UNCERTAINTY OF HEART RATE VARIABILITY DIAGNOSTIC INDICES IN PATIENT MONITORING SYSTEMS

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Abstract: Analysis of measurement uncertainty influence on the error of heart rate variability diagnostic indices is presented. Sensitivity of diagnostic indices for varying patient status has been evaluated in terms of the variations in histogram distribution parameters.

Introduction

Monitoring of heart rate variability (HRV) indices is an effective tool of patient monitoring, allowing evaluation of control process activity changes, which are representative of degree of adaptive response to adverse conditions [1-5].

In order to obtain HRV indices, sample of a certain volume of consecutive NN-intervals (systolic intervals) is being recorded and their length is measured followed by a variability analysis processing. Statistical estimates of NN-intervals distribution in the sample and spectral estimates, which reflect the wave structure of NN-intervals dynamic variation, can be used for this purpose.

Such estimates build up diagnostic indices, which enable judging the control balance between sympathetic and parasympathetic nervous systems. Method of the moving window, which is updated on a beat-to-beat basis, is widely used in patient monitoring systems employing real time recording of HRV indices. Such monitoring techniques demonstrate high clinical value and are widely used in anesthesiology, intensive care and reanimation [6-8].

Patient status diagnostics reliability is heavily depending upon the uncertainty of calculation of HRV indices, which is determined by the signal recorder precision characteristics and robustness of the statistic estimates employed. Absolute uncertainty of NN-intervals length measurement and NN-intervals sampling method have a major influence on the HRV indices calculation error. Thus, accuracy of obtained NN-intervals changes with the implementation of different means of heart rate signal recording (ECG, photoplethysmography, ultrasound) and various methods of cardiac cycle determination. Increasing number of errors causes a gradual decrease of diagnostic indices reliability and the same time, this limits the choice of sampling parameters. For example, with the increase of measurement error, statistical estimates remain correct only for relatively long samples [10]. This fact may seriously complicate the usage of HRV indices in real time monitoring. Therefore, selection criterion for the factors providing reliable diagnostics of patient status is an important part of patient monitoring design.

Materials and Methods

For the evaluation of influence of error sources on the uncertainty of HRV indices the following commonly used parameters have been selected [1,3]:

Diagnostic indices, defined by statistic estimates of NN-intervals durations within a sample:

a) SDNN, ms – standard deviation of all NN-intervals;

b) diagnostic indices, based on geometric methods of variability evaluation, i.e. NN-intervals distribution histogram shape analysis:

TINN – triangular interpolation of NN intervals histogram index,

HRV index – triangular index,

IN – Baevskiy tension index [3].

As a diagnostic index derived from the data spectral analysis, R ratio was selected because of its wide use in patient status diagnostics in anesthesiology [6,7]:

$$R = LF / HF$$

where LF, ms^2 – spectral power of NN-intervals duration oscillations in the low frequency range (0.04…0.15) Hz,

HF, ms^2 – spectral power of NN-intervals duration oscillations in the high frequency range (0.15…0.4) Hz,

Model signal was used in order to obtain samples for further investigations of HRV. For stationary segments distribution of NN-intervals recorded during the intraoperative patient monitoring shows good compliance with normal distribution (criterion χ^2 at 0.9 level). This effect confirms the heart rate regulation model, which implements multiloop delayed feedback. Based on this, the sample was compiled as a numeric array of NN-interval durations with normal distribution. Standard deviation σ_{st}, corresponding to SDNN, and NN_{avg} (mean duration of NN-intervals) has been used for altering the characteristics of distribution. Range of these parameters was set in accordance with the numeric scale, corresponding to the patient status described in [4]. So for normal distribution, good patient adaptation (“normal condition”) corresponds to σ_{st} = 100ms and more. Lack of adaptation is characterized by decrease of

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σ_{st} , reaching the value 20ms in case of "critical condition" or "breakdown" of control. The same time, NN_{avg} is changing from 1.0 to 0.5 s. Thus, 5 points on the numeric scale pertain the normal condition and 1 point – to the critical status of patient.

Table 1: Patient status numeric scale vs. variable distribution parameters of the sample.

Condition, points	1	2	3	4	5
σ_{st} , ms	20	40	60	80	100
NN_{avg} , s	0.50	0.57	0.67	0.80	1.00

Practically, sample data is produced by normal distribution random number generator with parameters according to the Table 1. In order to understand the influence of NN-intervals measurement absolute error on HRV indices error, durations of NN-intervals were varied. Provided that the measurement has a random error, NN-intervals durations were also random, centered on the NN-interval value in the sample and distributed normally. Changing the standard deviation of measurement error can vary absolute error of measurement σ_m . So, absolute error can be easily found (probability belief equals 0.9):

$$\Delta = 1.6\sigma_m$$

Investigating the geometric indices of heart rate variability, it is important to notice, that its values are highly influenced by the size of NN-intervals histogram bins. In patient monitors employing HRV analysis the bins have fixed size and this results in change of histogram distribution during the changing of patient status. That is why HRV indices error analysis also aims at finding the relation between HRV indices versus histogram bins size.

In case of spectral HRV indices, the data sample consisted of NN-intervals containing durations changing harmonically with frequencies, falling under LF and HF ranges. Ratio of modulation amplitudes was selected so that diagnostic index R has value from 1 to 10 units. This corresponds to patient status numeric scale from 5 to 1.

Evaluation of data sample length influence to diagnostic indices error was performed presuming that the "exact" value of the diagnostic index is calculated with 10000 NN-intervals. Estimation of geometric HRV indices was performed with probability belief 0.9.

Results

Relative error of SDNN and spectral index R versus absolute error of NN-intervals measurement taken at different patient status are described on Figure 1. Increase of measurement error results in the increase of HRV indices error. For critical conditions (1..2 points), errors are higher than for normal condition. Spectral index R has 1.5-2 times higher error values than SDNN, provided that measurement error remains unchanged.

Relation between NN-intervals histogram bin versus the indices sensitivity to the patient status is described on Figure 2.

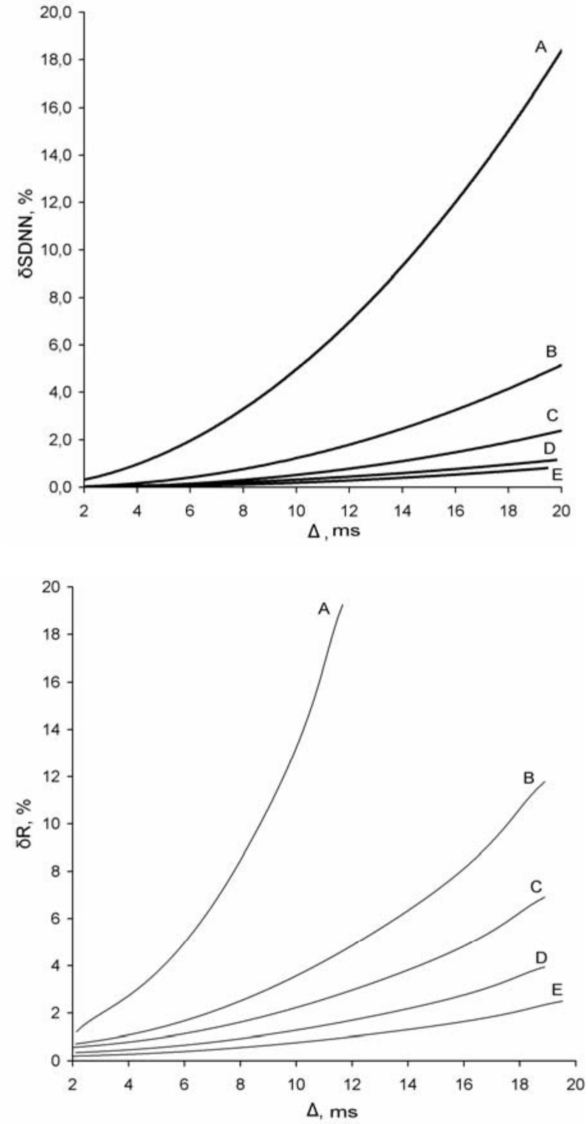

Figure 1: Relative error SDNN and R vs. NN-intervals measurement error for different patient status. A – 1 point, B – 2 points, C – 3points, D – 4 points, E – 5 points.

Sensitivity of TINN, IN and HRV indices to patient status change for given sizes of bins proves that sensitivity of indices is different for certain patient status. Sensitivity of indexes decreases while d is rising. For critical conditions sensitivity of TINN and IN is much higher, than for normal condition, especially for IN.

Dependence of relative error of TINN, HRV index and IN upon NN-intervals measurement error is shown on Figure 3. In this case histogram bin was 10ms and graphs shown relate to different patient status. For critical conditions area, measurement errors influence more severe than in the normal condition.

Research results of the influence of data sample size on the deviation of HRV indices are shown on Figure 4. Shrinking of the sample size causes increase of error, especially for the geometric indices deviations are drastically higher, than for SDNN. However, with the decreasing variability of heart rate (critical condition), the error decreases.

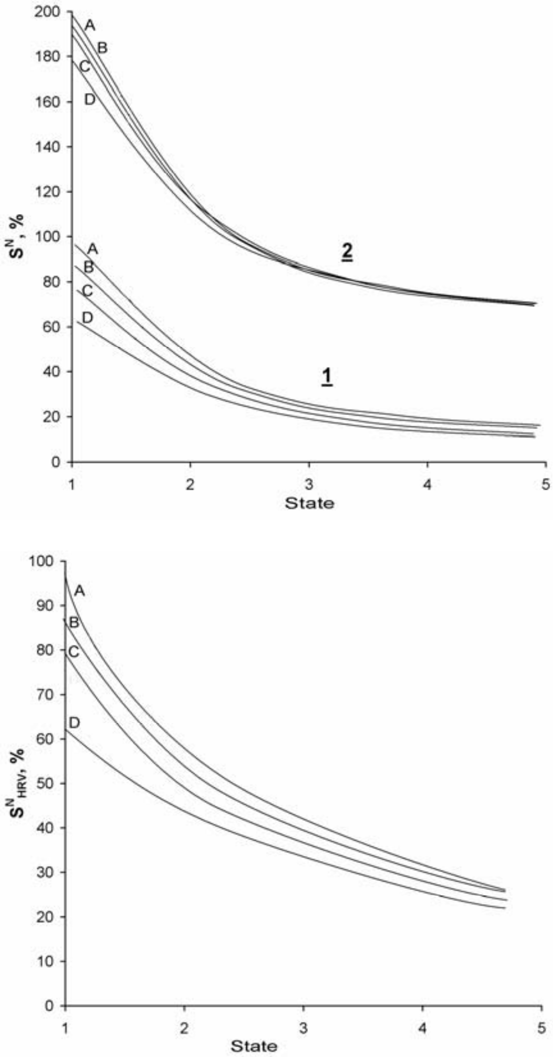

Figure 2: Sensitivity of TINN (1), IN (2), HRV index vs. the change of patient status for different size of bins (A- 5ms, B – 10ms, C – 20ms, D – 50ms).

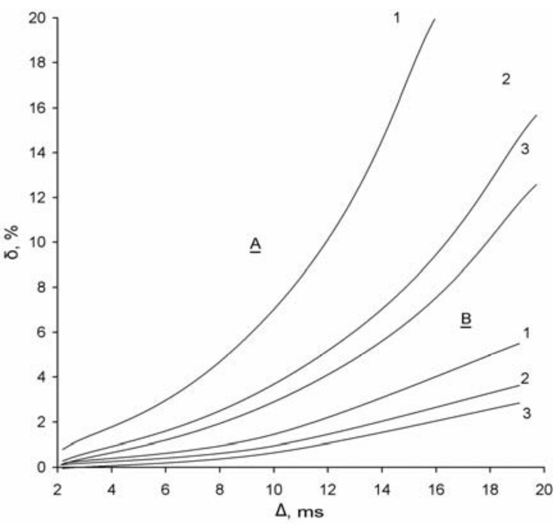

Figure 3: relative error of TINN (1), HRV(2) and IN (3) versus absolute error of NN-intervals measurements for different patient status (A – 1 point, B – 5 points)

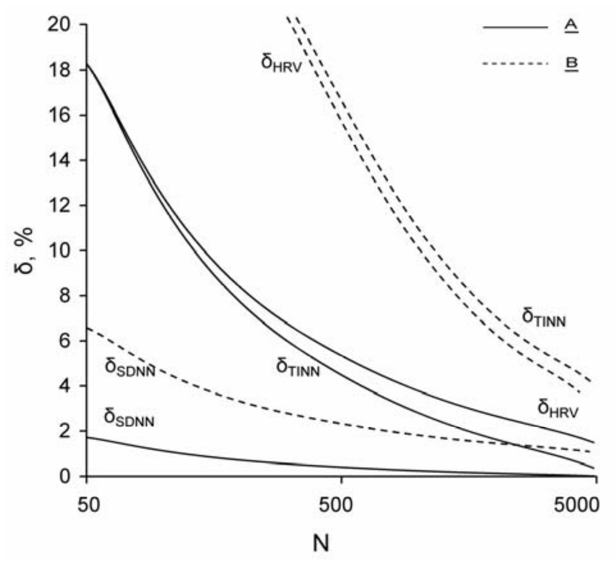

Figure 4: SDNN, HRV, TINN versus size of data sample for different patient status (A- 1 point, B – 5 points)

Discussion

Uncertainties of HRV indices depend upon the NN-intervals measurement accuracy. Increase of uncertainty widens the intervals distribution, and therefore estimates of heart rate variability as well as diagnostic indices become overvalued. As a result there is a threat of hypodiagnostics. If interval duration measurement error is high, then, HRV indices values depends mostly upon the values of these uncertainties, especially in the critical condition area, where heart rate variability is low. Limitation of the relative error of diagnostics indices may be chosen as reliability criteria of diagnostics. For example, if indices error is fixed at the value of 10%, then error of measurement should be within 8ms. This requirement can be easily met by means of widely used equipment for recording of heart rate. Photoplethysmographic and rheographic heart rate recording requires tests for the evaluation of measurement uncertainties.

Histogram bins size should be carefully selected especially when HRV-index or IN is being calculated. This stems from the fact, that these indices both use for calculation the value of mode amplitude of distribution. That is why, it is recommended to state the bin size for the diagnostics using indices derived from histogram data. It is also possible to show that without gradual decrease of HRV indices sensitivity, bins can be as long as 10ms that corresponds to the common used assumptions for heart rate variability analysis [1]. Increase of bins leads to decrease of diagnostic indices sensitivity to changing patient status and to mistakes in diagnostics.

For geometric indices, uncertainties were higher than for SDNN but lower than uncertainties of spectral indices. So, non-strict requirements to the accuracy of intervals measurement enable the use of recording methods like photoplethysmography, which in comparison with ECG recording is simpler and does not require special hardware design.

Monitoring of HRV indices using the moving sample for tracking of the fast changes of patient status requires reduction of the data sample length. This causes a decrease in statistic reliability and increases other errors. In the model used, geometric indices are calculated for short data samples (50…100 NN-intervals) and therefore these indices have high uncertainty, because of a strong deviation of the distribution from a normal one. However, these uncertainties fall into the critical condition area, where tracking of fast changes considered most important. When relative error of diagnostic indices is limited to 10%, data sample volume for reliable SDNN estimate can be chosen 50, for TINN and HRV-index – 250 beats (for critical condition area). SDNN is considered to be the most reliable to data sample shrinking. It has the minimum error for short data samples. Also, this index retains the best dynamic characteristics during patient monitoring.

Conclusions

Performed analysis shows that uncertainties of HRV indices (SDNN, R, TINN, HRV-index, IN) depend upon the accuracy of NN-intervals duration measurement and data sample length. Limitation of relative error of diagnostic indices is taken as patient status reliability criteria, so if error is limited to 10% then duration measurement error may be not more than 8ms. Photoplethysmographic and rheographic pulse sensors fulfill this accuracy requirement and are recommended for use in patient monitoring systems. Diagnostic indices, which employ distribution form analysis within the data sample, show decreasing sensitivity to changing patient status as a result of increasing histogram bins. SDNN index has a high resistance to shrinkage of data sample volume. It is recommended for tracking fast changes in patient status in real time monitoring.

References

[1] 'Heart rate variability: standards of measurement, physiological interpretation and clinical use': *European Heart Journal*., **17**, pp.354-81.

[2] A. HALLSTROM, PH. STEIN, R. SCHNEIDER, ET AL: 'Structural Relationships Between Measures Based on Heart Beat Intervals: Potential for Improved Risk Assessment', *IEEE Trans. BME*, **51**, pp.1414-20.

[3] R. BAEVSKIY, G. IVANOV, L. CHIREYKIN ET AL (2001): 'Analysis of heart rate variability using different electrocardiography systems: recommendations', *Vestnik Aritmologii*, **24**, pp.1-23.

[4] R. BAEVSKIY, G. NIKUNINA (2000): 'Holter monitoring in space medicine: heart rate variability point scale', *Vestnik aritmologii*, **16**, pp.6-14

[5] V. KALAKUTSKIY, V. KONYUKHOV, E. MANELIS (2002): 'Estimation of fetal heart rate using abdominal ECG recodings', Proc. of EMBEC'02, Austria, 2002, p.1544.

[6] GALLETLY DC, WESTENBERG AM, ROBINSON BJ, CORFIATIS T.(1994): 'Effect of halothane, isoflurane and fentanyl on spectral components of heart rate variability', *Br J Anaesth*., **72(2)**, pp.177-80.

[7] INTRONA R., MONTANO, N., YODLOWSKI E., MARTIN D., PRUETT, J., CRUMRINE R. (2000): 'Low-frequency Component of Heart Rate Variability', *Anesthesiology*, **93(1)**, pp 301-302.

[8] O'FLAHERTY D. (1993): 'Heart Rate Variability and Anaesthesia', *European Journal of Anaesthesiology*, **10**, pp. 419-32.

[9] L. KALAKUTSKIY, E. MANELIS (2003): 'Hardware and Methods of patient monitoring' (Vyschaya Shkola, Moscow), pp.1-165

[10] J. JEZEWSKI, J. WROBEL, K. HOROBA, ET AL (2002): 'Estimation of beat-to-beat accuracy of fetal heart rate data obtained via Doppler ultrasound'. Proc. of EMBEC'02, Austria, 2002, p.1536.

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