Limitations of ST analysis in clinical practice: three cases of intrapartum metabolic acidosis

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Objective To examine detailed intrapartum events in cases of neonatal metabolic acidosis despite monitoring using STAN® (cardiotocography [CTG] plus ST waveform analysis of fetal electrocardiogram [ECG]).

Design Retrospective case review.

Setting High-risk pregnancies monitored by STAN®.

Methods Case note review was performed in newborns with metabolic acidosis where no significant ST changes in the fetal ECG occurred prior to birth.

Main outcome measures Metabolic acidosis.

Results Detailed review of three cases identified poor signal quality, difficulties in CTG interpretation, failure to comply with STAN® clinical guidelines and deterioration of the CTG without ECG alert as the leading causes of these adverse outcomes.

Conclusions The cases illustrate some of the pitfalls associated with the clinical application of the STAN® technology which prevent severe metabolic acidosis being eradicated completely. It may be useful to expand the STAN® guidelines protocol towards the identification of exceptional clinical situations, such as in our cases, and towards appropriate additional interventions, as this may lead to a further reduction in adverse neonatal outcomes.

Keywords Cardiotocography, fetal electrocardiogram, fetal metabolic acidosis, intrapartum fetal monitoring, ST analysis.

Introduction

It has been reported that a combination of cardiotocography (CTG) and ST waveform analysis of the fetal electrocardiogram (ECG) during labour provides information on the fetal response to hypoxia. This observation resulted in the development of a CTG plus ST waveform analyser (STAN®; Neoventa Medical, Göteborg, Sweden). Two large randomised clinical trials comparing CTG versus CTG and ST analysis showed a significantly lower rate of metabolic acidosis at birth and fewer operative deliveries for fetal distress when CTG and ST analysis were used. This finding could not be reproduced in a recent, small randomised clinical trial.

The most important issue in intrapartum fetal monitoring concerns false-negative test results, leading to the birth of an infant with severe metabolic acidosis. Even with use of the recently introduced STAN® technique, such cases may still occur. This relatively new method of intrapartum fetal monitoring has some limitations in clinical practice, which need to be addressed to prevent future adverse events.

To this end, we report three cases from three different hospitals in which newborns with evident metabolic acidosis were born without significant ST changes in the fetal ECG, and we discuss some of the possible pathophysiological explanations for these apparent false-negative recordings. More importantly, we discuss some of the pitfalls associated with the clinical application of the STAN® technology in these cases.

Case reports

Case 1

A 36-year-old para 0 had an uncomplicated pregnancy until 41 completed weeks of gestation, when she was referred to hospital because of rupture of membranes of duration more than 24 hours and maternal fever.
Observations during labour
The recording was started at 19:00 hours and showed a baseline fetal tachycardia (170–180 beats per minute [bpm]), which was thought to be related to maternal pyrexia (39.2°C; treated with antibiotics intravenously). There were signs of reactivity with accelerations present and stable T/QRS ratios (Figure 1A). At 21:30 hours, pethidine was given, and thereafter, no accelerations were noted and heart rate variability became reduced (Figure 1B). Fetal blood sampling (FBS) at 22:15 hours showed a pH of 7.29. An oxytocin infusion was started.

At 02:00 hours (8–9 cm dilatation), uniform and late decelerations and reduced variability were noted with frequent contractions (Figure 1C). This pattern continued until full dilatation at 03:55 hours (Figure 1D). There were no ST events. With the onset of active pushing at 04:25 hours, a further reduction in heart rate variability was noted (Figure 1E). At 05:00 hours, a second FBS was obtained with pH 6.78, and an outlet vacuum extraction was performed at 05:30 hours. ST analysis showed adequate signal quality until the end of the first stage, with only intermittent ST information thereafter.

Neonatal outcome
At 5:30 hours, a boy weighing 4700 g was born. Apgar scores were 1, 4 and 7 at 1, 5 and 10 minutes, respectively.

Umbilical cord acid–base values were as follows: arterial pH (pHa) 6.78, PacO2 90, extracellular fluid base deficit (BD$_{ecf}$) 22.1 mmol/l and venous pH (pHv) 6.84, PacO2 70, BD$_{ecf}$ 22.3 mmol/l.

The baby received active resuscitation and respiratory support, with dopamine and antibiotics added to manage group B streptococcus (GBS) infection that was confirmed by blood cultures, placental histopathology (marked chorioamnionitis and umbilical funiculitis) and elevation in C-reactive protein (CRP). Neonatal seizures were noted on the second day. Ultrasound and magnetic resonance imaging (MRI) examination showed no abnormalities. After 1 week, the newborn was discharged home in good clinical condition.

Case 2
A 24-year-old para 0 woman had an uncomplicated pregnancy until 40 weeks of gestation. Labour was induced because of oligohydramnios and reduced fetal movements.

Observations during labour
Dinoprostin was administered intravaginally for cervical ripening. The CTG was normal. The next morning, the membranes were ruptured artificially and oxytocin augmentation was started.

STAN$^®$ recording was started at 11:00 hours with a normal CTG and good signal quality of the fetal ECG (Figure 2A). Oxytocin infusion was started, and pethidine was administered for pain relief. At 16:00 hours, the STAN$^®$ registration was stopped because of transport of the woman to the operation theatre for administration of epidural analgesia. At that time, the CTG trace was abnormal, showing uniform late decelerations (Figure 2B). At 17:15 hours, the woman returned to the labour room, and a new STAN$^®$ registration was started with good signal quality and an abnormal CTG trace, comparable to that before epidural administration (Figure 2C). At 22:00 hours (8 cm dilatation), treatment with intravenous antibiotics was started because of maternal pyrexia. The CTG then slowly changed to a preterminal trace at 22:50 hours (Figure 2D). At 23:28 hours, the epidural was stopped (full dilatation) and the CTG showed a preterminal trace with a tachycardia of 160 bpm, no variability, no accelerations and uniform late decelerations (Figure 2D). At 23:44 hours, a significant ST event (baseline T/QRS rise of 0.06) was noticed and a vacuum extraction was performed (Figure 2E).

Neonatal outcome
At 23:56 hours, a girl weighing 3240 g was born, with Apgar scores of 0, 0 and 0 after 1, 5 and 10 minutes, respectively. Umbilical cord acid–base values were as follows: pH$_{a}$ 6.79, extracellular fluid base deficit (BD$_{ecf}$) 22 mmol/l.

After 18 minutes of active resuscitation, breathing and spontaneous heart activity were established. The girl was intubated, and seizures were noted. She was transported to a tertiary referral centre and admitted to the neonatal intensive care unit (NICU). The newborn suffered serious hypotensive periods. During the first 12 hours, the metabolic acidosis was treated with supplementation of sodium bicarbonate. Hypertrophic cardiomyopathy of unknown cause was diagnosed. Neurological examination showed severe hypoxic ischaemic encephalopathy, with symptoms of seizures requiring treatment with two different anticonvulsive drugs. After 2 weeks, the newborn was discharged in a moderately good clinical condition, but at 8 months, she had cerebral palsy. There were no remaining signs of a cardiomyopathy.

Case 3
A 29-year-old para 0 with type 1 diabetes had an uncomplicated pregnancy and adequate blood glucose control. At 37 + 4 weeks, she went into spontaneous labour.

Observations during labour
STAN$^®$ recording started at 17:50 hours, with a normal CTG trace and good signal quality of the fetal ECG (Figure 3A). Oxytocin augmentation was started. At 20:00 hours (5–6 cm dilatation), the CTG trace was intermediary, showing uncomplicated variable decelerations >60 bpm. The T/QRS ratio of the fetal ECG was stable (Figure 3B). At 22:00 hours, the CTG became abnormal with complicated variable decelerations (Figure 3C). At 22:40 hours (full dilatation), the CTG trace became preterminal with deep complicated decelerations and severely reduced heart rate variability. The signal quality of
the fetal ECG was good, and there were no ST events (Figure 3D). At 23:09 hours, the woman had an absence or insult for about 1 minute, perhaps as a result of hyperventilation. Blood glucose values were normal. At 23:22 and 23:32 hours, there were two ST events, both with a T/QRS baseline rise of 0.06 (Figure 3E). Immediately, a vacuum extraction was performed.
Neonatal outcome
At 23:52 hours, after five vacuum tractions and shoulder dystocia, a girl weighing 3700 g was born with nuchal cord. Apgar scores were 3 and 5 after 1 and 5 minutes, respectively. Umbilical cord acid–base values were as follows: pHa 6.95, PaCO₂ 60, BD_{ecf} –15 mmol/l, pHv 7.00.

Figure 2. STAN® registration case 2. Paper speed 1 cm/minute.
Because of peripartal asphyxia, the newborn was admitted to the NICU. Metabolic acidosis disappeared within 1 hour after delivery, as confirmed by blood gas analysis. There was a unilateral fracture of the clavicle, likely caused by the rotation manoeuvre for shoulder dystocia, and a small subarachnoid haemorrhage from a skull fracture at the base of the

Figure 3. STAN® registration case 3. Paper speed 1 cm/minute.

Because of peripartal asphyxia, the newborn was admitted to the NICU. Metabolic acidosis disappeared within 1 hour after delivery, as confirmed by blood gas analysis. There was a unilateral fracture of the clavicle, likely caused by the rotation manoeuvre for shoulder dystocia, and a small subarachnoid haemorrhage from a skull fracture at the base of the
suction cup. The newborn suffered from seizures and vomiting and was treated with phenobarbital. Further neonatal evolution was normal. Fifteen days after delivery, the neurological condition had improved, and the child was discharged in good clinical condition. A paediatric check-up 3 months after delivery showed a normal clinical and neurological evolution. An MRI scan showed no abnormalities apart from remnants of the subarachnoidal bleeding.

**Discussion**

The aim of intrapartum monitoring is to identify the fetus at risk for hypoxia and acidosis in a timely fashion, which may lead to interventions towards the prevention of neonatal and long-term morbidity.

Since its introduction in the 1970s, CTG has become the standard method for intrapartum fetal monitoring. In the presence of CTG abnormalities, FBS is recommended to identify the acidotic fetus. Recently, STAN technology has been introduced, which offers additional information regarding fetal oxygenation through fetal ECG analysis, thereby reducing the need for FBS. However, some limitations in clinical applications of STAN technology have already been reported. In a Swedish randomised trial, 16 of 41 cases with cord artery metabolic acidosis at birth (pH < 7.05 and BD > 12.0 mmol/l) had no ST events signalled by the event log. In a Dutch observational study, 7 of 18 neonates with a metabolic acidosis were not identified by ST changes. These were all neonates with a pH between 7.00 and 7.04. All five neonates with arterial blood pH below 7.00 had been identified by significant ST events 18–31 minutes before birth. In both studies, all infants with metabolic acidosis not identified by ST changes had a favourable outcome.

Here we report three cases in which the limitations of the clinical application of ST analysis were demonstrated, as a result of which severely acidotic infants (pHa < 7.00) were born with severe neonatal morbidity. The most important limitation of ST analysis is deviation from STAN clinical guidelines by labour ward personnel rather than a fault in the technology. However, lack of definition of poor signal quality and absence of clear STAN guidelines in the case of a CTG trace changing from normal to abnormal, without ST events, were also found to be limitations. Moreover, STAN training material (CD-ROM, brochures and website) showing severely abnormal CTG traces in the absence of ST events and favourable infant outcomes may have misled clinicians.

For each case, possible pathophysiological mechanisms will be discussed to try and explain why the cases did not follow the expected norm of ST events in connection with CTG abnormalities. Furthermore, aspects of deviation from and shortcomings of STAN clinical guidelines will be discussed. The reported cases represent 3 of approximately 2600 STAN registrations made in our three hospitals.

In the first case, the final part of the registration showed poor signal quality. Hence, STAN might have missed T/QRS rises or biphasic ST segments. Poor signal quality was reported in 4.6% of cases in the Swedish randomised trial, 7.9% of cases in the Dervaitis study, 1.3% of cases in the Plymouth randomised controlled trial and 10% of cases in the Dutch observational study. Unfortunately, there are no clear guidelines as to what signal quality or duration of signal loss is acceptable, especially when an abnormal CTG is present. Our case illustrates the need for clear management guidelines when poor ECG signal quality is observed.

This case also illustrates findings in association with the development of marked intrauterine GBS infection. Maternal pyrexia causes fetal heart rate and metabolism to increase and consequently leads to a need for more oxygen. It is possible that intrauterine infection interferes with the STAN recorded ECG signals. However, in reported studies, there are no indications that STAN is unreliable in the case of maternal fever or chorioamnionitis. The relationship between intrauterine and fetal infection and use of ST analysis may need further investigation.

The most significant finding in this case was the progressive reduction in variability, with the CTG pattern becoming preterminal. To what extent ST analysis provides additional information in such a situation is unclear but is likely to be related to the extent to which the myocardium is being affected. An interesting issue is the extent to which sepsis or hypoxia was the primary cause of the events. Although there was marked acidosis, such acidosis could be caused by inadequate peripheral blood flow not affecting the central organs. The lack of MRI abnormalities would also support sepsis as the primary cause and not hypoxia per se.

Finally, a (pre)terminal CTG trace started 65 minutes before delivery and 35 minutes before FBS was performed. As such, the STAN guidelines were not followed because they indicate immediate delivery in the case of a (pre)terminal CTG. This case illustrates the difficulty of classification of the CTG, especially the assessment of fetal reactivity, which should be carried out continuously. This seems to be the most problematic issue clinically.

In the second case, STAN signal quality was good. Furthermore, as the registration started with a normal CTG, we assume that the ST analysis started with a normal T/QRS baseline ratio. Unfortunately, the STAN registration was stopped during the administration of epidural anaesthesia. When STAN registration is stopped, all ST information is closed, including the T/QRS baseline ratio needed to analyse T/QRS rises or biphasic ST segments in the case of developing hypoxia. When a new registration is started, STAN has to recalculate the T/QRS baseline, which may be different from before. In this case, the CTG was abnormal when STAN was restarted, in contrast to the normal CTG in the first registration. It is possible that the T/QRS baseline at the beginning of
the second part of the registration differed from that in the first part, thereby obscuring a rise in T/QRS ratio. To prevent problems of missing ST information, it is recommended that the 'pause' function on the STAN® monitor be used. If this function is used, a woman can be disconnected for 2 hours without losing any ST information.

The CTG trace presented in Figure 2B may be indicative of uniform late decelerations. Therefore, the STAN® recording was disconnected in the presence of an abnormal CTG trace. In this case, a possible significant ECG alert may have been missed during the placement of the epidural. From the presented observations, it is unclear whether or not relevant information was missed during monitor disconnection, but the traces for case 2 illustrate once more the difficulties encountered in CTG interpretation, even when International Federation of Obstetrics and Gynecology criteria are used.

An important finding in this case is neonatal and probably also fetal cardiac hypertrophy. This observation indicates a fetal heart unable to react fully to the stress of labour. The pattern illustrated in this case is that of progressive loss of fetal heart rate variability, with a preterminal CTG pattern persisting for at least 1 hour before birth, which should have been acted upon at an earlier stage. The slow fetal ST response in connection with the developing asphyxia and metabolic acidosis does not follow the common pattern of reaction and may be associated with the blunted ability of a dysfunctional myocardium to respond.

In the third case, registration started with a normal CTG pattern, signal quality was good and registration was not interrupted. This trace showed an abnormal pattern 80 minutes before the first ST event (and 110 minutes before delivery), with a (pre)terminal pattern 42 minutes before this event and 72 minutes before delivery. This case therefore shows, or at least suggests, that a CTG can slowly change from abnormal to (pre)terminal, without significant ECG alerts. This contradiction illustrates that the search for more measures should continue for the assessment of intrapartum fetal heart rate variability in relation to developing acidosis.18,19

Perhaps the most important lesson from this case is that one should continue to assess the CTG rather than relying solely on ST events arising. In this case, the transition from abnormal to (pre)terminal CTG should have prompted either delivery or FBS, irrespective of ST waveform. In the Swedish randomised trial, a preterminal CTG (defined as absent variability) was an indication for intervention regardless of ST waveform, as was an abnormal CTG persisting for 60 minutes.5 However, this advice is not included in the STAN® guidelines.16 These guidelines should therefore be adjusted and should include clear recommendations on situations in which (missing) ECG alerts are to be ignored and decisions are to be made on clinical and/or CTG information only.

An important finding in this case was the occurrence of sudden maternal hyperventilation. Hyperventilation may cause maternal respiratory alkalosis, which has been associated with fetal distress and adverse perinatal outcome.20 Acute hyperventilation causes alterations in ionised calcium, and hypocalcaemia has been reported in association with loss of fetal beat-to-beat variability on CTG and a prolonged QT interval on ECG.21,22 In this case, the QT interval was markedly increased in connection with loss of beat-to-beat variability of the CTG, but this can only be observed on the raw ECG signal and was not indicated by a warning from the STAN® monitor. This situation may warrant further investigation in efforts to improve the STAN® technology.

Finally, another important limitation of the STAN® clinical guidelines is the narrow time window of only 20 minutes to deliver in the case of a significant ST event. As is illustrated in our third case, this short time interval may not be long enough to effect delivery before the onset of metabolic acidosis, which obviously depends on how obstetric care is organised locally.

The STAN® technique is a relatively new device for intrapartum fetal monitoring, and randomised clinical trials have shown promising results towards the reduction of neonatal metabolic acidosis and operative interventions. The cases presented in this report illustrate some of the limitations of this methodology in the prevention of peripartum metabolic acidosis. Poor signal quality, difficulties in correct interpretation of CTG signals and in compliance with the STAN® clinical guidelines and our, as yet, incomplete knowledge of intrapartum fetal pathophysiology may still result in unexpected unfavourable outcomes. We recommend that the STAN® clinical guidelines should include more detailed instructions regarding the correct identification of 'difficult cases' and suggest adequate interventions.

References

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