entropy (SampEn) and Correlation Dimension (D_2).

Statistical analysis: Hypotension was defined as a drop in mean arterial blood pressure of >20% from baseline value. All data were checked for normal distribution using Kolmogorov-Smirnov (KS). Afterwards, data were analyzed with T of Student or the Mann-Whitney U-test, according to KS. Pearson correlation was applied between HRV measures and fetal cord data. A two tailed p-value <0.05 was chosen as statistically significant. Logistic regression was performed to investigate independent factors with a significant association to hypotension within a multivariate model. A forward stepwise algorithm (inclusion criteria) was used. Statistics were performed by using the statistics program SPSS version 15.0 (SPSS, Inc., Chicago IL).

Table 1. Demographic data and HRV indices with statistically significant correlated with hypotension. Hypotension (GH) and non hypotension groups (GNH) represented as mean (μ), standard deviation (σ), p-value (p), and area under ROC curve (ROC). Sample and approximate entropy in supine dubitus position ($SampEn^{SD}$ and $ApEn^{SD}$) the surgery day.

| | | μ | σ | p | ROC |
|---------------|-----|-------|----------|-------|------|
| Age [yrs] | GNH | 31.8 | 5.1 | 0.023 | 0.70 |
| | GH | 35.5 | 4.6 | | |
| G. Age [wks] | GNH | 38.6 | 1.0 | 0.045 | 0.69 |
| | GH | 38.0 | 0.9 | | |
| $SampEn^{SD}$ | GNH | 1.1 | 0.3 | 0.012 | 0.72 |
| | GH | 0.8 | 0.3 | | |
| $ApEn^{SD}$ | GNH | 1.0 | 0.2 | 0.013 | 0.73 |
| | GH | 0.8 | 0.2 | | |

Table 2. Data of the differences between LD and SD the day of surgery of correlation dimension (ΔD_2^{LD-SD}), sample entropy ($\Delta SampEn^{LD-SD}$), approximate entropy ($\Delta ApEn^{LD-SD}$) and between supine and seated for total power (ΔTP^{SD-SP}) and extended total power (ΔTP_{EXT}^{SD-SP}) represented as mean (μ), standard deviation (σ), p-value (p), and area under ROC curve (ROC).

| | | μ | σ | p | ROC |
|---------------------------|-----|-------|----------|-------|------|
| ΔD_2^{LD-SD} | GNH | 0.2 | 0.9 | 0.002 | 0.79 |
| | GH | -1.1 | 0.3 | | |
| $\Delta SampEn^{LD-SD}$ | GNH | 0.1 | 0.3 | 0.006 | 0.75 |
| | GH | -0.2 | 0.3 | | |
| $\Delta ApEn^{LD-SD}$ | GNH | 0.06 | 0.18 | 0.006 | 0.76 |
| | GH | -0.1 | 0.2 | | |
| ΔTP^{SD-SP} | GNH | 420 | 84 | 0.010 | 0.80 |
| | GH | 138 | 54 | | |
| ΔTP_{EXT}^{SD-SP} | GNH | 428 | 240 | 0.033 | 0.77 |
| | GH | 165 | 295 | | |

3. Results

Hypotension occurred in 26 patients (GH) (65%) and not in 14 (GNH). In the demographic data only maternal and gestational age (G. Age) were correlated with hypotension with significant differences between groups $p < 0.05$. Regarding non-linear parameters, both SampEn and ApEn, computed during supine decubitus position the day of the surgery, show significant differences with lower values in GH. Data are shown in Table 1.

Differences between values for the different protocol positions and comparisons between groups were calculated. For the day of surgery data, the differences of both extended and classical total power, between SD and SP,

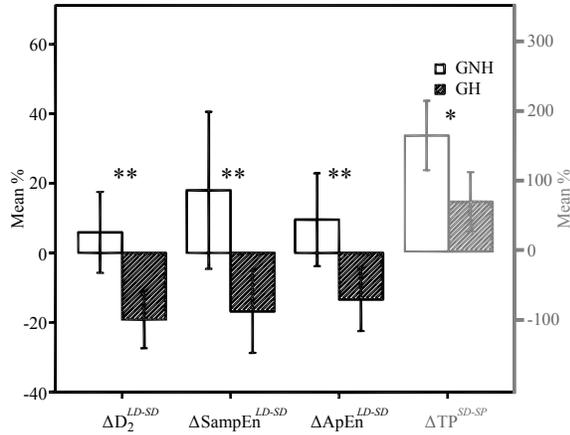


Figure 1. Mean percentage variations of the changes, expressed as mean±standard deviation, of linear and non-linear indices for position changes. * means $p < 0.01$ and ** means $p < 0.006$.

ΔTP^{SD-SP} and ΔTP_{EXT}^{SD-SP} were significantly smaller in GH than in GNH. For non-linear parameters, differences in D_2 , SampEn and ApEn between LD and SD positions were highly significant between GH and GNH ($p < 0.01$), data are shown in table 2. Figure 1 shows these differences expressed as mean percentage variation changes.

Regarding data from the fetal cord, only arterial lactic acid shows significant differences comparing groups GH and GNH (arterial lactate: 2.6 ± 1.1 vs. 1.9 ± 0.6 mEq/L). Studying the correlation between HRV indices and fetal cord data, differences in ΔD_2^{LD-SD} , $\Delta SampEn^{LD-SD}$ and $\Delta ApEn^{LD-SD}$ were found significantly correlated with venous lactic acid with values of $r = -0.362$, $p = 0.028$; $r = -0.329$, $p = 0.047$ and $r = -0.360$, $p = 0.029$ respectively.

The logistic regression equation contains three variables: gestational age, ΔTP^{SD-SP} , ΔD_2^{SD-LD} :

$$p_H = 121.20 + (-0.018 \Delta TP^{SD-SP}) + (3.114 \Delta D_2^{LD-SD}) + (-3.023 G.Age)$$

Reaching a balanced accuracy of hypotension prediction of 89,7%, a sensitivity of 90,5% and a specificity of 87,5%.

4. Discussion and conclusions

The high incidence of hypotension events and their potential risks, joined to the non-pharmacological prophylaxis limited efficiency and the possible risks of the pharmacological prevention, have led to the searching and identification of risk factors and prediction models.

Under the assumption that the main underlying mechanisms for hypotension are a decrease in both systemic vascular resistance and venous return by vena cava compression, first studies focused on the detection of induced

hemodynamic changes induced by changing position from lateral to supine decubitus, called Stress supine test (SST), i.e. Dahlgren et al in [11] about 80,5%.

Global predictive value of parameters studied in literature is scarce. The highest predictive values have been shown by: increased basal systemic vascular resistances [12] with an accuracy of 80,5% and changes in heart rate from SD to LD position [13] with a 79% and perfusion index derived from pulsi oximeter with a 83,5% [14]. Efforts to find predictive models by logistic regression using several clinical parameters associated with hypotension events have demonstrated poor results in the ROC curve analysis: i.e. 0.68 in [15].

Our results show high correlation values between hypotension and individual parameters with large areas under the ROC curves and a predictive power of the logistic regression model about 90,5% sensitivity, 87,5% specificity and global predictive value of 89,7% being much higher than the previously reported.

None of linear and non-linear indices in all of the studied positions showed significant differences between the groups for the previous day of the surgery in agreement with the work of Hanns [5].

Ghabach in [7] found an association between ApEn and weight increment during the pregnancy. Pregnant women with less weight increment (< 11 kg) presented with higher ApEn values and propensity to suffer a hypotension event after spinal anesthesia. Our results, on the contrary, show significantly lower values in patients who suffered a hypotension event, in ApEn as well as in SampEn for SD position.

Differences of LD-SD and SD-SP for each parameter were also computed and compared between GH and GNH groups, in order to study the possible qualitative differences in the reactivity to the position change stimulus. Significant differences were only observed the day of the surgery for ΔTP^{SD-SP} and ΔTP_{EXT}^{SD-SP} ($p < 0.05$, $p < 0.01$), with lower values in GH; while ΔD_2^{LD-SD} , $\Delta SampEn^{LD-SD}$ and $\Delta ApEn^{LD-SD}$ were significantly higher in GNH group ($p < 0.005$). Regarding these former values it is worthy to note that the change provokes a response with opposite direction, incremented in GNH and decreased in GH

The fact that the best parameters for discriminating the groups are the responses to position change stimulus, may possibly reflect the different adaptation capability of the hemodynamic regulation system and, therefore, the response to sympathetic blockade of the spinal anesthesia. The correlation of HRV indices and the acid-base cord fetal values shows only significant correlation between venous acid lactic and differences between LD and SD of correlation dimension, sample entropy, approximate entropy.

Ephedrine is a sympathicomimetic drug with betadren-ergic effects responsible of the metabolic activation that

produces lactic acid. An increment in lactic acid in fetuses whose mothers were treated with ephedrine is related with hypotension events [16]. Thus, HRV index correlation with lactic acid shows the relation with hypotension events, being greater in GH group.

Conclusions: Among the linear and non-linear HRV indices and protocol positions, only the day of the surgery significant differences were found between GH and GNH groups in the following parameters: SampEn and ApEn in supine decubitus position. The different response observed to position changes from SD to SP position in TP (ΔTP^{SD-SP}), and from LD to SD in D_2 , SampEn and ApEn, in the results obtained from the recordings of the day of the surgery, show a higher prediction power to suffer hypotension events, with a significant correlation of these parameters with the fetal venous lactic acid. The estimated prediction model by multivariable logistic regression, taken into account gestational age, ΔTP^{SD-SP} and ΔD_2^{LD-SD} , reaches a global predictive value of 89,7%, a sensibility of 90,5% and a specificity of 87,5%.

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