Review Article

Use of Fetal Electrocardiogram for Intrapartum Monitoring

Lin-Lin Su,[1,2] *MBBS, MRCOG, MMed (O&G)*, Yap-Seng Chong,[1,2] *MRACOG, MMed (O&G), MD*, Arijit Biswas,[1,2] *FRCOG, MD, FAMS*

Abstract

Introduction: Intrapartum fetal monitoring is essential for the identification of fetal hypoxia to reduce perinatal morbidity and mortality. Cardiotocography is associated with low specificity for fetal acidosis and poor perinatal outcome leading to unnecessary operative deliveries. ST waveform analysis of the fetal electrocardiogram has been shown to be a promising adjunctive intrapartum assessment tool. We aim to present the pathophysiology, the role of intrapartum monitoring and the practical usage of this relatively new technology in our review. Methods: An electronic search of Medline and OVID was carried out, followed by a manual search of the references identified by the electronic search. Results: The incorporation of ST waveform analysis to cardiotocography has been shown to reduce the rates of neonatal metabolic acidosis, moderate and severe neonatal encephalopathy, thus improving perinatal outcome. The reduction in operative delivery rates due to fetal distress is also significant. The pathophysiology and practical usage of this technology were discussed. Conclusions: With more accurate identification of fetal hypoxia and reduction of unnecessary intervention rates, incorporation of ST waveform analysis of fetal electrocardiography into cardiotocography can improve the standard of intrapartum fetal monitoring.

Ann Acad Med Singapore 2007;36:416-20

Key words: Cardiotocography, Fetal electocardiography, Fetal ST waveform analysis, Intrapartum, Perinatal outcomes

Introduction

Intrapartum fetal monitoring is essential for the identification of fetal hypoxia to reduce perinatal morbidity and mortality. Although electronic fetal heart rate monitoring leads to reduction in the rates of neonatal seizures, no significant differences were observed in Apgar scores, admissions to neonatal intensive care units and perinatal deaths.[1] Low specificity for fetal acidosis and poor perinatal outcome provided by cardiotocography leads to unnecessary operative deliveries.[1,2] Subjective and incorrect interpretation of cardiotocography data is a common finding in intrapartum event-related asphyxia.[3,4] In a review of 110 cases of obstetric litigation for cerebral palsy, Symonds and Senior[5] found that 70% of these claims were based on cardiotocography abnormalities and their interpretation. Computerised cardiotocography may offer more objective and accurate information of intrapartum fetal health assessment[6-8] but randomised controlled trials in this field are very limited.

Adjunctive methods are important in improving the sensitivity and specificity of intrapartum fetal monitoring. Fetal blood sampling may decrease unnecessary intervention without adversely affecting the fetal outcome.[9] However, fetal blood sampling requires additional expertise, generates discomfort for the mother and is invasive.[10,11] Repetitive procedures are also required when abnormalities on cardiotocography persist as fetal scalp samples can only give intermittent information about fetal acid-base status, which limits its use.[12]

To address these challenges, technologies such as fetal pulse oximetry, fetal electrocardiogram and umbilical artery Doppler velocimetry have been developed to monitor various fetal parameters in labour.[13-15] Over the years, ST waveform analysis (STAN) of the fetal electrocardiogram has emerged from experimental and observational studies to clinical use, and this technology has been shown to be a promising intrapartum assessment tool. Despite the publication of studies including 25,000 patients, the use of

[1] Department of Obstetrics and Gynaecology, Yong Loo Lin School of Medicine, National University of Singapore, Singapore
[2] Department of Obstetrics and Gynaecology, National University Hospital, Singapore
Address for Correspondence: Dr Su Lin Lin, Department of Obstetrics and Gynaecology, Yong Loo Lin School of Medicine, National University of Singapore, National University Hospital, 5 Lower Kent Ridge Road, Singapore 119074.
Email: obgsll@nus.edu.sg

this technology remains limited, especially in the Asian countries. Increasing the awareness of this system would hopefully allow a wider use of the ST waveform analysis among various Asian countries. A review of the literature on the underlying pathophysiology of ST waveform analysis, its role in intrapartum monitoring and the practical usage of this relatively new technology will be presented in this article.

Materials and Methods

An electronic search of Medline and OVID was carried out, followed by a manual search of the references identified by the electronic search. The key words used in the electronic search were cardiotocography, fetal electrocardiography, fetal ST waveform analysis, intrapartum and perinatal outcomes. Additional sources were obtained through cross-referencing. Educational materials on the subject were also reviewed.

Usage of STAN in Various Countries

STAN is currently used in more than 200 European hospitals and other countries such as the United Kingdom. Despite good evidence supporting the advantages of ST waveform analysis, usage of this technology remained sparse outside of the European countries until recently. Lack of awareness of the beneficial application of the STAN system and the stringent evaluation of the system before FDA (Food and Drug Administration) approval are 2 reasons for the non-usage of this device in many centres. None of the other adjunctive modalities for intrapartum fetal monitoring has been tested as extensively by randomised controlled trials as has the STAN system.[16] Sufficient evidence allowed the STAN device to be approved by the FDA in the United States in November 2005. Introduction of this system into routine clinical practice in the United States is being encouraged and an increase in the usage of this device would be expected. The use of STAN in Asian countries remains limited partly due to the lack of awareness of the benefits and usage of this system in many centres.

Components of Fetal Electrocardiography

ST waveform changes of the fetal electrocardiogram provide continuous information on the ability of the fetal myocardium to respond to stress throughout labour. Fetal electrocardiogram is a reflection of the electrical currents generated by the myocardium. The p wave represents atrial contraction, QRS complexes ventricular contraction and T wave ventricular repolarisation. The STAN system combines RR interval with analysis of the ST waveform. The ratio between the height of the T wave and the QRS amplitude provides the T/QRS ratio, which serves as an accurate measurement of changes in T-wave height.

Pathophysiology

The balance between energy-yielding and energy-consuming processes forms the basis of the ST waveform, with a negative energy balance being created with hypoxia. In the event of hypoxia, the fetus responds with a catecholamine surge, activation of beta adrenoceptors, myocardial glycogenolysis and metabolic acidosis.[17] T- wave amplitude increases as the rate of glycogenolysis increases.[18,19] This myocardial hypoxia also results in biphasic ST waveforms on the electrocardiogram, where the ST segment demonstrates a downward direction instead of being horizontal or leaning positively.[20]

The important parameters are T/QRS ratio and ST depression with biphasic negative T waves. Episodic T/QRS rise corresponds to short-lasting hypoxia, resulting in the utilisation of fetal anaerobic metabolism to support its myocardium. Baseline T/QRS rise reflects a situation where the fetus has to respond to persistent hypoxic stress with anaerobic metabolism. Biphasic ST occurs when the fetal myocardium has not had time to respond to hypoxia or does not have the capacity to react.[21] It may also be seen with fetal infections and fetal cardiac malformations[22] and among preterm fetuses, which may be related to the immaturity of the myocardium.[23]

The clinical impact of T/QRS increase depends on the cardiotocography pattern. With intermediate cardiotocography, a greater increase in T/QRS can be accepted than when the cardiotocography is abnormal. The classification of cardiotocography is illustrated in Table 1. The STAN clinical guidelines illustrating the need for intervention are shown in Table 2. Intervention can be delivery or alleviation of the cause of fetal distress such as uterine hyperstimulation.

Evidence from Literature

To date, 2 randomised controlled trials[24,25] have been published on the use of ST-waveform analysis. The first randomised controlled trial (Plymouth trial) by Westgate et al[24] showed a 46% reduction in operative interventions for fetal distress with the incorporation of ST analysis. The findings were confirmed by Amer-Wahlin et al[25] (Swedish trial), who showed the improved specificity of intrapartum monitoring following incorporation of ST waveform analysis, with reduced operative delivery rates for fetal distress as well as the overall operative delivery rates.

The incorporation of ST waveform analysis resulted in significantly lower rates of overall metabolic acidosis compared to monitoring with cardiotocography alone [0.7% versus 2%; relative risk, 0.47 (95% confidence interval {CI}, 0.25 to 0.86)]. There was also a significant reduction of moderate or severe neonatal encephalopathy among term newborns from 0.33% in the cardiotocography-only

Table 1. CTG Classification (Modified from the FIGO Guidelines, 1997)

CTG classification	Baseline heart frequency	Variability reactivity	Decelerations
Normal CTG	• 110-150 bpm	• 5-25 bpm • Accelerations	• Early decelerations • Uncomplicated variable decelerations with a duration of <60 seconds and loss of <60 beats
Intermediary CTG	• 100-110 bpm • 150-170 bpm • Short bradycardia episode	• >25 bpm without accelerations • <5 bpm for >40 min	• Uncomplicated variable decelerations with a duration of <60 seconds and loss of >60 beats
	A combination of several intermediary observations will result in abnormal CTG		
Abnormal CTG	• 150-170 bpm and reduced variability • >170 bpm • Persistent bradycardia	• <5 bpm for >60 min • Sinusoidal pattern	• Complicated variable decelerations with a duration of >60 seconds • Repeated late decelerations
Preterminal CTG	• Total lack of variability and reactivity with or without decelerations or bradycardia		

bpm: beats per minute; CTG: cardiotocography; FIGO: International Federation of Gynecology and Obstetrics

Table 2. STAN Guidelines for Clinical Intervention Based on CTG Abnormalities ST Waveform Changes[25]

ST \ CTG	Intermediary CTG	Abnormal CTG	Preterminal CTG
Episodic T/QRS rise (Duration of change <10 minutes)	• >0.15	• >0.10	• Immediate delivery
Baseline T/QRS rise (Duration of change >10 minutes)	• >0.10	• >0.05	
Biphasic ST	• Continuous >5 min or 3 episodes	• Continuous >2 min or 2 episodes	

CTG: cardiotocography

group to 0.04 (odds ratio 0.12; 95% CI, 0.01 to 0.94; $P = 0.02$).[26] The incorporation of ST waveform analysis therefore allows more accurate identification of fetal hypoxia and earlier intervention, leading to improved perinatal outcome.

A recent Cochrane review[15] supported the use of ST-waveform analysis when a decision has been made for continuous electronic fetal heart rate monitoring during labour. However, the reviewers commented that satisfactory cardiotocography traces can be obtained by external monitors in most women during labour and suggested the restriction of fetal ST waveform analysis to fetuses demonstrating disquieting features on cardiotocography. The problem with this is that hypoxic fetuses may not demonstrate abnormal ST waveforms at the stage where the adaptive mechanisms have failed, whilst this could be detected if STAN was commenced earlier.

The important clinical use studies of STAN usage are the Nordic Study,[27] European Union Project,[28] Gothenburg Study[29] and the United States Study.[30] These studies reconfirmed the value of ST waveform analysis in identifying intrapartum hypoxia. The use of cardiotocography plus ST waveform analysis may replace fetal blood sampling during the second stage of delivery.[28,31] Ross et al[32] showed that STAN improved observer consistency in both the decision for and timing of obstetric interventions. The important clinical studies on ST waveform analysis are summarised in Table 3.

Practical Usage of STAN

A fetal scalp electrode is required to obtain the fetal electrocardiography. The STAN system has an event log which displays the time of occurrence and the types of ST events. When the STAN system is started, the event log requires 20 minutes before identifying the baseline from which subsequent changes may be demonstrated. ST waveform analysis requires close attention to the signal quality of the fetal electrocardiogram. Signal disturbance caused by improper fetal scalp electrode application may result in fetal heart trace still being recorded but without adequate signals for ST waveform analysis.

Some fetuses may not display ST changes either because monitoring is started after ST changes have taken place or the fetus does not display identifiable ST changes for unknown reasons. Preterminal CTG traces warrant intervention even without any accompanying ST changes because this may be the only sign of severe hypoxia with failing adaptive mechanisms.[25] In hypoxic fetuses with a rise in the T/QRS ratio, one warning in the ST log should be considered sufficient evidence to intervene, if the

Table 3. Important Clinical Studies on the Use of Intrapartum ST Waveform Analysis of Fetal Electrocardiogram

Author and Year	Type of study	Description	Conclusion
Westgate et al[24] 1993	Randomised controlled trial	*Plymouth RCT:* Comparison of CTG alone versus CTG plus ST analysis for intrapartum fetal monitoring. Outcomes were obstetric intervention and fetal outcome.	A 46% reduction in operative interventions for fetal distress was reported when ST analysis was incorporated.
Amer-Wahlin et al[25] 2001	Randomised controlled trial	*Swedish RCT:* Comparison of CTG only versus CTG plus ST analysis of fetal ECG for intrapartum fetal monitoring. Primary outcome was metabolic acidosis at birth. Secondary outcomes were operative deliveries, low Apgar scores and admissions to special care unit.	Intrapartum monitoring with CTG combined with ST analysis increases identification of fetal hypoxia and allows more appropriate intervention, leading to improved perinatal outcome.
Amer-Wahlin et al[27] 2002	Nordic observational multicentre study	Assessment of the diagnostic power of CTG plus ST waveform analysis clinical guidelines to identify adverse labour outcomes.	STAN clinical guidelines identify fetuses at risk of intrapartum asphyxia.
Noren et al[26] 2003	Randomised controlled trial	Review of cases of perinatal death, neonatal encephalopathy or metabolic acidosis at birth from Swedish RCT.	CTG plus ST analysis may prevent intrapartum asphyxia and neonatal encephalopathy.
Kwee et al[28] 2004	Prospective observational study	Evaluation of the monitoring of high-risk labours using STAN S21 fetal heart monitor. The recordings were analysed for perinatal outcome in relation to ST changes.	ST changes were present in all 5 cases with severe metabolic acidosis. CTG plus ST analysis was more specific in detecting fetal acidaemia than CTG alone with reduction of false-positive test results. CTG plus ST analysis may replace fetal blood sampling during the second stage of delivery.
Ross et al[32] 2004	Clinical trial	Evaluation of the effect of adding ST analysis to CTG on observer agreement for clinical decision making.	Incorporation of ST analysis to CTG improved observer consistency in both the decision for and timing of obstetric interventions.
Neilson[15] 2005 – meta-analysis	Cochrane review	Meta-analysis of randomised controlled trials comparing the effects of analysis of intrapartum fetal ECG with alternative methods of fetal monitoring	Use of fetal ST analysis is supported when a decision has been made to undertake continuous electronic fetal heart rate monitoring in labour. An approach suggested is to restrict fetal ST analysis to fetuses demonstrating disquieting features on CTG.
Noren et al[29] 2006	Prospective observational study	Monitoring the introduction of the STAN methodology.	Increasing STAN usage provided consistent improvements in fetal outcome.
Devoe et al[30] 2006	Prospective non-randomised trial	Evaluation of STAN usage by the clinicians in the United States in decision making regarding intervention.	Clinicians in the United States used the STAN system appropriately, in a manner similar to that of experienced STAN users.

CTG: cardiotocography; ECG: electrocardiogram; RCT: randomised controlled trial; STAN: ST analysis

intervention criteria used in the clinical guidelines are fulfilled. The clinical scenario and course of labour are paramount and the type of intervention must take into account critical information such as stage of labour and maternal conditions.

As with any new methodology, structured efforts on training and user feedback are essential to fully implement the STAN methodology in clinical practice. Amer-Wahlin et al[33] showed that retraining improved the interpretation of cardiotocography and ST waveform analysis, resulting in better clinical outcome. The STAN S21 (Neoventa Medical, Moelndal, Sweden) saw the full use of digital signal processing with automatic detection of the ST changes (Fig. 1).

Conclusion

Strong evidence exists to support the incorporation of ST waveform analysis of fetal electrocardiogram into cardiotocography for intrapartum monitoring, with reduction in the rates of neonatal metabolic acidosis as well as neonatal encephalopathy. This is achieved with fewer operative deliveries, which could lead to reduced maternal

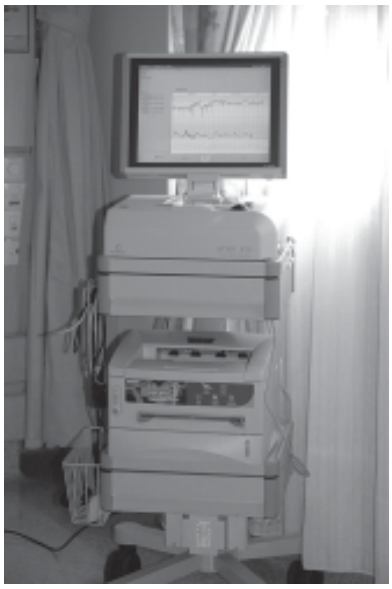

Fig. 1. The STAN S21 (Neoventa Medical, Moelndal, Sweden) device.

morbidity or mortality. With more accurate identification of fetal hypoxia and the reduction of unnecessary intervention rates, continuous improvement of intrapartum fetal monitoring can be achieved. Wider use of this robust technology should be encouraged.

Acknowledgements

We acknowledge the assistance of the Medical Publications Support Unit at the National University Hospital, Singapore.

REFERENCES

1. Thacker SB, Stroup D, Chang M. Continuous electronic heart rate monitoring for fetal assessment during labor. Cochrane Database Syst Rev 2001;2:CD000063.
2. Hornbuckle J, Vail A, Abrams KR, Thornton JG. Bayesian interpretation of trials: the example of intrapartum electronic fetal heart rate monitoring. Br J Obstet Gynaecol 2000;107:3-10.
3. Nielsen PV, Stigbsy B, Nickelsen C, Nim J. Intra- and inter-observer variability in the assessment of intrapartum cardiotocograms. Acta Obstet Gynecol Scand 1987;66:421-4.
4. Murphy KW, Johnson P, Moorcraft J, Pattinson R, Russell V, Turnbull A. Birth asphyxia and the intrapartum cardiotocograph. Br J Obstet Gynaecol 1990;97:470-9.
5. Symonds EM, Senior EO. The anatomy of obstetric litigation. Curr Opin Obstet Gynaecol 1991;1:241-3.
6. Dawes G, Meir YJ, Mandruzzato GP. Computerized evaluation of fetal heart rate patterns. J Perinat Med 1994;22:491-9.
7. Dawes GS, Moulden M, Redman CW. Improvements in computerized fetal heart rate analysis antepartum. J Perinat Med 1996;24:25-36.
8. Taylor GM, Mires GJ, Abel EW, Tsantis S, Farrell T, Chien PF, et al. The development and validation of an algorithm for real-time computerised fetal heart rate monitoring in labour. Br J Obstet Gynaecol 2000;107: 1130-7.
9. Parer JT. The current role of intrapartum fetal blood sampling. Clin Obstet Gynecol 1980;23:565-82.
10. Clark SL, Paul RH. Intrapartum fetal surveillance: the role of fetal scalp blood sampling. Am J Obstet Gynecol 1985;153:717-20.
11. Wheble AM, Gillmer MD, Spencer JA, Sykes GS. Changes in fetal monitoring practice in the UK: 1977-1984. Br J Obstet Gynecol 1989;96:1140-7.
12. Westgate J, Greene K. How well is fetal blood sampling used in clinical practice? Br J Obstet Gynaecol 1994;101:250-1.
13. Siristatidis C, Salamalekis E, Kassanos D, Creatsas G. Alterations in Doppler velocimetry indices of the umbilical artery during fetal hypoxia in labor, in relation to cardiotocography and fetal pulse oximetry findings. Arch Gynecol Obstet 2005;272:191-6.
14. Klauser CK, Christensen EE, Chauhan SP, Bufkin L, Magann EF, Bofill JA, et al. Use of fetal pulse oximetry among high-risk women in labor: a randomized clinical trial. Am J Obstet Gynecol 2005;192:1810-7.
15. Neilson JP. Fetal electrocardiogram (ECG) for fetal monitoring during labour. Cochrane Database of Syst Rev 2003;2:CD000116.
16. Rosen KG, Amer-Wahlin I, Luzietti R, Noren H. Fetal ECG waveform analysis. Best Pract Res Clinic Obstet Gynaecol 2004;18:485-514.
17. Hokegard KH, Karlsson K, Kjellmer I, Rosen KG. ECG changes in the fetal lamb during asphyxia in relation to beta-adrenoceptor stimulation and blockade. Acta Physiol Scand 1979;105:195-203.
18. Hokegard KH, Eriksson BO, Kjellmer I, Magno R, Rosen KG. Myocardial metabolism in relation to electrocardiographic changes and cardiac function during graded hypoxia in the fetal lamb. Acta Physiol Scand 1981;113:1-7.
19. Lilja H, Greene KR, Karlsson K, Rosen KG. ST waveform changes of the fetal electrocardiogram during labour - a clinical study. Br J Obstet Gynaecol 1985;92:611-7.
20. Westgate JA, Bennet L, Brabyn C, Williams CE, Gunn AJ. ST waveform changes during repeated umbilical cord occlusions in near-term fetal sheep. Am J Obstet Gynecol 2001;184:743-51.
21. Widmark C, Jansson T, Lindecrantz K, Rosen KG. ECG waveform, short term heart rate variability and plasma catecholamine concentrations in response to hypoxia in intrauterine growth retarded guinea-pig fetuses. J Dev Physiol 1991;15:161-8.
22. Sundstrom AK, Rosen D, Rosen KG. Fetal Surveillance. Neoventa Medical AB, 2000.
23. Rosen KG. Intrapartum fetal monitoring and the fetal ECG – time for a change. Arch Perinat Med 2001;7:7-12.
24. Westgate J, Harris M, Curnow JS, Greene KR. Plymouth randomized trial of cardiotocograph only versus ST waveform plus cardiotocogram for intrapartum monitoring in 2400 cases. Am J Obstet Gynecol 1993;169:1151-60.
25. Amer-Wahlin I, Hellsten C, Noren H, Hagberg H, Herbst A, Kjellmer I, et al. Cardiotocography only versus cardiotocography plus ST analysis of fetal electrocardiogram for intrapartum fetal monitoring: a Swedish randomized controlled trial. Lancet 2001;358:534-8.
26. Noren H, Amer-Wahlin I, Hagberg H, Herbst A, Kjellmer I, Marsal K, et al. Fetal electrocardiography in labor and neonatal outcome: data from the Swedish randomized controlled trial on intrapartum fetal monitoring. Am J Obstet Gynecol 2003;188:183-92.
27. Amer-Wahlin I, Bordahl P, Eikeland T, Hellsten C, Noren H, Sornes T, et al. ST analysis of the fetal electrocardiogram during labor: Nordic observational multicenter study. J Matern Fetal Neonatal Med 2002;12:260-6.
28. Kwee A, van der Hoorn-van den Beld CW, Veerman J, Dekkers AH, Visser GH. STAN S21 fetal heart monitor for fetal surveillance during labor: an observational study in 637 patients. J Matern Fetal Neonatal Med 2004;15:400-7.
29. Noren H, Blad S, Carlsson A, Flisberg A, Gustavsson A, Lilja H, et al. STAN in clinical practice – the outcome of 2 years of regular use in the city of Gothenburg. Am J Obstet Gynecol 2006;195:7-15.
30. Devoe LD, Ross M, Wilde C, Beal M, Lysikewicz A, Maier J, et al. United States multicenter clinical usage study of the STAN 21 electronic fetal monitoring system. Am J Obstet Gynecol 2006;195:729-34.
31. Luttkus AK, Noren H, Stupin JH, Blad S, Arulkumaran S, Erkkola R, et al. Fetal scalp pH and ST analysis of the fetal ECG as an adjunct to CTG. A multi-center, observational study. J Perinat Med 2004;32:486-94.
32. Ross MG, Devoe LD, Rosen KG. ST-segment analysis of the fetal electrocardiogram improves fetal heart rate tracing interpretation and clinical decision making. J Matern Fetal Neonatal Med 2004;15:181-5.
33. Amer-Wahlin I, Kallen K, Herbst A, Rydhstroem H, Sundstrom AK, Marsal K. Implementation of new medical techniques: experience from the Swedish randomized controlled trial on fetal ECG during labor. J Matern Fetal Neonatal Med 2005;18:93-100.