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European Community Multi-Center Trial "Fetal ECG Analysis During Labor": ST plus CTG analysis

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1 Introduction

Continuous fetal heart rate (FHR) and uterine contraction recording (cardiotocography or CTG) is widely used to assess fetal well being during labor. This method has, however, limitations. A normal CTG trace reflects optimal fetal oxygenation and is of reassurance regarding fetal conditions [10]. The significance of FHR changes is unclear and thus difficult to interpret [9]. Some of these difficulties might be overcome by a better training of medical and midwifery staff. However it is also evident that there are situations where the CTG changes are not specific for the presence of fetal hypoxia and additional information is necessary for appropriate decision making [7].

In the clinical scenario this can result in unnecessary intervention for suspected fetal hypoxia or inappropriate delay in action with potentially disastrous consequences for the fetus [2]. Analysis of ST waveform changes of the intrapartum fetal electrocardiogram (ECG) has the potential to provide specific information on the fetal reactions to hypoxemia, independent and complementary to the information contained in the CTG.

Evidence from experimental work indicate that ST waveform elevation reflects compensated myocardial stress and a switch to anaerobic metabolism [5, 12, 13]. A progressive rise in ST waveform (quantified by the T/QRS ratio) represents continuing anaerobic metabolism. This can lead to decompensation due to the depletion of myocardial glycogen stores and to the development of a progressive metabolic acidosis. The role of anaerobic glycogenolysis as a defense mechanism to maintain myocardial function and survival of the fetus during asphyxia is also well known. Thus, ST analysis may inform on the defense reactions taking place in a high priority organ.

Persistently biphasic and negative ST waveform changes indicate myocardial decompensation as a result of the impact of myocardial hypoxia/ischemia on myocardial function [19]. This physiological model of interpretation has been evaluated in observational studies [1, 8], and validated in a large randomised controlled trial comparing CTG + ST analysis versus CTG only [17]. The Plymouth trial [17] showed a significant reduction in the number of operative interventions for suspected intrapartum asphyxia with the use of ST waveform analysis without worsening outcome and with a trend towards less incidence of metabolic acidosis in the CTG + ST arm of the trial.

At the time of the Plymouth study the European Community Multi-center Trial "Fetal ECG Analy-

sis During Labor" was set up (EC Trial) [15]. In this prospective study the ECG information were not available to the clinician during labor but stored for analysis after delivery. Aim of the trial was to identify changes in the fetal ECG waveform with cases of verified fetal hypoxia. We report in this paper the result of this study. We also report on the use of a newly developed automatic system for identification of ST waveform changes (ST Log).

2 Methodology

This report form part of the European Community Multi-center Trial "Fetal ECG analysis During Labor". This trial has been operating under the auspices of the European Community Concerted Action Project "New Methods for Perinatal Surveillance". The data has been collected from the following perinatal centers:

- Dept. of Obstetrics and Gynecology, Östra sjukhuset, Gothenburg, Sweden
- Dept. of Obstetrics and Gynecology, Hôtel Dieu, Lyon, France
- Dept. of Obstetrics and Gynecology, University of Parma, Italy
- Dept. of Obstetrics and Gynecology, Klinikum Grosshadern, München, Germany
- Dept. of Obstetrics and Gynecology, Hvidovre University Hospital, Copenhagen, Denmark
- Dept. of Obstetrics and Gynecology, Karolinska Hospital, Stockholm, Sweden
- Dept. of Obstetrics and Gynecology, Central University Hospital, Turku, Finland.

During the multi-center trial, a total of 618 cases were collected. However, due to clinical data inconsistencies, it was decided to limit the analysis to the total number of cases collected in only two of the centers that took part in the trial. This report, therefore, includes data from 320 cases. For all these cases it was possible to review and compare the original case notes with the data entered in the data base and ensure that complete and accurate clinical information were available for each case.

The outcome parameters considered were: birth weight, birth weight centile using local growth chart, Apgar scores at 1, 5 and 10 minutes, cord artery and vein acid-base assessment, need and method of resuscitation, transferral to neonatal intensive care unit if required. The minimal gestational age for the cases in the trial was 36 completed weeks.

All ECG were recorded with a single spiral scalp electrode connected to the STAN®8801 recorder (Neoventa Medical AB, Gothenburg, Sweden) which allowed for the acquisition of an unfiltered fetal ECG signal (bandpass: 0.05−100 Hz − 3 dB). The CTG was recorded and used according to the different routines at the different centers. The ST information was not displayed during labor in order not to influence the clinical management.

The ECG signal was transferred on line to an ordinary PC for further signal processing with data reduction and subsequent data storage on storage media, including an optical disk. This STAN-PC system allowed for automatic data collection to take place using a simple power on/off routine. Information on the methodology of data storage has previously been reported [14, 15]. Data from each case consisted of the following data stored as digital data files; R-R intervals, uterine activity, 10 beat fetal ECG averages and real time.

These data were processed further to regenerate a CTG trace and a 30 beat ECG average for subsequent ST waveform analysis. This off-line signal processing would check for signal quality to secure that only high quality ECG averages were included. Apart from the calculation of the T/QRS ratio, averaged ECG complexes with a negative slope of the ST segment were identified. ST waveform changes were assessed in two ways:

1) by visual inspection of the recording using the CTG + ST display module (STAN Trainer®, Neoventa Medical AB, Gothenburg Sweden). This module allows the fetal heart rate, uterine activity, T/QRS ratio and a selection of 30 beats averaged fetal ECG waveforms to be displayed (figures 1−5) on a PC screen and paper;
2) by using an automatic PC based algorithm, the ST Log®, to identify changes in the T/QRS ratio.

The ST Log. The aim with this new feature is to provide a continuous support for the interpreta-

tion of ST waveform changes during labor. The following events are identified:

1) Episodic rise in T/QRS ratio, i. e. an increase in the median filtered T/QRS values of > 0.10 units for < 10 minutes.
2) Baseline rise in T/QRS ratio, i. e. consistent changes of more than 10 minutes duration. The baseline T/QRS was calculated as the median value of data recorded for a 10-minute époque, which was continuously updated on a minute-by-minute basis. A significant event was identified when the baseline T/QRS increased for > 0.05 units.
3) The appearance of repeated episodes of depression/negative slope of the ST segment. These changes are quantified by a scoring system where:
   - Biphasic ST grade 1 (BP1) means a negative ST segment slope above baseline.
   - Biphasic ST grade 2 (BP2) means a negative ST segment slope cutting the baseline, and
   - Biphasic ST grade 3 (BP3) means a negative/depressed ST segment below the baseline of the ECG.
4) The appearance of repeatedly negative T waves with ST depression and negative T/QRS ratios.

The CTG was assessed retrospectively and blind to clinical outcome according to FIGO standards by the two of the authors (RL-KGR) [4]. The data were grouped according to the CTG + ST clinical guidelines for clinical intervention developed for the purpose of the ST Log application (table I).

Table I. CTG+ST clinical guidelines that indicate when delivery is recommended. These guidelines are applicable from 36 + 0 weeks gestation.

CTG ST	CTG Normal	CTG Intermediate	CTG Abnormal
Episodic increase in T/QRS	> 0.25	> 0.15	> 0.10
Increase in baseline T/QRS	–	> 0.10	> 0.05
Baseline T/QRS	–	–	> 0.25
Negative T/QRS	> 20 min	> 20 min	Repeated episodes
Biphasic ST	–	–	Repeated BP2 and BP3

3 Results

The results presented are based on 320 cases, corresponding to 1117 hours (46,5 days) of recording with a mean recording time of 3,5 hours. The quality of the traces allowed 84 % of the available ECG to be used for fetal heart rate analysis and 80 % of those for ST analysis.

The recordings include the complete duration of second stage of labor for all the cases with vaginal delivery, while varying lag-times exist between end of recording and delivery in those cases that had an operative delivery. This database include 6 cases of intrapartum hypoxia as defined by an Apgar score of < 6 at one minute and cord artery pH < 7.10. The CTG was abnormal in 55 cases at retrospective analysis. Twenty-seven cases showed changes in ST waveform. In 21 cases these changes were represented by an increase in T/QRS ratio. In 6 cases the changes were represented by biphasic or negative ST waveform (table II).

Table II. Number of cases with normal ST waveform, increased T wave amplitudes and ST depression in relationship to different CTG patterns. The data is separated into cases with and without operative intervention for fetal distress.

Cases with no operative intervention for fetal distress, n = 290	Normal ST	ST rise	ST depression
Normal CTG	213	1	4
Intermediate CTG	34	0	1
Abnormal CTG	24	13	0
Cases with operative intervention for fetal distress, n = 30	**Normal ST**	**ST rise**	**ST depression**
Normal CTG	2	0	0
Intermediate CTG	10	0	0
Abnormal CTG	10	7	1

Baseline rise in T/QRS. An increase in the T/QRS ratio lasting more than 10 minutes (baseline T/QRS increase) occurred in five cases. All these cases were associated with an abnormal CTG. All the neonates showed a low 1 minute Apgar score (range 0−5) and evidence of cord artery acidemia (pH ≤ 7.10). This group include one case of intrapartum death, one case with neonatal seizures and in two cases the neonates required assisted ventilation. Figures 1−4 illustrates the findings in two of these cases.

Episodic rise in T/QRS ratio. Episodic ST changes occurred in 16 of the 21 cases that showed an increase in T/QRS ratio during labor. An increase in T/QRS ratio of > 0.10 for less than 10 minutes appeared in association with an abnormal CTG in all cases but one (table II). The case with a rise in T/QRS ratio and normal CTG showed an episodic event lasting two minutes. No baby required assisted ventilation, lowest 5 min Apgar score was 7 and they all had an uneventful neonatal period.

Biphasic/negative ST. There were 6 cases who showed biphasic or negative ST changes (table II). In five, these changes were intermittent, short-lasting and associated with a normal CTG. All these cases had normal outcome. One case showed persistently biphasic ST with negative T waves associated with an abnormal CTG (figure 5). This was an IUGR fetus (birth weight 2310 grams at 40 weeks gestation). At birth this baby showed a low Apgar (4 at 1 minute) and cord artery acidemia (pH 7.05).

The material includes one more case with neonatal symptoms that may be related to intrapartum asphyxia. This baby was born with a low Apgar score (2 at 1 minute and 3 at 5 minutes), developed neonatal seizures, and showed a subarachnoidal bleeding on CT scan. This baby also developed cerebral palsy. CTG and ST were normal and the mother was delivered by ventouse extraction for failure to progress. Unfortunately, no CTG or ST recording was made during the last 25 minutes before delivery, neither were any cord blood gases obtained.

Mode of delivery. The mode of delivery is summarized in table II. An operative delivery for fetal distress occurred in 30 cases (18 cases of instrumental vaginal delivery and 12 cases of emergency cesarean section). ST changes were present

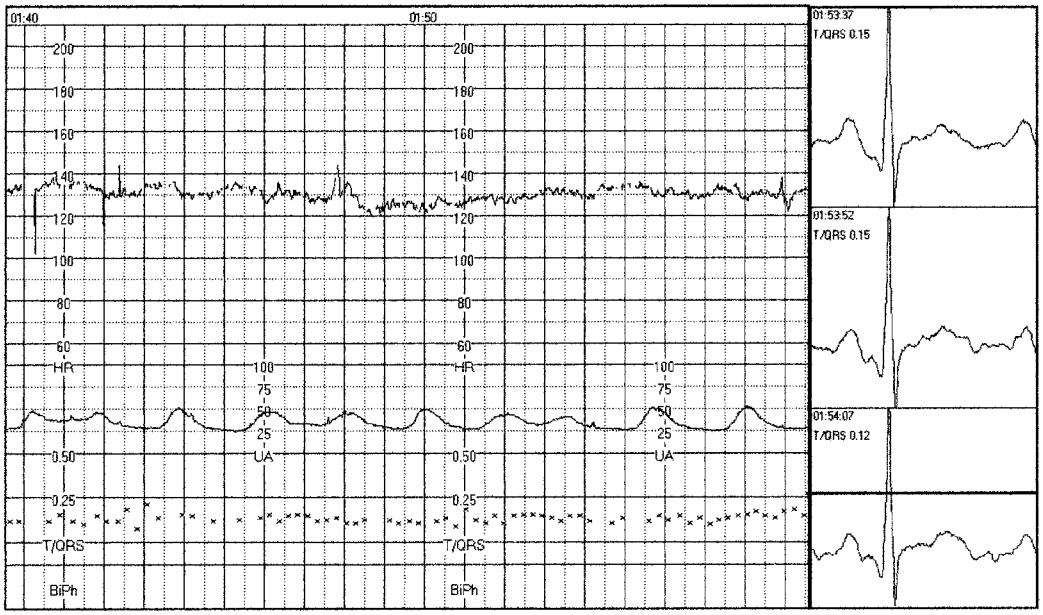

Figure 1. An example of a case with abnormal CTG and baseline T/QRS increase. Figure shows CTG+ST recording at start of labor (baseline T/QRS 0.15).

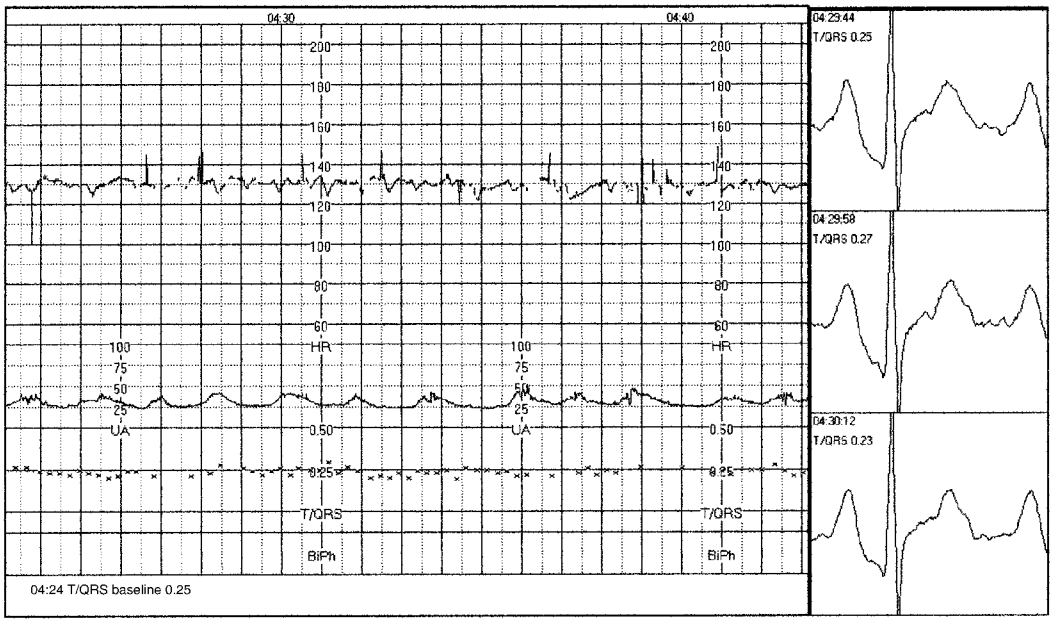

Figure 2. Same case as figure 1. CTG+ST recording 3 hours later. Note the increase in baseline T/QRS to 0.25 from 04.24 hr (arrow), as indicated by the ST Log. Progressive CTG changes until profound bradycardia at 05.30. Outcome: spontaneous vaginal delivery of stillborn fetus.

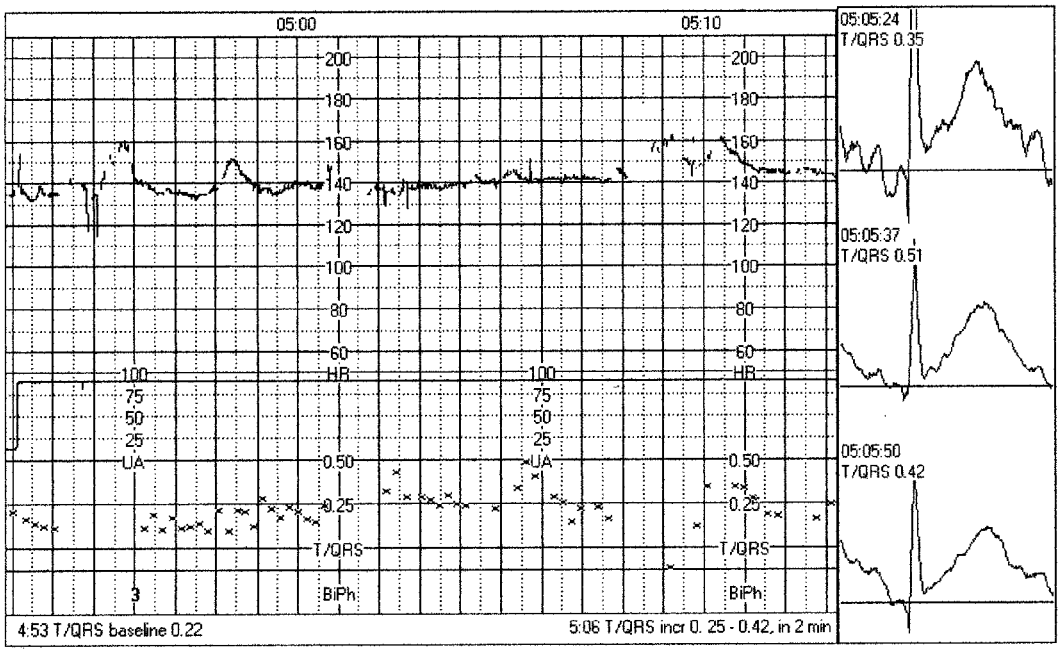

Figure 3. An example of a case with abnormal CTG and baseline T/QRS increase. Figure show CTG+ST at the start of recording at 04.52 hr. Note the episodic increase in T/QRS as indicated by the ST Log.

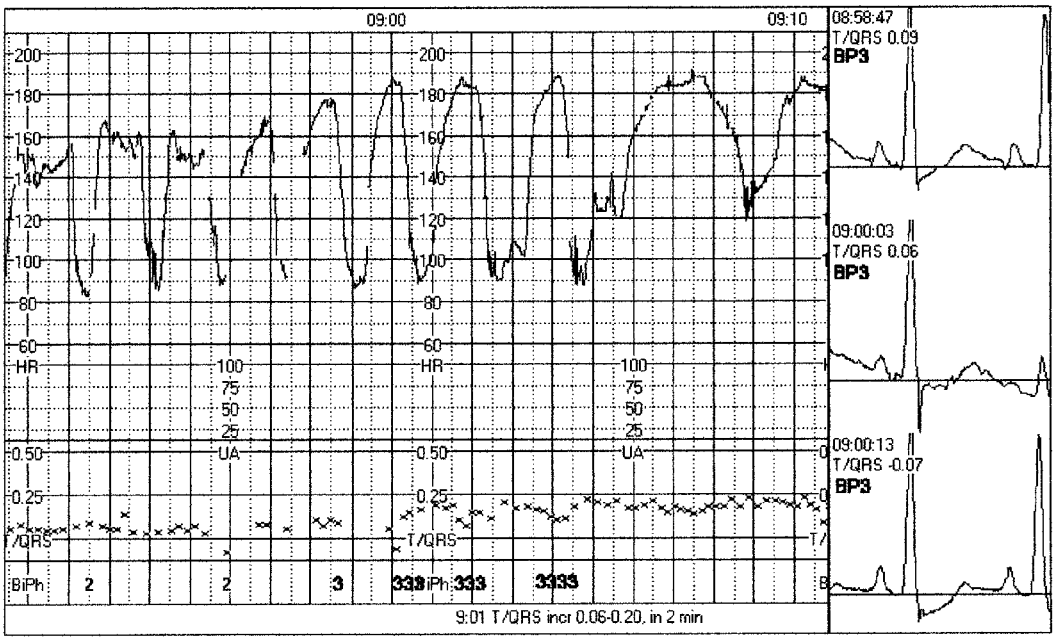

Figure 4. Same case of figure 3. CTG+ST trace 4 hours later at the start of active second stage. Note the appearance of a marked ST segment depression (BP grade 3), followed by an increase in T wave height and baseline T/QRS ratio, associated with progressive deterioration of the CTG. Outcome: spontaneous vaginal delivery of male fetus at 09.12 hr. Birth weight 3250 g. Neonate required 5 minutes of assisted ventilation at birth and developed seizures in the neonatal period.

in 8 cases (baseline ST rise in one case, biphasic ST in one case and episodic ST rise in the remaining cases), all associated with CTG changes. Of the 12 cases of cesarean section, 3 had associated T/QRS changes.

In the group with spontaneous vaginal delivery, ST changes were present in 13 cases in association with abnormal CTG. These include 4 cases with intrapartum hypoxia. In fact among the six fetuses with signs of intrapartum hypoxia, an operative intervention for fetal distress occurred in two cases only. Both these cases showed abnormal CTG and ST.

FBS. 42 samples were taken from one center. Only two of these had a pH < 7.20 assisting in the decision to deliver operatively. Both cases displayed a rise in T/QRS during the time of the sampling. 14 samples were obtained with a normal CTG and 21 with an intermediate CTG. Thus, 80 % of the fetal scalp samples were obtained to verify normality and only 20 % were used to grade the level of hypoxia associated with an abnormal CTG.

4 Discussion

The capacity of fetuses to handle hypoxemia may differ greatly, depending not only on the condition prior to labor but also due to events during labor which may affect the ability to mobilize defense systems. Therefore it may be difficult to rely only on the actual level of oxygenation. Instead it should be more rewarding to try to interpret the reactions taking place in a high priority organ like the heart or the brain. We also recognize that although many fetuses face periods of relative oxygen deficiency during labor very few suffer long term damage as a result. Indeed, even the consequences of a severe lack of oxygen will vary from one fetus to another [7].

During labor, the ECG signal is not only available continuously, it also provides additional informa-

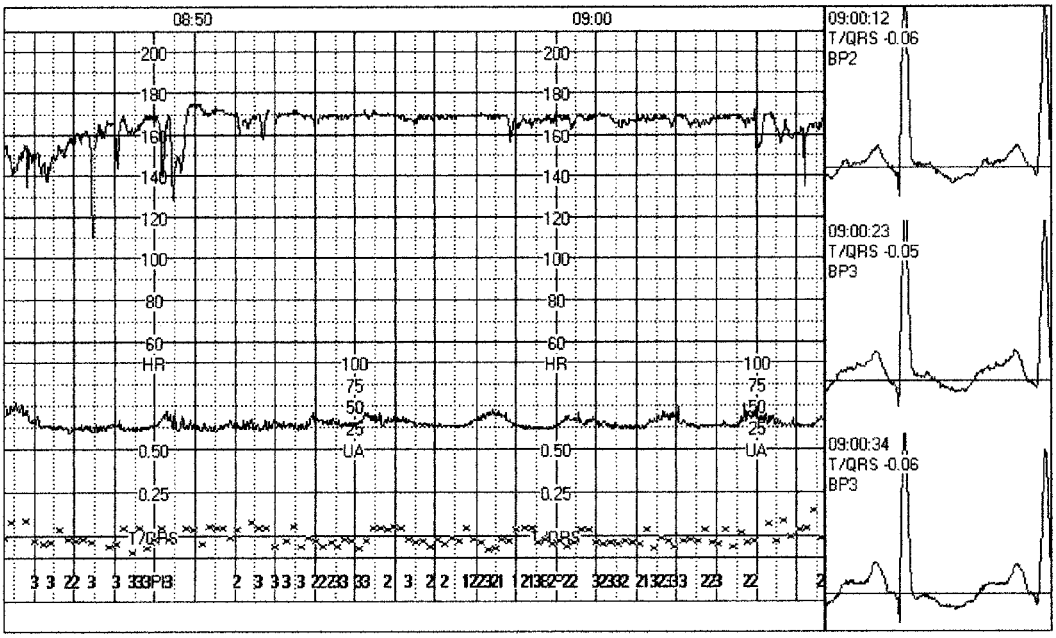

Figure 5. Example of a CTG+ST recording showing persistent biphasic ST waveform and negative T in a fetus with growth retardation (birth weight 2310 grams at term). Outcome: forceps delivery for abnormal CTG. Apgar 4 at 1 minute. Cord artery pH 7.05.

tion without the need to change patient handling routines. Further, the signal provide information about the situation in the myocardium. ST waveform changes have been extensively studied over the last 25 years [6]. This work has included experimental, methodological and clinical work [16], including one of the largest randomized controlled trial within the field [17].

The current study was designed to be a prospective, descriptive multi-center study of ECG changes occurring during labor. The ECG data was blinded to the labor ward staff and was stored in a computer for subsequent analysis. The data was collected during 1991−92, using the old STAN 8801 technology. Since then further developments have occurred. An example is the ST Log module used to recognize changes in ST waveform such as biphasic ST and trend analysis of the T/QRS ratio.

Quantification of the degree of intrapartum asphyxia has to be based on a combination of acid-base and clinical data [18]. Lack of precise and verifiable clinical information from some of the centers participating in the EC Trial has resulted in a reduction in the number of cases suitable for analysis. Despite this, the current database still included an appropriate span of adverse events ranging from intrapartum death to operative interventions for threatening asphyxia. Thus, it was felt worthwhile to continue with the evaluation of the EC database on computerized fetal ECG.

The strong association between ST waveform changes and adverse intrapartum events could be illustrated by the following:

- All five cases with the most marked ST change, i. e. a rise in T/QRS of > 0.10 units and lasting more then 10 minutes also had signs of ongoing intrapartum hypoxia.
- Six out of six cases with evidence of intrapartum asphyxia, showed ST changes.

The case with low Apgar scores and neonatal symptoms had a normal CTG and ECG and it is unclear to what extent the baby suffered from intrapartum asphyxia. This case also illustrates the need for cord-acid base data to more accurately identify adverse intrapartum events.

Thus, there is little doubt that ST waveform analysis may add to current techniques for intrapartum fetal surveillance. One of the shortcomings of CTG based monitoring is the inconsistency of data interpretation [3]. After years of clinical use and training, one can only assume there to be some inherent limitations, maybe not as much on the methodology itself but more as to the technique applied to convey the information to the clinical staff. Obviously, this will cause uncertainty. STAN clinical guidelines are based on the combined analysis of the CTG and the ST waveform. The latter parameter allows for a most detailed assessment of changes, which could be used to verify normality as well as to quantify abnormality.

In the Plymouth trial 48 % of the interventions in the CTG-only arm of the trial were judged to be unnecessary whereas the figure for the CTG + ST arm was only 5 % [17]. In spite of this overreaction, 18 % of abnormal traces in the CTG arm should have had an intervention as compared with 9 % in the STAN arm. It is among these "missed" cases we should expect cases of intrapartum asphyxia. Once a pattern has not been recognized as abnormal it is most likely that pattern will continue to be unrecognized and labor allowed to progress (11). Thus, it is not surprising to find four cases of intrapartum asphyxia not being acted upon. The two cases with the most marked degree of asphyxia showed a loss of variability as the main CTG finding.

The obvious strength of the ST analysis is the possibility to identify specific events. In the majority of cases (5 % of the recordings) these events are short-lasting but may still be of significance if we want to prevent intrapartum hypoxia. As the increase in T/QRS ratio is maintained for > 10 minutes, the fetal situation becomes more severe and in the current study all fetuses showed evidence of intrapartum hypoxia progressing into asphyxia.

ST depression and or negative T waves appear as a specific sign of lack of myocardial reactivity. Usually, the changes are short-lasting and may occur as the first sign of hypoxia (figure 4). Persistent changes have been reported in conjunction with growth retardation, septicemia and myocardial dystrophy [6, 19]. In the current analysis there were 6 cases, who showed negative ST changes. In five, these changes were intermittent, short-lasting with no marked CTG changes. The sixth case was growth retarded fetus who showed persistently biphasic ST with negative T waves and had an abnormal CTG (figure 5).

On the basis of our multi-center trial it appears as if the combined analysis of CTG and ST waveform changes provides an accurate way to identify adverse events during labor. To what extent would a scalp-pH improve or secure the situation? A normal scalp pH is often regarded as the ultimate proof of a non-asphyxiated fetus. It is well known that a metabolic acidemia develops in the tissue and the protons liberated from the lactic acid will be buffered in the extra-vascular fluid buffering system before they will start to affect the blood pH [18]. Time is thus required before a metabolic acidemia by itself could cause a drop in blood pH.

In the vast majority of cases the decrease seen in scalp pH is due to the commonly developing respiratory acidosis where the protons are produced in the erythrocytes and readily transferred to the plasma. Thus, if there is only an accumulation of lactic acid there is the risk that the protons will be buffered and no drop seen in the pH until the buffering capacity has been used, i. e. quite late during the hypoxic process. From the current data it appears as if an FBS was used mainly to verify normality in cases of uncertainty in CTG interpretation. Obviously a normal ST pattern may significantly reduce the uncertainty factor in verifying the normal CTG as shown by Westgate and co-workers [17]. Furthermore, the two cases with low scalp-pH also had an episodic rise in T/QRS. From the above it appears as if an FBS would have limited information regarding fetal tissue hypoxia in contrast to the direct information obtained from the ST waveform of the fetal ECG.

What is the situation today more then 5 years after the last data was entered into the EC Fetal ECG trial database? The work is continuing with a new STAN recorder developed by Neoventa Medical in Göteborg and currently being tested in a Swedish randomized, controlled multi-center trial.

Abstract

This report form part of the European Community Multi-Center Trial "Fetal ECG Analysis during Labor". Aim of this prospective trial was to identify changes in the fetal ECG waveform with cases of verified fetal hypoxia. In this paper we also report on the use of a newly developed automatic system for identification of ST waveform changes (ST Log). All ECG were recorded with the STAN recorder (Neoventa Medical AB, Gothenburg, Sweden). The ECG information was not displayed during labor in order not to influence the clinical management. This report includes data from 320 cases and include six cases of fetal intrapartum hypoxia. Twenty seven cases showed changes in ST waveform. All five cases with the most marked ST change (a rise in T/QRS of > 0.10 units and lasting more then 10 minutes) had signs of ongoing intrapartum hypoxia. Six out of six cases with evidence of intrapartum asphyxia, showed ST changes. On the basis of our multi-center trial it appears that the combined analysis of CTG and ST waveform changes provides an accurate way to identify adverse events during labor. The work is continuing with a new STAN recorder developed by Neoventa Medical in Göteborg and currently being tested in a Swedish randomized, controlled multi-center trial.

Keywords: Fetal electrocardiogram, fetal monitoring, fetal surveillance, intrapartum asphyxia.

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