ABSTRACT

The main principle of present-day perinatology is to ensure successful childbirth. Antepartum biophysical monitoring is usually performed by means of cardiotocography (CTG). In an attempt to minimize subjectivity and poor reproducibility of visual evaluation of CTG traces, computerized systems for automated analysis of cardiotocographic signals are commonly used. They perform several tasks where the most important are real-time acquisition and analysis of cardiotocografic signals from several fetal monitors. Further extension of computerized cardiotocography is a qualitative analysis of antepartum cardiotocograms which is carried out within non-stress test (NST). The NST idea based on fetal heart rate acceleration associated with fetal movement is a good prognostic sign with high predictive value of fetal well-being. This paper presents the procedure of establishing criteria for automated evaluation of non-stress test in computer-aided cardiotocography.

INTRODUCTION

Cardiotocography (CTG) as a fetal heart rate monitoring with simultaneous recording of uterine activity is the dominant method for fetal surveillance. The aim of the computerized approach [2, 4] is to automate the execution and interpretation of CTG recordings. Further extension of computerized cardiotocography to qualitative analysis of antepartum traces carries problems with verifying the correctness of interpretation. The qualitative evaluation of a trace is not to help a clinician diagnose a fetal condition but to aid interpreting a test of fetal well-being in order to predict the fetal outcome. The traditional non-stress test (NST) procedure in fetal heart rate monitoring is based upon the presence or absence of acceleration episodes in a limited time period. Since the earlier studies were based on intrapartum recordings or traces from patients who delivered within hours of their last monitoring, the correlation between trace interpretation and actual fetal outcome was almost immediate. Currently, in antepartum cardiotocography, longitudinal serial CTG recordings start much earlier, particularly in high risk pregnancies. As a result, the correctness of trace interpretation is evaluated retrospectively on the basis of data referring to symptoms of intrapartum fetal distress and to fetal outcome components.

In order to define correlation between CTG-trace features and a fetal outcome, the collection of appropriate data is required. This should include not only cardiotocograms and obstetric information but also a description of all monitoring conditions that can affect a current fetal state. In perinatology, unlike other disciplines of medicine, bad outcomes are relatively rare. Therefore, a group of cases classified as bad fetal outcome will not be representative unless a large number of cases in general
are collected [3]. All this data has to be included in a perinatal database which is a basic part of computerized fetal monitoring system with quantitative analyzing of cardiotocographic traces.

**COMPUTERIZED CARDIOTOCOGRAPHY**

In the system for computerized cardiotocography, fetal monitor is an input device (Fig. 1). The fetal monitor output enables fetal heart rate (FHR), uterine contractions and fetal movement information to be accessed by computer. Communication with the computer is bidirectional via RS232 serial interface. Several monitors can be connected to the system at the same time. Interface unit that assures the patient’s safety complying with general IEC standards for medical equipment, is inserted between the fetal monitor and computer. It contains signal conditioning circuits and isolation barrier. Monitors with analog output require an application of analog-to-digital converter [5]. Incoming CTG data is dynamically presented on the screen and analyzed on-line. The results of quantitative analysis of cardiotocographic trace are presented both in textual and graphical forms. Received data is stored in a system database. The database includes patient’s personal data, monitoring logs, results of analysis, parameters of alerting events and cardiotocographic traces.

Incorporation of a qualitative analysis of antepartum cardiotocograms within a non-stress test was a next stage of system development, and the aim of this paper was to present the process of establishing NST criteria as well as the procedure of automatic test evaluation.

**QUALITATIVE ANALYSIS OF CARDIOTOCOGRAM**

![Functional block diagram of non-stress test evaluation procedure](image)

In Fig. 2 Functional block diagram of non-stress test evaluation procedure

Incorporation of a qualitative analysis of antepartum cardiotocograms within a non-stress test was a next stage of system development, and the aim of this paper was to present the process of establishing NST criteria as well as the procedure of automatic test evaluation.
The idea based on fetal heart rate acceleration associated with fetal movement is a good prognostic sign with high predictive value of fetal well-being. The automatic NST evaluation comprises two blocks: classification and inference (Fig. 2). The classification block enables to determine all the non-stress test components on the basis of quantitative analysis of CTG parameters. In the simplest case, a value of a given parameter is compared to established discriminant thresholds, and as a result one of four values is assigned. The inference relies on transforming the set of logical values of components into a final NST result using fixed decision rules. The test result can assume one of four values: reactive, suspicious, non-reactive and alerting.

The two-stage process of NST evaluation allows to adapt evaluation criteria to clinical factors and to account for interactions between individual trace parameters. Occurring in the classification block, it does not affect the rules, which take into account only qualitative influence of individual parameters on a final result. The standard thresholds values determined for reference conditions are globally modified by clinical factors. These factors result from monitoring description (gestation age, patient's position, etc.) and from obstetric history (maternal risk factor, twin-birth pregnancy, etc). Interaction between individual quantitative parameters consist in local modification of thresholds for a given parameter on the basis of other parameter value.

Basic CTG parameters are: indices of short-term (STV) and long-term (LTV) fetal heart rate variability, signal loss, fetal movement etc. STV and LTV indices are computed on-line for all successive one-minute intervals on the base of FHR values averaged for intervals of 2.5 sec duration. Both LTV and STV indices are expressed for a whole record as a mean minute variation. Deceleration periods are ignored while accelerations only cause a modification of the method [6]. The minute variability is calculated as a difference between the maximum and minimum averaged values within a one-minute interval. Short-term variability is determined as a mean value of absolute differences of successive averaged values within a one-minute interval.

If the ratio of short- to long-term variability (STV/LTV) is below the mean value 0.18, more than double standard deviation from the mean (2 \( \ast 0.13 \)), then rare FHR trace with sinusoidal pattern can occur [9]. NST component \( c_5 \) (Fig. 3) identifying sinusoidal FHR trace is determined from STV value with the local modification of thresholds basing on LTV value.

**NST EVALUATION CRITERIA**

Verified records from the database are divided into two groups. One group comprises traces corresponding to fetal outcome qualified as bad, while the other contains the remaining traces - qualified as good outcome. The definition of good/bad fetal outcome is based on widely accepted components: perinatal mortality, intrapartum fetal distress, Apgar score, umbilical cord blood pH, etc. Each group is split into study and control subgroups. Material from study subgroups serves in successive cycles to optimize a set of NST criteria. Control subgroups are used to verify correctness of the incorporated criteria. The basic knowledge structure was taken from FIGO guidelines [8] for visual evaluation of antepartum cardiotocograms. The criteria are then modified and refined with heuristic procedures based on intuition and experience of clinical experts. FIGO guidelines contain information which cannot be unequivocally presented as an algorithm, although they are comprehensible for clinicians. Consequently, they have to be modified for computerized analysis by introducing detailed and unambiguous definitions. An additional assumption is that these criteria should be complemented by parameters that could be precisely measured only by computer. A physician carrying out a visual-trace as-

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**Fig. 3 Evaluation of STV component with local threshold modification**

\[ c_5 = CE(T \rightarrow 2', STV), \quad T \rightarrow 2 = LTM(T \rightarrow 2, LTV) \]

\[ T \rightarrow 2 = \{0.18 - 2 \ast 0.13, 0.18 + 2 \ast 0.13\} \]
essment is familiar with all clinical data. Therefore, when evaluating a CTG trace, he can often deliberately modify criteria to conform to a given situation. A similar effect of a computerized NST evaluation is achieved with the objective conditioning of discriminant thresholds in relation to clinical factors.

In every optimization cycle, recordings from study subgroups are evaluated by computer on the basis of NST criteria adopted for a given cycle. NST result qualifies traces to four classes: BN, BR, GR, or GN (see Fig. 4). The number of recordings in the GN and BR classes is reduced in the subsequent cycles. When analyzing recordings that have been found in these classes, clinical experts focus on CTG parameters causing false classification. Then they modify the criteria so that traces can be transferred respectively from BR to BN, and from GN to GR. Individual modifications are accepted only when there is no parallel transition of other traces respectively from GR to GN, and from BN to BR. Every cycle contains only one type of modification in reference to CTG parameter and clinical factor. After every optimization cycle, the resulted criteria are validated on the basis of control subgroups. The validation enables one to estimate universality of a modification and provides a conclusion to finish the optimization process.

RESULTS AND DISCUSSION

Our one-year study resulted in gathering 896 traces from 266 women. Each patient was monitored three to five times in the antepartum period. When revising the delivery and newborn data, in the light of fetal outcome evaluation, it was necessary to delete 77 unsatisfactorily described cases, which amounted to 273 records. Then the quality of traces was checked by evaluating the fetal heart rate signal loss and trace duration. As a result, 182 traces had to be deleted. Among the remaining traces there were 87 with incomplete monitoring logs, so data of 11 further patients were deleted. The final research material consisted of 122 women (354 traces). The bad-fetal-outcome group contained 62 (17.5 %) traces, good-fetal-outcome group 292. The ratio of the study to control subgroups was assumed as 1:3. The study group could not be too numerous, since the expert would not have been able to analyze properly details of traces classified as GN and BR.

For an initial set of criteria, sensitivity of NST was 52%, specificity 85%, positive predictive value 42%, and negative predictive value 89%. The set of results {52, 85, 42, 89} referred to the study and control groups joined together. Results achieved were better than those obtained through a conventional visual assessment, as done e.g. by Platt {27, 90, 44, 88} [7]. The results were comparable to computer analysis of recordings, e.g. Breborowicz {60, 87, 50, 91} [1]. The optimization procedure applied made better results possible - {65, 94, 70, 93}. Comparing the results obtained with regard to predicting bad fetal outcome, we noted an increase in sensitivity and positive predictive value. Simultaneously, no decrease in specificity or negative predictive value was observed.

CONCLUSION

The proper perinatal database enables a retrospective analysis of correlation between selected parameters of cardiotocographic traces and different aspects of fetal outcome. The procedure presented for extracting criteria for NST evaluation is the first step towards an automated qualitative
analysis of a trace. The method proposed is not entirely optimal, because it is grounded on knowledge and intuition of a clinical expert who cannot follow all relationships between CTG parameters and clinical factors. With a view to further research, it is proposed to collect more material and to introduce an automatic procedure of establishing criteria. Human action will apply only to modifying discriminative threshold, for both measurable and observable arguments. Thus, the establishing of rules will consist in reducing false and non-deterministic evaluations.

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