Changes in Heart Rate Variability in Patients under Local Anesthesia

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***Abstract*— Spectral analysis of Heart Rate Variability (HRV) is widely used for the assessment of cardiovascular autonomic control. Several studies have shown the effect of anesthetic agents on HRV parameters. In this study a systematic approach of HRV analysis has been employed. The effect caused by the ectopic beats on the spectral measurements has been investigated and results are presented. A detrending method using Wavelet Packets has been developed which was able to remove slow varying trend from HRV signals without causing significant changes in the low frequency (LF) and high frequency (HF) component of the HRV signal. Using this methodology electrocardiogram (ECG) signals from 14 patients undergoing local anesthesia (brachial plexus block) were analyzed with parametric Autoregressive (AR) method. The results showed that the $\frac{LF}{HF}$ ratio values calculated from the HRV signal decreases within an hour of the application of the brachial plexus block compared to the values at the start of the procedure. This change was noticed in approximately 80% of the patients.**

I. INTRODUCTION

The Autonomic Nervous System (ANS) modulates the cardiac pacemaker and provides the beat to beat regulation of the cardiovascular system through complex interaction between the sympathetic and the parasympathetic nervous system input to the sinus node. Heart Rate Variability (HRV) is the study of this inter-beat variability of the ECG signal and therefore, can be used as a non-invasive technique to assess the autonomic influence on the heart [1]. Different methods have been used in HRV analysis but the two most commonly used are the time domain and frequency domain analysis. In the frequency domain, three frequency bands can be distinguished in the spectrum of short term (2 to 5 minutes) HRV signals [1]. 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 less than 0.04 Hz frequencies. The HRV indexes such as the ratio of $\frac{LF}{HF}$ power or the fractional LF power have been used to describe sympathovagal balance [2].

HRV has also been used to study the effects of different drugs on the cardiovascular system. Spectral analysis techniques have been used to show the effect of anticholinesterase edrophonium on heart rate and blood pressure variability [3]. Changes in HRV due to atropine administration have also been studied using spectral analysis techniques [4]. Such studies have shown that with the first dose of atropine the HRV increased followed by a progressive decrease with higher doses. In the case of propranolol, there was a significant increase in heart rate variability, which progressively disappeared after the last dose [4].

The aim of this study is the investigation of the effect of local anesthesia (induced with Bupivacaine + Lignocaine, in patients having brachial plexus block) on HRV.

Manuscript received April 2, 2007.

This work was supported by Chelmsford Medical Education and Research Trust (CMERT).

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II. METHODS

A. Subject and Protocol

Research ethics committee approval was obtained prior to commencing the study on ASA 1 and 2 patients. 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 axillary approach was used for the Brachial plexus block. A combination of 30 ml Lignocaine and 29 ml of 0.5% Bupivacaine was used as anesthetic agent. Patients were also given 1:200000 part adrenaline at the time of the block. An AS/3 Anesthesia Monitor (Datex-Engstrom) 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 12-bit data acquisition card (National Instruments Corporation, Austin, Texas).

B. ECG R-wave detection

The algorithm for R wave detection implemented in this work is based on the algorithm presented by Sahambi *et al.*

[5]. First derivative of the Gaussian smoothing function was used as the mother wavelet. Characterization of ECG was done using wavelet scales 2^m, m=4 8 12 16 20.

C. *Ectopic Beat correction and HRV signal representation*

For the representation of the HRV signal, the Heart Timing (HT) signal [6] was used. In the absence of ectopic beats the HT signal can be written, using the Integral Pulse Frequency Modulation (IPFM) model, as.

$$ht(t_k) = kT - t_k = \int_0^{t_k} m(\tau)d\tau \qquad (1)$$

Where t_k is the k^{th} beat time and T is the mean heart rate. This signal was preferred as it provides an unbiased estimate of the modulating signal $m(t)$.

Dealing with ectopic beats is essential in the analysis as the time domain signal associated with the HRV can exhibit a sharp transient at the ectopic beat, making it unsuitable particularly in the Power Spectral Density (PSD) estimate of the HRV. It has been shown previously that the area of the low frequency (LF) component of the HRV spectrum in normal subjects can increase up to 89% if the analysis signal has 4% of ectopic beats. The same amount of ectopic beats also causes an increase of up to 402% in the area of the high frequency (HF) component of HRV [7].

The criterion for the detection of the ectopic is based on a threshold (U) on the estimate of the derivative of instantaneous HR, as given in (2). The beats are classified as anomalies if the derivative passes the threshold.

$$\left|\hat{r}_k^i\right| = 2\left|\frac{t_{k-1} - 2t_k + t_{k+1}}{(t_{k-1} - t_k)(t_{k-1} - t_{k+1})(t_k - t_{k+1})}\right| \qquad (2)$$

The threshold is defined as $U = \min(4.3.\sigma_{\hat{r}_k}, 0.5)$ where $\sigma_{\hat{r}_k}$ is the standard deviation of the derivative of instantaneous HR [8].

In order to see the effectiveness of the HT signal for the representation of the HRV signal and to evaluate the performance of the ectopic beat handling algorithm an AR model was used as the modulating signal in the IPFM model. The coefficients and the variance of the AR model used for a sampling rate of 1 Hz were

$$\left.\begin{array}{c} a = [1 - 1.6265 1.8849 - 1.8327 1.297 - 0.7758 0.4133 - 0.2136] \\ \sigma^2 = 404 \cdot 10^{-6} \end{array}\right\} \qquad (3)$$

The HT signal was generated using this model and this signal was resampled using cubic spline at a sampling rate of 4 Hz as recommended for HRV studies [9].

D. *Detrending Method*

Nonstationarities in the HRV signal can cause distortion in the time and frequency domain analysis. In particular these nonstationarities will distribute large amount of variance in the lowest frequency. In order to deal with this problem many researchers detrend the data prior to analysis. Detrending is usually based on first order [10], [11] or higher order [11] polynomial model or by using successive-difference filters.

The detrending algorithm was implemented using Wavelet Packets (WP). The algorithm was implemented using Daubechies compactly supported orthonormal wavelet transform method with an order of 12. The VLF component of the signal was attenuated by discarding the coefficients of node (7,0) and (9,6) of the basis shown in Fig. 1.This basis was chosen according to the bandwidth of the resulting filters.

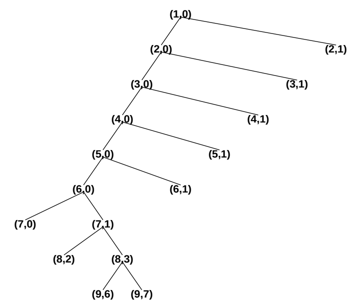

Fig. 1: WP tree used for detrending. The pair of numbers in the bracket at each node represent particular part of the decomposition. The first number in the pairs shows the level of the decomposition j and the possible values for the second number (n) are 0..... $2^{(j-1)} - 1$ except for $j - 1$ which represents the original signal

E. *Spectrum analysis*

The spectral analysis was carried out using parametric, autoregressive (AR), method. The coefficients were calculated using modified covariance method. For spectral analysis of the real HRV signal, five minutes of data (1200 points at 4 Hz) and a model order of 20 was used.

The AR model for the simulated study was chosen as its PSD approximately matches with the PSD for a normal subject at supine rest [6]. Twenty random realizations of $m(t)$ were made using this model. To study the global behavior of the spectrum with frequency, Mean Normalized Error (MNE) defined in (4) was used [6].

$$MNE(f) = \frac{\sum_{i=1}^{20}\left(\overline{PSD_i(f)} - PSD_i(f)\right)}{PSD_i(f)} \qquad (4)$$

Where $\overline{PSD_i(f)}$ is the i^{th} realization of the original spectrum and $PSD_i(f)$ is the PSD estimate of the i^{th} realization.

III. Results

In the acquired ECG signals, the peak detection algorithm achieved an accuracy of 99.96% and sensitivity of 99.7%. Typical examples of peak detection of ECG signals are shown in Fig. 2.

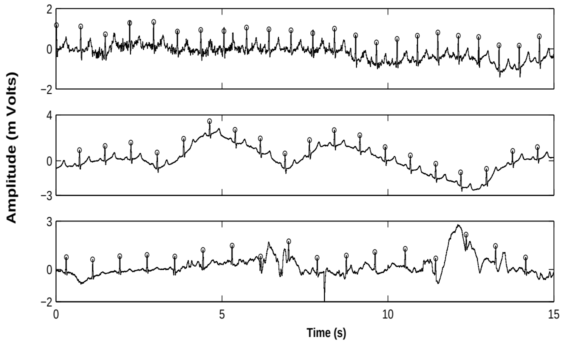

Fig. 2: ECG peak detection in three signals acquired from different patients involved in the study

The mean spectrum of the simulated $m(t)$ signal (see section C) and the mean spectrum obtained with a 9[th] order AR model for the HT signal are presented in Fig. 3. The MNE and the error associated with the power in the LF and the HF bands are shown in Fig. 4(a) and Fig. 4(b) respectively.

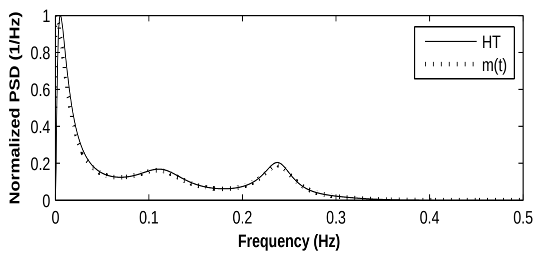

Fig 3: Mean spectrum of $m(t)$ and HT signal obtained from twenty random realization

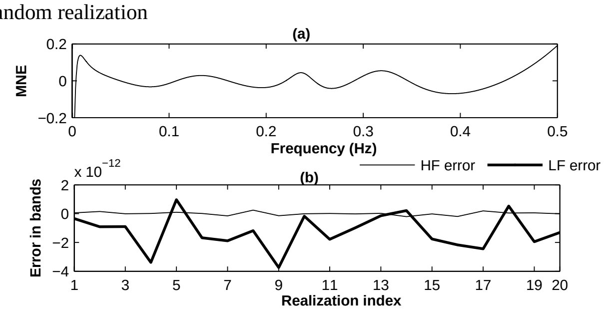

Fig 4; (a) Mean Normalized Error (MNE) and (b) error in the power of the LF and the HF band

In order to see the effect of ectopic beats on the power spectrum, ten signals were generated by randomly removing five beats from the beat locations generated by one of the realizations of $m(t)$ discussed above. Fig. 5 shows one example of the spectrum of the modulating signal $m(t)$ and the spectrum obtained before and after the ectopic beat correction. As before, the results for the MNE and the error in the power of the LF and the HF band before and after ectopic beat correction are presented in Fig 6 and Fig. 7 respectively.

The result obtained by detrending a typical HT signal from a patient is presented in Fig. 8. The spectrum of the same HT signal after detrending with WP algorithm and after removing a liner trend is presented in Fig. 9.

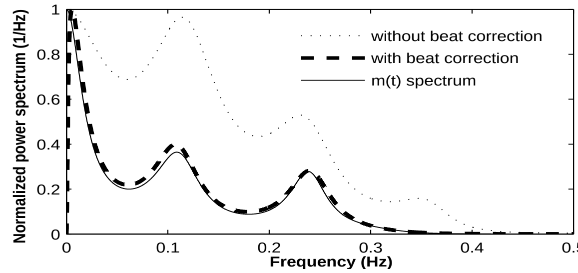

Fig 5: Spectrum of the $m(t)$ signal (solid line), the spectrum before the beat correction (thin dotted line) and the spectrum after beat correction (thick dotted line).

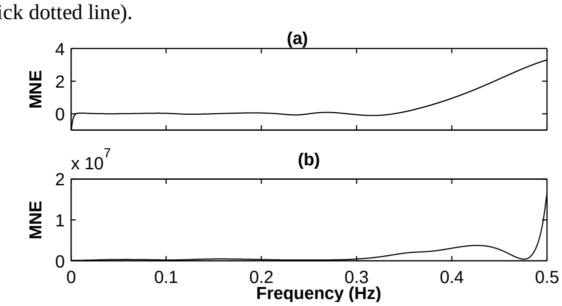

Fig 6: (a) MNE before the ectopic beat correction and (b) MNE after beat correction

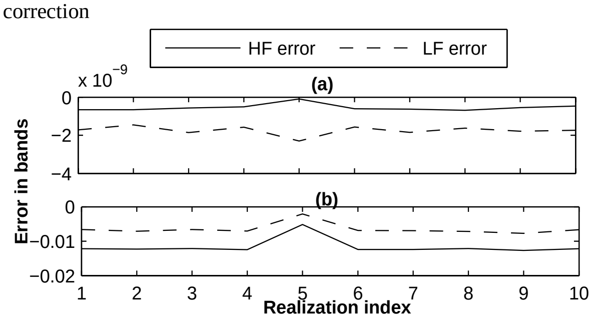

Fig. 7: Error in the power of the LF and the HF band (a) after ectopic beat correction, (b) before ectopic beat correction

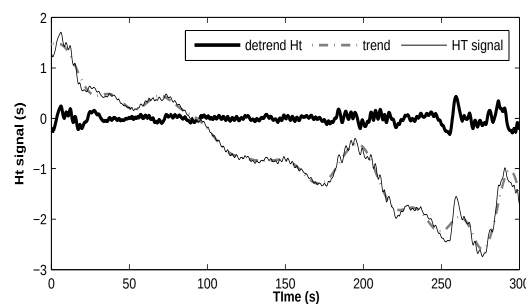

Fig. 8: HT signal before and after detrending and trend removed from the signal

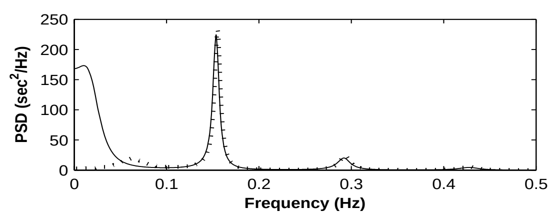

Fig. 9: Spectrum of the HRV signal after removing linear trend (solid line) and after detrending using WP algorithm (dotted line)

The spectrum obtained after linear trend removal (Fig. 9 (solid line)) shows that the spectrum is dominated by a large

component at very low frequency, and because of this, interpretation of other smaller frequency components is difficult. By comparing this with the spectrum obtained after WP detrend removal (dotted line in Fig. 9) it is clear that the components in the LF and HF region of the signal are not affected by the trend removal technique. Further more, in this case it is relatively easier to distinguish the spectrum components.

From the patients data the power spectrum was again calculated using 1200 points, but in this case the signal was overlapped by 50% so that each time 600 new samples were used.

The analysis of the signal from the patients revealed that in most cases the $\frac{LF}{HF}$ ratio increases just after the application of the brachial plexus block and then decreases considerably compared to the values at the start of the block. The timing of the drop in the ratio value differs from patient to patient, but in each case the drop occurs within an hour of the start of the block. Some examples of the changes in the ratio values after the application of the block are presented in Fig. 10.

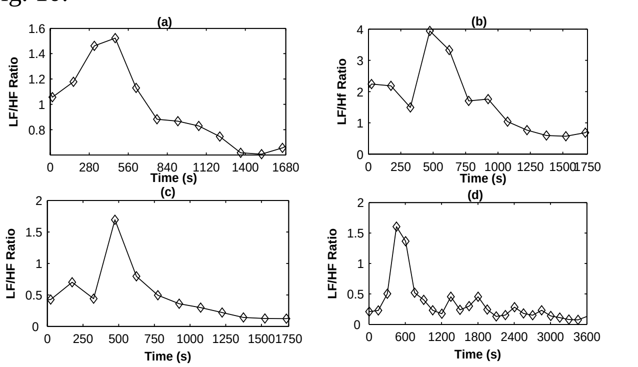

Fig. 10: Ratio $\frac{LF}{HF}$ changes after the brachial plexus block. In each case there is an increase right after the block and then the ratio values shows considerable decrease compared to the starting value

The drop in the $\frac{LF}{HF}$ ratio value was expected as a result of the introduction of local anesthesia. The anesthetic agents Lignocaine and Bupivacaine are known to have a decreasing effect on the heart rate. The changes in the ratio values were observed in the majority of the recruited patients (11 out of the 14).

IV. CONCLUSION

In this study various techniques of HRV analysis have been discussed and successfully evaluated. The HT signal which provide unbiased estimate of the modulating signal has been used. The effects caused by ectopic beats on the power spectrum of a five minute signal are shown in Fig. 5. Results shown in Fig. 6 and Fig. 7 indicate that the ectopic beat correction has managed to reduce the distortion caused by the missing peaks in the spectrum of the signal.

The detrending algorithm developed using Wavelet Packets (WP) has successfully removed the slow moving trend from the signal without creating significant distortion or reduction in the power of the signal in the LF and HF region. Fig. 8 shows the detrending of a typical HT signal and Fig. 9 provides the evidence that this technique has removed the slow varying components successfully without significant changes in the power of the signal in the LF and HF region.

Finally the ECG data acquired from 14 patients undergoing local anesthesia, using a combination of 30 ml Lignocaine and 29 ml of 0.5% Bupivacaine as the anesthetic agent were analyzed using AR spectral technique. The results from the power spectral analysis indicate that the $\frac{LF}{HF}$ ratio increases just after the block is applied and then decreases significantly compared to the starting value. Typical examples of such traces are shown in Fig. 10.

This pilot clinical study suggests that during brachial plexus block using a mixture of Lignocaine and Bupivacaine there is a noticeable and almost consistent change in HRV. Such encouraging results suggest further and more rigorous clinical studies.

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