JOURNAL OF MEDICAL INFORMATICS & TECHNOLOGIES Vol.6/2003, ISSN 1642-6037

fetal heart rate variability,
Doppler ultrasound method,
fetal electrocardiogram

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RELIABILITY AND QUALITY OF ULTRASOUND MEASUREMENTS OF FETAL HEART RATE VARIABILITY

This work was aimed at assessment of usability of Doppler ultrasound method for the analysis of fetal heart rate variability at a level of single heart beats. The purpose of this study was to check if today fetal monitors provide the signal of accuracy comparable with an electrocardiography method. The virtual instrumentation software for measurement system and processing of acquired signals was implemented using LABVIEW environment. The results obtained reveal that accuracy of today monitors which use Doppler ultrasound technique is sufficient for visual analysis of the FHR traces. However, for the computerized analysis at a beat-to-beat level, this accuracy is below the acceptable value.

1. INTRODUCTION

Fetal heart activity monitoring is a part of routine obstetrical care and it is focused on detection of the earliest stages of fetal hypoxia. This monitoring relies on recording and analysis of fetal heart rate. The instantaneous fetal heart rate (FHR) expressed in beats per minute is a reciprocal function of time interval calculated as the distance in time between a two consecutive cardiac cycles. The most common is the monitoring of mechanical activity of fetal heart using the ultrasound Doppler method [8]. The method is based on that ultrasound waves which have possibility of penetrating tissues but are partly reflected. When the reflecting surface is not in motion, there is not any change in the frequency of the return wave. On the other hand, when the ultrasound waves meet a moving surface, the reflected part of the beam will have a different frequency. The analysis of the reflected wave permits measuring the periodicity of the signal by determining the consecutive cardiac cycles and then estimating the instantaneous values of FHR (Fig. 1).

At present, computer-aided systems of fetal monitoring are commonly used, which perform automated analysis of FHR signal [6, 7]. One of the basic elements of automated analysis of FHR is evaluation of instantaneous variability of fetal heart rate, which follows the changes of duration of consecutive T_{RR} intervals (Fig. 2). The work was aimed at assessment of usability of Doppler ultrasound method for the analysis of fetal heart rate variability at a level of single heart beats [5]. Accuracy of fetal heart rate measurement at a level of 1% sufficient for visual analysis of strip-chart

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record is ensured by present-day bedside monitors using this method [1, 2, 9]. However, the computer analysis of short-term FHR variability, requires measurements of instantaneous FHR values with higher accuracy. That requirement was met by fetal electrocardiogram from penetrating electrode, which was commonly used in the past, but now is replaced by the non-invasive ultrasound method. The purpose of this study was to check if today fetal monitors provide the signal of accuracy comparable with an electrocardiography method. It is connected with an assumption that the measurement accuracy of time interval between two successive heart beats ≤ 1 msec ensures the required statistical significance of calculated short-term variability indices.

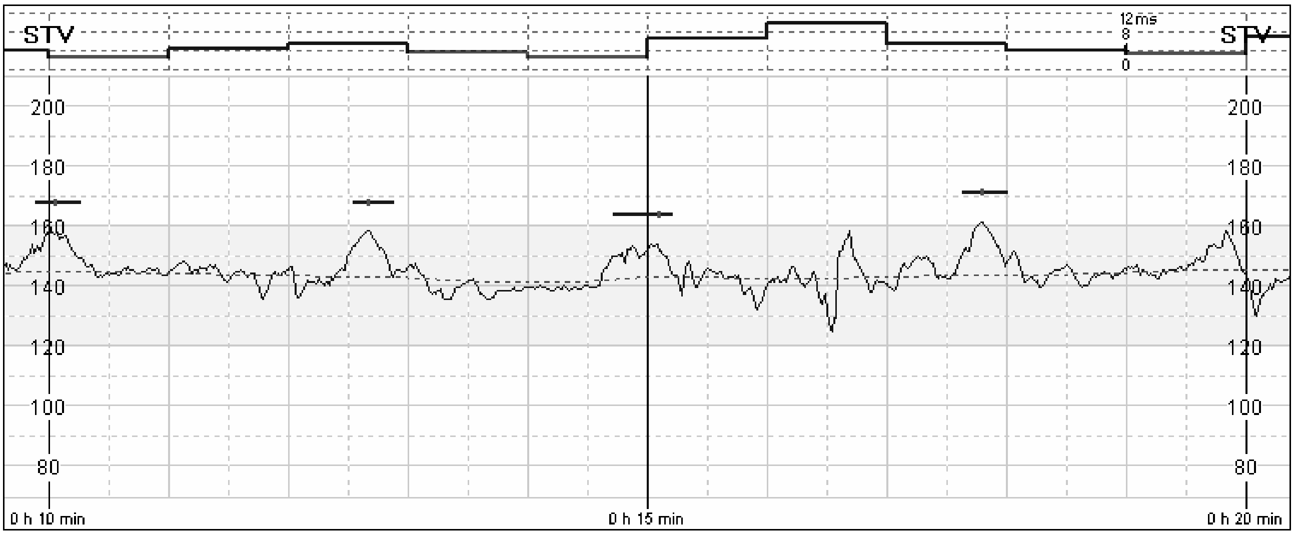

Fig.1. Segment of FHR waveform with automated interpretation: estimated baseline (dotted line), and recognized accelerations (horizontal lines above accelerations correspond to the pattern duration, and the vertical section represents the maximum peak). Above FHR waveform the basic measure of short-time variability – STV index expressed in milliseconds.

2. METHODS

The measurement instrumentation allowed for evaluation of Doppler ultrasound signal FHR_{US} delivered by a bedside monitor in comparison to a reference signal FHR_{REF} determined on the basis of our own algorithm for QRS complexes detection directly from a fetal electrocardiogram (FECG) [3, 4]. Analog signal FHR_{US} from a fetal monitor output was sampled with a rate 16 Hz and resolution 0.05 bpm. The FECG was obtained from the electrode penetrating fetal head. Amplified and initially filtered FECG signal was sampled at 2 kHz rate and 4 μV resolution. These signals were acquired by a portable computer with built-in data acquisition card. The virtual instrumentation software for measurement system was implemented using LABVIEW environment. The processing of acquired signals and estimation of accuracy were done off-line. Determination of FHR reference signal was based on two independent detection methods of QRS complexes: energy sensitive technique and cross correlation analysing the entire shape of signal (Fig. 3). The reference R-R interval was accepted if the difference of R waves location between the methods was ≤ 0.5 msec. The process of comparison comprised the instantaneous values of FHR_{US} signal determined by a monitor (in beats per minute – bpm) and recalculated into $T_{R\text{-}R}$ intervals (in msec). Synchronization with the reference signal was obtained by delaying the FHR_{REF} signal in relation to FHR_{US} by 225 msec.

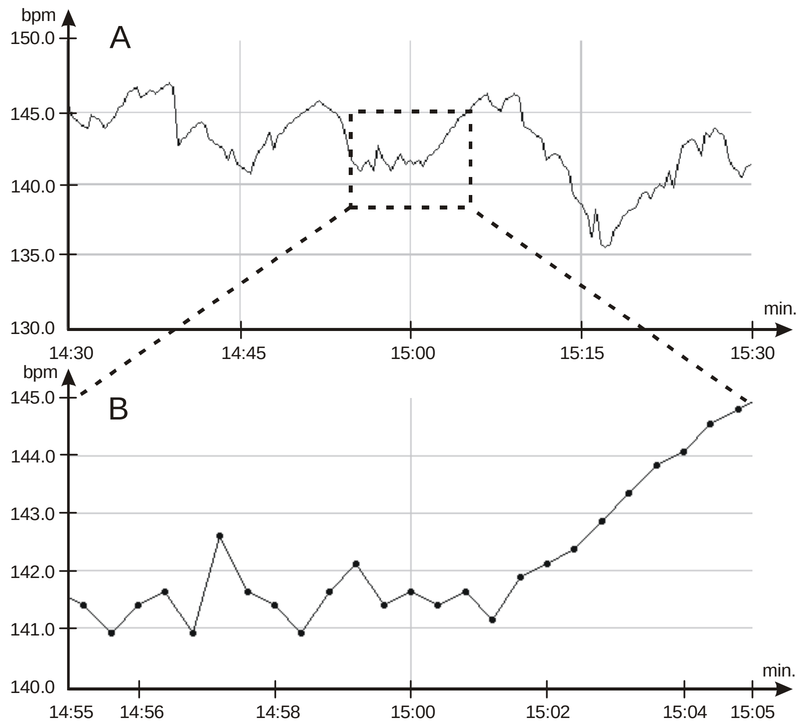

Fig.2. Variability of fetal heart rate: A – long-term variability (LTV) calculation in 1 minute window, B – short-term variability (STV) calculation at a level of heart beats.

Difference between the signals was evaluated basing on the difference between corresponding $T_{R\text{-}R}$ intervals, where the timing signal were events connected with consecutive R waves in FECG signal. Data were collected during the labours of 5 women, total duration of recordings was 185 minutes, which made possible to compare about 25 thousands of cardiac periods.

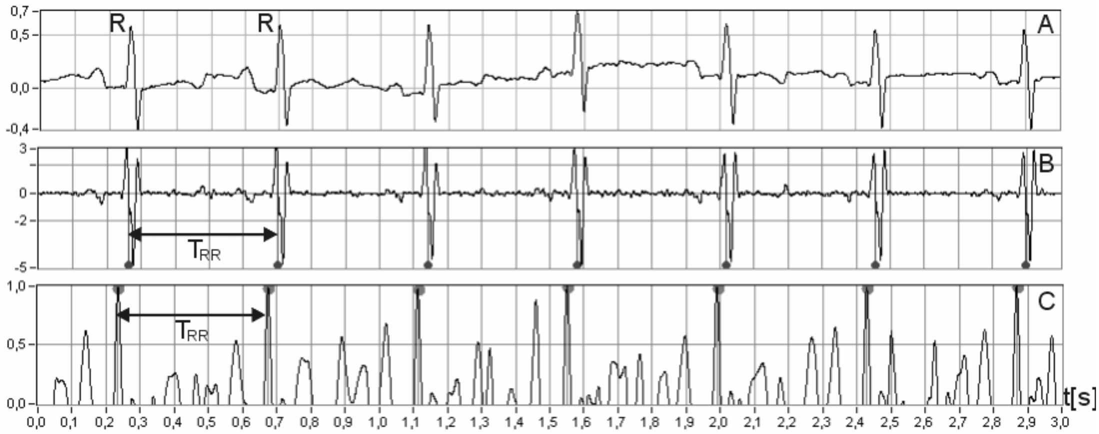

Fig.3. Determination of $T_{R\text{-}R}$ intervals for reference signal. A - input FECG signal, B - derivative of FECG with detected R-segments, C - cross correlation function with R-segments.

3. RESULTS

When verifying the reference signal, 3.3% of the number of cardiac intervals detected in FECG signal have been rejected and next 8.1% of intervals were eliminated with regard to signal loss in FHR_{US}. Significant differences were observed in the level of signal loss in relation to a particular trace: 0.1% ÷ 16.2% for FHR_{REF} and 2.3% ÷ 33.5% for FHR_{US}. The main reason was the fetal movement activity. There was visible a difference in the length of signal loss. For the reference signal, 75% of signal loss had the length ≤ 2 beats, whereas for FHR_{US} 75% had the length ≤ 5 beats.

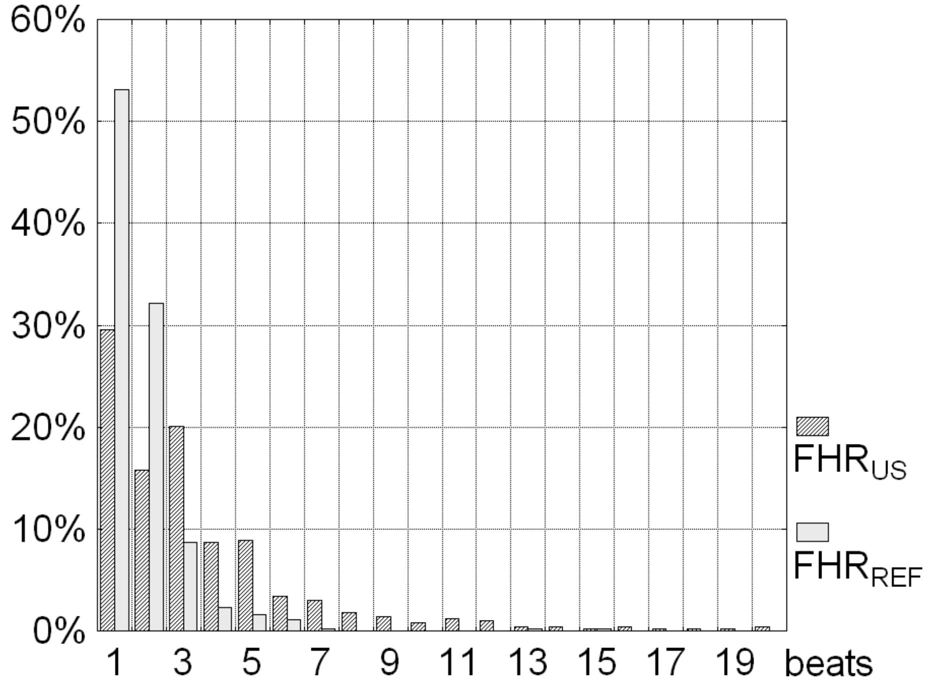

Fig.4. Frequency distribution of particular signal loss segments, segment length is expressed in lost beats.

Figure 4 presents frequency distribution of particular signal loss segments expressed in lost beats. It can be noted that in case of FHR_{US} 30% of all segments represents 1 beat loss, while 20% the signal loss of 3 beats. However, the highest number of lost beats (15% of all lost beats) comes from segments characterized by 3 beats loss (Fig. 5).

It has been proved that 76% of errors of the ultrasound method were > 1 msec, and 46% were > 2 msec. In general, 95% of errors do not exceed the value 8.4 msec (Fig. 6), which is considerably more than the acceptable value for correct short-term variability analysis. According to visual analysis, 60% of errors were < 1 bpm, and only 25% of errors exceeded 2 bpm. Taking into account, that the line thickness on a strip chart corresponds to 0.5 bpm – these differences are difficult to observe. The mean error of the method calculated from absolute differences of corresponding $T_{R\text{-}R}$ intervals was equal to 0.9 bpm and the relative FHR_{US} measurement error was 0.8%. That was below the value of 1%, which was declared.

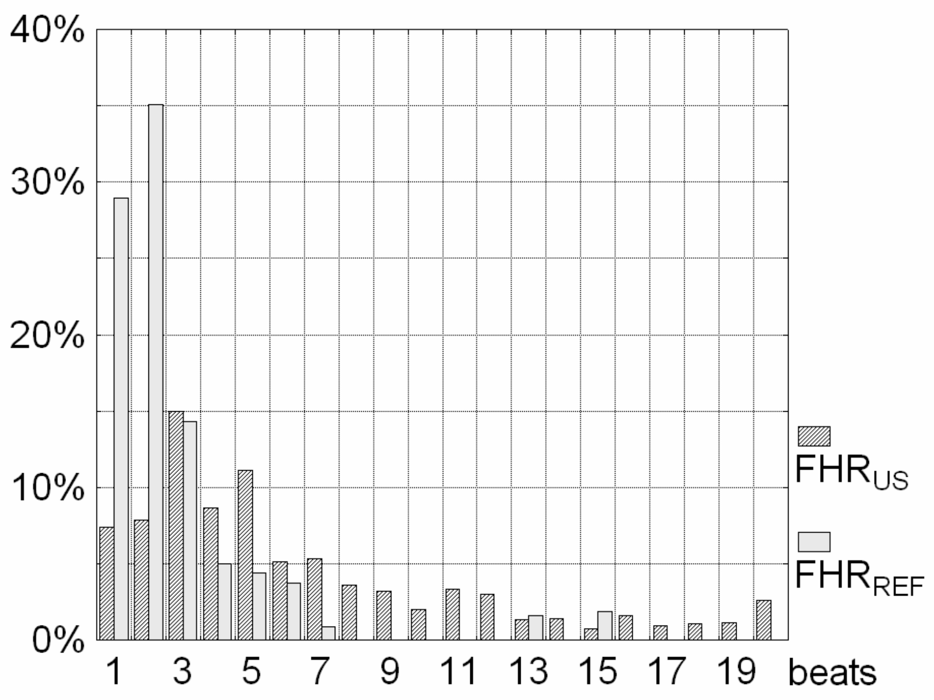

Fig.5. Percentage of lost beats observed in segments of particular length in overall number of lost beats.

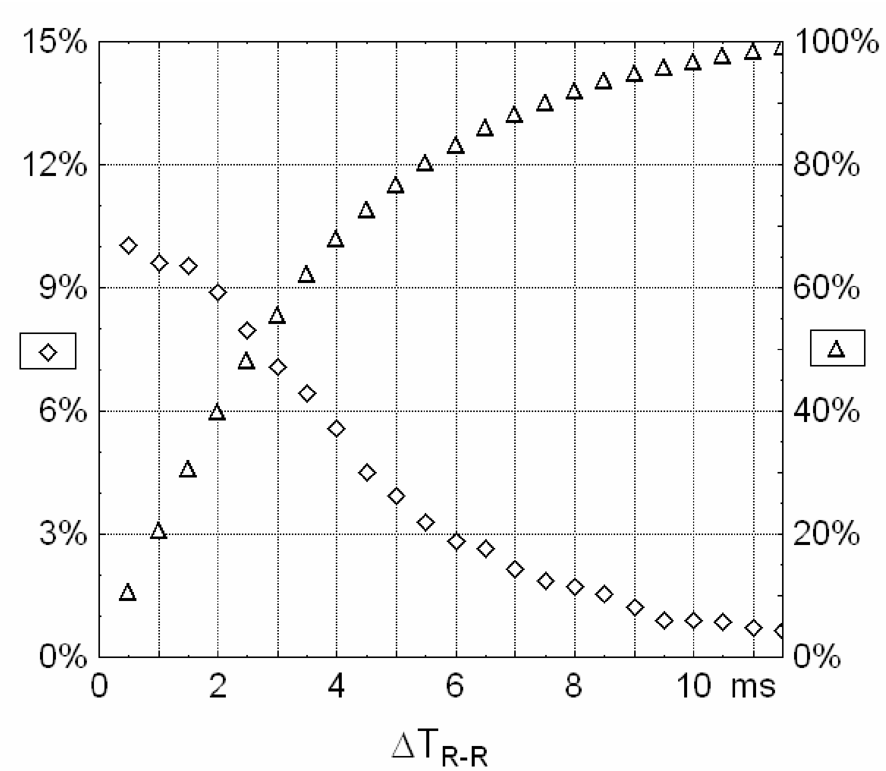

Fig.6. Absolute error ΔT_{R-R} of measurement of T_{R-R} intervals using ultrasound method in relation to the reference: ◊ – frequency distribution, Δ – cumulative histogram.

4. CONCLUSIONS

In the presented work, a quantitative estimation of determination error of FHR_{US} signal received from ultrasound monitor's channel has been made. The FHR_{REF} signal was a reference obtained from the full FECG signal by means of independent algorithm of R waves detection. The results obtained reveal that accuracy of today monitors which use Doppler ultrasound technique is sufficient for visual analysis of the FHR traces. However, for the computerized analysis at a beat-to-beat level, this accuracy is far below the acceptable value.

BIBLIOGRAPHY

[1] CARTER M.C., Present-day performance qualities of cardiotocographs., Br. J. Obster. Gynecol, Suppl., 100, 9, pp. 10-14, 1993.
[2] DAWES G. S., VISSER G. H. A., GOODMAN J. D .S., REDMAN C. W. G., Numerical analysis of the human fetal heart rate: The quality of ultrasound records, Am. J. Obst. and Gynecol., 141, pp. 43-52, 1981.
[3] HUANG X.B., CROWE J.A., HERBERT J.M., WOOLFSON M.S., A Windows Application for Real-Time Fetal ECG Analysis. Comp. Biomed. Res., 27, pp. 419-433, 1994.
[4] JEŻEWSKI J., WRÓBEL J., HOROBA K., CHOLEWA D., GACEK A., KUPKA T., MATONIA A., Monitoring of mechanical and electrical activity of fetal heart: The nature of signals, Archives of Perinatal Medicine, Vol. 8(1), pp. 40-46, 2002.
[5] JEŻEWSKI J., WRÓBEL J., HOROBA K., GACEK A., Instrumentation for fetal monitoring – improvement in Doppler ultrasound technology, J. of Medical Informatics and Technologies, Vol. 2,2, pp. 17-26, 2001.
[6] JEŻEWSKI J., WRÓBEL J., HOROBA K., GRACZYK S., GACEK A., SIKORA J., Computerized perinatal database for retrospective qualitative assessment of cardiotocographic traces, Current Perspectives in Healthcare Computing, BJHC Limited, Ed. B. Richards, pp. 187-196, 1996.
[7] JEŻEWSKI J., WRÓBEL J., HOROBA K., GRACZYK S., Implementation of graphical user interface in computer-aided fetal monitoring system, Proc. of 5th Conf. of the European Society for Engineering and Medicine, pp. 249-250, Barcelona, 1999.
[8] JEŻEWSKI J., WRÓBEL J., HOROBA K., MOCZKO J., BRĘBOROWICZ G., GRACZYK S., Advances in Doppler ultrasound FHR monitoring, Kliniczna Perinatologia i Ginekologia, Suppl.IX, pp. 235-240, 1995.
[9] KOYANAGI T., YOSHIZATO T., NAKANO H., Quantification of fetal heart rate variation using a probability distribution matrix, Bailliere's Clin. Obstet. and Gynecol., 8,3, Ch. 2, pp. 549-563, 1994.

This study was supported by the State Committee for Scientific Research, Warsaw, Poland (KBN Grant No. 4 T11E 006 22).