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# Time-Frequency analysis of HRV data from locally anesthetized patients

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***Abstract*—Spectral analysis of Heart Rate Variability (HRV) can be used for the assessment of cardiovascular autonomic control. In this study Smoothed-Pseudo Wigner-Ville Distribution (SPWVD) has been used to evaluate the effect of local anesthesia on HRV parameters in a group of fourteen patients undergoing brachial plexus block (local anesthesia) using the transarterial technique. Instead of using the fixed boundaries of the LF (0.04-0.15 Hz) and the HF (0.15-0.4 Hz) components, the center frequency and the standard deviation spectral extension was used to estimate the boundaries related to the two components of the HRV signal. The boundaries related to the HF component of the signal were estimated using the cross-spectrum between the HRV signal and the respiration signal. The LF component boundaries were estimated directly from the time-frequency representation of the HRV signal. The statistical analysis showed that the $^{LF}/_{HF}$ amplitude ratio decreased within an hour of the application of the brachial plexus block compared to the values at the start of the procedure. These changes were observed in eleven of the fourteen patients included in this study.**

## I. Introduction

THE study of interbeat variations of the Electrocardiograph (ECG) is known as Heart Rate Variability (HRV). In the frequency domain, three frequency bands can be distinguished in the spectrum of short term (2 to 5 minutes) HRV signals [9]. These components are termed as High-Frequency (HF) band (0.15 Hz to 0.4 Hz), Low-Frequency (LF) band (0.04 Hz to 0.15 Hz) and Very Low-Frequency band (VLF) which is the band of frequencies of less than 0.04 Hz frequencies. The HRV indices such as the ratio of $^{LF}/_{HF}$ power or the fractional LF power have been used to describe sympathovagal balance [4]. The dependence on linearity and stationarity make the parametric and non-parametric spectral methods unsuitable for the analysis of transient changes that might be occurring in the HRV data due to local anesthesia.

In this study the Smoothed-Pseudo Wigner-Ville Distribution (SPWVD), which is a quadratic transform from Cohen's class [3], [2], has been used to evaluate the effect of local anesthesia on HRV parameters in a group of patients undergoing local anesthesia. This technique has been used previously in various HRV studies [5], [1], [14].

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## II. Methods

### A. Subject and Protocol

Before commencing clinical trials on ASA 1 and 2 patients undergoing local anesthesia, research ethics committee approval was obtained. Fourteen patients (7 males and 7 females) aged 50.6 ± 20.7 years (mean weight 67 ± 15.3 Kg, mean height 1.6 ± 0.2 m) undergoing elective general surgery under local anesthesia were recruited to the study. In all cases the transarterial approach was used for the brachial plexus block. A combination of 30 ml of 1% Lignocaine and 29 ml of 0.5% Bupivacaine with 1:200000 part Adrenaline was used as anesthetic agent. An AS/3 Anesthesia Monitor (Datex-Engstrom, Helsinki, Finland) was used to collect lead II ECG signals from the patients. The monitoring started about 30 minutes before the start of the block and continued for approximately another 30 minutes after the surgery in the recovery ward. The ECG signal was digitized at 1 kHz sampling frequency using a PCMCIA 6024E 12-bit data acquisition card (National Instruments Corporation, Austin, Texas).

### B. Data preprocessing

Wavelet transform with first derivative of Gaussian smoothing function as the mother wavelet was used for the detection of R-waves in the recorded ECG signals. The detection was carried out using wavelet scales $2^m$, m=4, 8, 12, 16, 20. The algorithm achieved an accuracy of 99.96% and sensitivity of 99.7% in the recorded ECG signals. After the R-wave detection the *heart timing* signal [6] was used for the HRV signal representation and also for the correction of missing and/or ectopic beats. The signals were resampled using cubic spline at a sampling rate of 4 Hz as recommended for HRV studies [9]. The performance of the *heart timing* representation and the beat correction algorithm has been validated in previous studies [7], [12]. The VLF component of the signal was removed by detrending the signal using wavelet packet analysis which have been validated previously [13]. The respiration signal was estimated using the ECG Derived Respiration (EDR) technique [8]. After these preprocessing steps the data was ready to be analyzed with the SPWVD technique.

### C. Time-frequency analysis

The derivation of the discrete SPWVD is presented in detail in the literature [11], [10]. For a discrete sequence $s[n]$, the discrete SPWVD can be expressed as shown in Eq. 1.

$$SPWVD_x[n,k] = \sum_{l=-P+1}^{P-1} h[l] \sum_{m=-Q+1}^{Q-1} g[m] \times r[n-m,l]\, e^{-j2lk\pi/M} \quad (1)$$

Where $r[n,l] = s[n+l]s^*[n-l]$ is the instantaneous auto correlation function. In this case the smoothing in the time direction is done using a window $g[m]$ of length $2Q-1$ and window $h[l]$ of length $2P-1$ is used for frequency smoothing. The signals were analysed in their analytical form. In this study time smoothing was done using a Gaussian window of 129 samples while frequency smoothing was done with a Hamming window of 257 samples.

Time-Frequency distribution (TFD) was used to estimate the instantaneous frequency and standard deviation spectral extension using Eq. 2 and Eq. 3. These parameters were obtained for the HF component in the frequency range of 0.15 to 0.5 Hz and for the LF component in the frequency range of 0.04 Hz to 0.15 Hz. Instantaneous frequency $\pm$ the standard deviation spectral extension was considered as the range for each band. In the case where the lower boundary of the HF component was below 0.15 Hz then this lower boundary was used in the estimation of the LF component instantaneous frequency and the boundaries. The instantaneous frequency and the boundaries were smoothed using a median filter with a length of 10 seconds to avoid sharp fluctuations in these parameters. The parameters related to the HF band of the signal were calculated using the cross-spectrum between the HRV signal and the respiration signal whereas, the parameters of the LF components were calculated from the TFD of the HRV signal.

$$\bar{f}_p = \frac{\int_{-\infty}^{\infty} f\, SPWVD(t,f)\, df}{\int_{-\infty}^{\infty} SPWVD(t,f)\, df} \quad (2)$$

$$\Delta f_p = \left( \frac{\int_{-\infty}^{\infty} (f-\bar{f}_p)^2\, SPWVD(t,f)\, df}{\int_{-\infty}^{\infty} SPWVD(t,f)\, df} \right)^{1/2} \quad (3)$$

Using the estimated boundaries, the instantaneous power related to each band was calculated using Eq. 4.

$$P_{inst.}(t) = \int_{-\infty}^{+\infty} SPWVD(t,f)\, df \quad (4)$$

### *D. Statistical test*

An unpaired t-test and a Mann–Whitney rank sum test were used to compare the values of the parameters estimated from the data obtained from the locally anesthetized patients. The parameters from each patient were tested individually to check for differences before and after the block. The statistical analysis was carried out using *SigmaStat 2.03* (Systat Software Inc., USA). The significance level was set at $P < 0.05$ in all the tests.

## III. Results

### *A. HRV data from locally anesthetized patients*

After establishing the boundaries of the LF and the HF band of the HRV signal as mentioned in section II-C the instantaneous power related to these components was calculated using Eq. 4. Using these estimates along with the total instantaneous power, the power related to each band was also calculated in normalized units. The parameters estimated from one of the patient data included in this study are presented in Fig. 1.

Figure 1 shows the $^{LF}/_{\mathrm{HF}}$ ratio, the total instantaneous power and the power in the LF and the HF band of the signal. The power in the two bands is also presented in the normalized units. The parameter values shown in Fig. 1 are the mean values calculated from a period of one minute. After the application of the local anesthetic drug the $^{LF}/_{\mathrm{HF}}$ ratio values decreased as compared to the values approximately fifteen minutes before the application of the local anesthetic drug. Similar results were obtained from other data sets included in this study. The decrease in the ratio values was observed in each case within an hour of the application of the block. The total power also showed a decrease after the application of the block in all these patients. The normalized HF components power (Fig. 1(e)) showed an increased after the application of the block whereas, the normalized LF component power (Fig. 1(f)) decreased after the block. The changes in the instantaneous frequencies of the LF and the HF band, shown in Fig. 1(g) and Fig. 1(h) respectively were less significant and changes in their values did not correlated well with the changes in the ratio ($^{LF}/_{HF}$) after the application of the block.

The SPWVD representation along with the instantaneous frequencies and the boundaries related to the LF and HF band for the data set, from which the results presented in Fig. 1 are obtained, is presented in Fig. 2. Figure 2(a) and Fig. 2(b) shows the SPWVD representation obtained from the data fifteen minutes before the block (anesthetic drug) was applied and during the block respectively. Similarly the representation obtained from a fifteen minute data segment after the application of the block is shown in Fig. 2(b). This data segment covers the region where the ratio values have decreased which in Fig. 1(a) is approximately at 2400 second. Even though it can be seen that the HF band frequency has increased slightly after the application of the block the results presented in Fig. 1 indicate that in this case the changes in the instantaneous frequency of the HF and the LF bands are almost insignificant. The total instantaneous power has also decreased after the application of the block. This power reduction has effected the LF band more than it has effected the HF band as indicated by the decrease in the normalized instantaneous power of the LF band (see Fig. 1(h)) and increase in the normalized instantaneous power of the HF band (see Fig. 1(g)).

### *B. Statistical analysis*

Statistical tests were also carried out on the parameters estimated using the SPWVD analysis technique. Depending on the normality test results, data was analysed by using either an unpaired t-test or the Mann–Whitney rank sum test. The parameters, total instantaneous power, instantaneous power in the LF and the HF band both in the absolute and normalized units and instantaneous frequencies related to the two bands, were compared to see if their values differ significantly after the introduction of the anesthetic drug into the patient system. Table I indicates that the $^{LF}/_{HF}$ ratio values calculated using the SPWVD analysis showed significant changes after the application of the block as compared to the values before

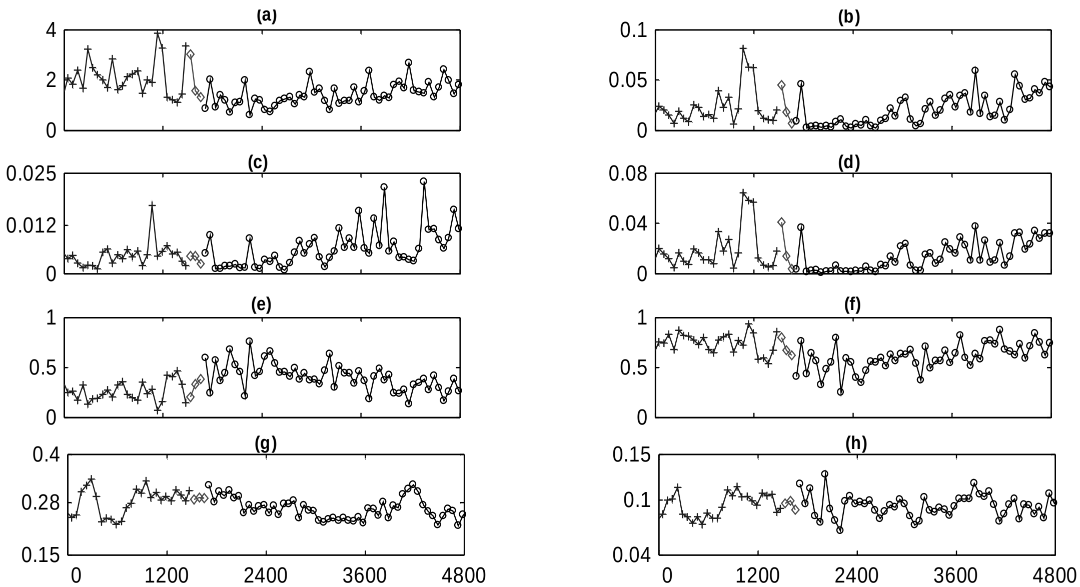


**Fig. 1:** Results obtained from the SPWVD analysis of a patient undergoing local anesthetic procedure;(a) $^{LF}/_{HF}$ ratio, (b) total instantaneous power, (c) instantaneous power in the HF region of the signal, (d) instantaneous power in the LF region of the signal, (e) normalized HF power, (f) normalized LF power, (g) instantaneous HF frequency, (h) instantaneous LF frequency. In the graph the data values before and during the block and presented by plus and diamond markers respectively where as the values after the block are indicated by circle markers. The units on x-axis for each plot are seconds. The units on y-axis for the plots showing power are ($^{s^2}/_{\mathrm{Hz}}$) and for the plots showing frequency values is (Hz)

**Table I:** Summary of the statistical test results obtained from the SPWVD analysis of the data from locally anesthetized patients. $^{LF}/_{HF}$ ratio cell indicates the total number of cases showing significant changes after the block. For all other parameters the first value indicates the number of cases where the parameter values have shown significant changes while the second value indicates the cases where the parameter values have shown significant changes simultaneously with the $^{LF}/_{HF}$ ratio changes

| $^{LF}/_{HF}$ ratio | PT | $\mathrm{HF}_P$ | $\mathrm{LF}_P$ |
|---|---|---|---|
| 11 | 7, 6 | 8, 7 | 9, 8 |
| $\mathrm{HF}_{Pnorm}$ | $\mathrm{LF}_{Pnorm}$ | $\mathrm{HF}_f$ | $\mathrm{LF}_f$ |
| 10, 10 | 10, 10 | 3, 2 | 3, 3 |

the application of the block in eleven out of the fourteen data sets analysed in this study. The changes occurring in the normalized power parameter related to the two frequency bands, the HF and the LF band, were more strongly correlated with the changes in the ratio values than the changes in the other parameters values. There were very few cases in which the instantaneous frequency of the HF and the LF band showed significant changes.

## IV. Conclusion

In this study a joint time-frequency analysis method (SPWVD) which has been used extensively in the analysis of non-stationary signals including HRV signals was used for the analysis of the data obtained from fourteen patients undergoing local anesthesia, using a combination of 30 ml Lignocaine and 29 ml of 0.5% Bupivacaine as the anesthetic agent.

The instantaneous frequency (see Eq. 2) related to the LF component was estimated in the range of 0.04 Hz to 0.15 Hz and for the HF component was estimated in the range of 0.15 Hz to 0.5 Hz. The boundaries of each component was defined as instantaneous frequency $\pm$ the standard deviation spectral extension (see Eq. 3) and the power related to each component was calculated using this range. The instantaneous frequency and boundaries related to the HF component were estimated using the cross spectrum between the estimated respiration signal and the HRV signal while, the time-frequency distribution of the HRV signal was used for the estimation of the same parameters for the LF component. This boundary definition was used to avoid the error caused by the use of fixed boundaries for the LF ((0.04-0.15 Hz) and the HF (0.15-0.4 Hz) component. As the signal parameters such as respiration frequency were dynamically changing it made sense to try to use an adaptive boundary rather than keeping the boundary fixed.

The results presented in Fig. 1 showed that the ratio and the total instantaneous power values decreased after the application of the block as compared to the values fifteen minutes before the application of the block. The results also indicated a slight shift in the power from the LF region to the HF region of the signal.

Statistical tests were carried out to check for significant differences in the parameters values before and after the

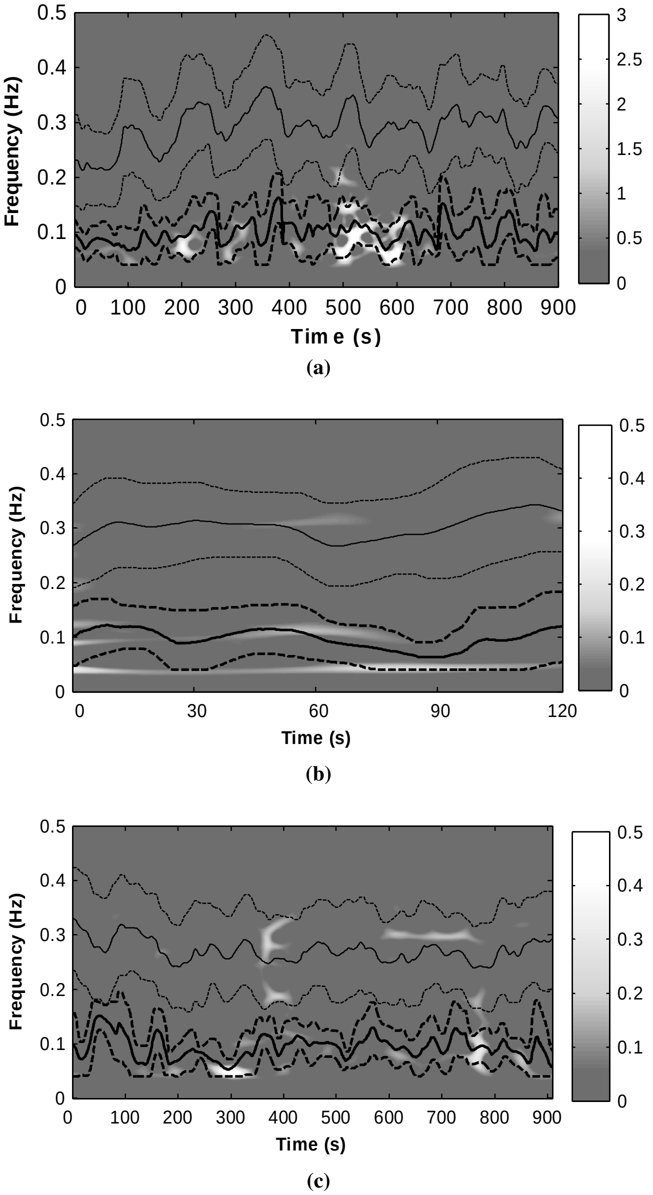


**Fig. 2:** SPWVD representation of the data obtained from a locally anesthetized patient; (a) the representation for the data segment approximately fifteen minutes before the application of the anesthetic block, (b) the representation for the data obtained during the application of the block, (c) the representation of the data obtained fifteen minutes after the application of the block when the ratio value have reach minimum. The thin black line represent the HF band of the signal with dotted lines representing the upper and lower boundaries while the solid line represents the instantaneous frequency estimated for the HF region. The same information is presented with thick lines for the LF band of the signal

application of the brachial plexus block. Table I indicates that the $^{LF}/_{HF}$ ratio values calculated using the SPWVD analysis showed significant changes after the application of the block as compared to the values before the application of the block in eleven out of the fourteen data sets analysed in this study. The changes occurring in the normalized power parameter related to the two frequency bands, the HF and the LF band, were more strongly correlated with the changes in the ratio values than the changes in the other parameters values. There were very few cases in which the instantaneous frequency of the HF and the LF band showed significant changes.

One of the major drawbacks of using quadratic transforms such as SPWVD is the presence of the interference terms in the TFD representation of the multi-component data such as HRV signal. These interference terms cause an error in the power estimation. These terms could be reduced by using larger windows for time smoothing but this also causes reduction in the time resolution achieved by the method. With poor time resolution the transient changes occurring in the signal might be missed. In real practical signals it is quite difficult to adjust the length of the widows for optimal time and frequency resolution. These results suggests that during brachial plexus block using a mixture of Lignocaine and Bupivacaine there is a noticeable change in the sympathovagal balance which can be detected through HRV analysis. However, more rigorous clinical studies with larger data sets should be carried out and results should be compared with other methods of time-frequency analysis.

## REFERENCES


[1] Hsiao-Lung Chan, Ming-An Lin, Pei-Kuang Chao, and Chun-Hsien Lin. Correlates of the shift in heart rate variability with postures and walking by time-frequency analysis. *Comput Methods Programs Biomed*, 86(2):124–130, May 2007.

[2] L. Cohen. Time-frequency distributions-a review. 77(7):941–981, 1989.

[3] Patrick Flandrin. *TIME-FREQUENCY/TIME-SCALE ANALYSIS*. Acadamic press, 1998.

[4] J. J. Goldberger. Sympathovagal balance: how should we measure it? *Am J Physiol*, 276(4 Pt 2):H1273–H1280, Apr 1999.

[5] H. H. Huang, H. L. Chan, P. L. Lin, C. P. Wu, and C. H. Huang. Time-frequency spectral analysis of heart rate variability during induction of general anaesthesia. *Br J Anaesth*, 79(6):754–758, Dec 1997.

[6] J Mateo and P Laguna. Improved heart rate variability signal analysis from the beat occurrence times according to the IPFM. *IEEE Trans. Biomed. Eng.*, 47(8):985–996, 2000.

[7] J Mateo and P Laguna. Analysis of heart rate variability in the presence of ectopic beats using the heart timing signal. *IEEE Trans. Biomed. Eng.*, 50(3):334–343, 2003.

[8] George B. Moody, Roger G. Mark, Andrea Zoccola, and Sara Mantero. Derivation of respiratory signals from Multi-lead ECGs. *Computers in Cardiology*, 12:113–116, 1985.

[9] Task Force of the Euro. Society of Cardiology the N. American Society of Pacing Electrophysiology. Heart Rate Variability Standards of Measurement, Physiological Interpretation, and Clinical Use. *European Heart Journal*, 17:354, 1996.

[10] J.C. O'Neill, P. Flandrin, and W.J. Williams. On the existence of discrete wigner distributions. 6(12):304–306, 1999.

[11] M.S. Richman, T.W. Parks, and R.G. Shenoy. Discrete-time, discrete-frequency, time-frequency analysis. 46(6):1517–1527, 1998.

[12] K. Shafqat, S.K. Pal, S. Kumari, and P.A. Kyriacou. Changes in heart rate variability in patients under local anesthesia. In *Proc. 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society EMBS 2007*, pages 299–302, 2007.

[13] K. Shafqat, S.K. Pal, and P.A. Kyriacou. Evaluation of two detrending techniques for application in heart rate variability. In *Proc. 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society EMBS 2007*, pages 267–270, 2007.

[14] Lucia Spicuzza, Luciano Bernardi, Alessandro Calciati, and Giuseppe Ugo Di Maria. Autonomic modulation of heart rate during obstructive versus central apneas in patients with sleep-disordered breathing. *Am J Respir Crit Care Med*, 167(6):902–910, Mar 2003.