

Review Article

Physiological Interpretation of Cardiotocograph: Does the Emerging Scientific Evidence Suggest a Reversal in the “Thunder and Lightning” Phenomenon?

Edwin Chandraharan*

Director, Global Academy of Medical Education & Training, London, UK.

*Corresponding Author: Edwin Chandraharan

Director, Global Academy of Medical Education & Training, London, UK.

Email: edwin.c@sky.com

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Abstract

Physiological interpretation of Cardiotocograph (CTG) involves incorporation of the knowledge of fetal physiological response to intrapartum hypoxic and mechanical stresses and diagnosing different types of fetal hypoxia, to individualise care. It advocates two key questions whilst interpreting CTG traces: “Is THIS fetus FIT to undertake the progressively hypoxic journey of labour?” at the beginning of the recording, and “How is THIS fetus?” during labour. Therefore, it differs from other national and international CTG guidelines which arbitrarily group several “features” of the fetal heart rate into different “categories” (reassuring, non-reassuring and abnormal), and then having an overall classification system by randomly grouping 2 “non-reassuring” features as “suspicious”, and two or more “non-reassuring features or one or more “abnormal” features as “pathological” without incorporating fetal physiological responses. Fortunately, most clinical guidelines are evidence-based and logical, and therefore their implementation (lightening) happens first, and changes in clinical practice (thunder) follows this to improve outcomes. However, in rare occasions where, unfortunately, continuation of historical, and entrenched, unscientific cultural practices are likely to cause patient harm, clinical practice may need to change first to safeguard patients, followed by the production of appropriate clinical guidelines based on emerging scientific evidence.

Keywords: Physiological interpretation; Cardiotocograph; Fetal blood sampling; Emerging evidence; Hypoxic-ischaemic encephalopathy; Emergency caesarean section; Perinatal outcomes.

Abbreviations: CTG: Cardiotocograph; HIE: Hypoxic Ischaemic Encephalopathy.

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A brief history of physiological interpretation of cardiotocograph (CTG)

The concepts of physiological interpretation of CTG were developed and first implemented at St George’s University Hospitals NHS Foundation Trust (formerly known as St George’s NHS Trust) in London, UK, (approximately 5000 births/year), from 2006. This was following an external review into the maternity service in 2004 due to concerns regarding excessive number of babies born with severe hypoxic-ischaemic encephalopathy (HIE). This hospital in 2005 was using the “inherited” national guidelines for CTG interpretation which was produced by the National Institute of Health and Care Excellence (NICE). It was called “inherited” because NICE simply adopted the Electronic Fetal Monitoring Guideline produced by the Royal College of Obstetricians and Gynaecologists (RCOG) in May 2001 [1].

This guideline unfortunately stipulated grouping different “features” of the fetal heart rate (FHR) into different “categories” (reassuring, non-reassuring and abnormal) based on arbitrarily determined time limits without any robust scientific evidence. The guideline also erroneously defined normal baseline variability as >5 bpm, leading to clinicians missing fetuses showing excessive baseline FHR variability due to a rapidly evolving hypoxia or fetal neuroinflammation in chorioamnionitis. This was because similar to clinicians who would have misclassified ongoing tachycardia of 160 bpm as normal in adults, if the national guideline had erroneously recommended that baseline FHR of >60 bpm was normal, instead of providing a range (60-90 bpm) with upper and lower limits, obstetricians and midwives were misclassifying baseline FHR variability >25 bpm as “normal” because the national guideline had erroneously stipulated that baseline FHR variability >5 bpm was normal, without providing a range (5-25 bpm), as per all other national and international guidelines on CTG interpretation.

Moreover, contrary to every other national and international guideline on CTG interpretation which, based on scientific evidence, had defined the normal baseline FHR as 110-160 bpm, and defined fetal tachycardia of >160 bpm as abnormal, the UK national guidelines increased the threshold of abnormal baseline FHR to 180 bpm. This increased the risks to fetuses with intrauterine growth restriction and post term fetuses who would not be able release sufficient catecholamines to increase their baseline FHR beyond 180 bpm to be classified as “abnormal”. Similarly, fetuses with subclinical chorioamnionitis would not have been able to increase the FHR beyond 180 bpm to be classified as “abnormal”, increasing the risks of poor perinatal outcomes due to missing ongoing FHR abnormalities as a result of incorrect threshold used to define an abnormal FHR (> 180 bpm instead of >160 bpm).

The national guideline also disregarded scientific evidence, and international consensus on the maximum acceptable duration of fetal deep sleep to classify it as abnormal (50 minutes), and arbitrarily increased it to 90 minutes. This increased the risk of a delay in instituting appropriate interventions for fetuses showing reduced baseline FHR variability due to ongoing metabolic acidosis. Unlike the CTG guideline produced by the American College of Obstetricians and Gynaecologists [2], which considered the abnormal variability in conjunction with

ongoing decelerations and an increase in the baseline FHR, the UK national CTG guideline simply considered variability in isolation, which increased the likelihood of unnecessary operative interventions.

Therefore, it was not surprising that if such erroneous parameters were used to determine whether the individual features were “reassuring, non-reassuring and abnormal” perinatal outcomes may be compromised. Conversely, “early” decelerations (believed to be due to fetal head compression) were considered in isolation as a “non-reassuring” feature [2], which would increase the rate of intrapartum operative interventions without any improvement in perinatal outcomes. CTG traces were then classified into “Normal, Suspicious, and Pathological” simply based on grouping individual features in isolation (if any feature was “non-reassuring” – suspicious, and if >2 features non-reassuring or one feature was abnormal – pathological) without any consideration of the fetal response to ongoing hypoxic or inflammatory stress or different types of fetal hypoxia.

The guideline also attempted to classify decelerations which were normal fetal physiological responses to ongoing hypoxic and mechanical stresses as “abnormal”, based on their morphological appearances which not only resulted in inter-and intra-observer variability in interpretation of CTG traces, but also was likely to increase the rate of intrapartum operative interventions. In order to counteract the iatrogenic increase in caesarean sections as a result of classifying morphological appearances of fetal physiological responses (decelerations) as “pathological”, fetal scalp blood sampling (FBS) was recommended for *pathological CTG* with the mistaken belief that a sample of capillary blood taken from the skin of the fetal scalp would somehow reflect the oxygenation of fetal brain to prevent hypoxic ischaemic brain injury due to the proximity of the fetal scalp to the fetal brain.

FBS was abandoned in the USA approximately 25 years ago due to lack of evidence [3], and despite the knowledge of its limitations in improving perinatal outcomes or reducing intrapartum operative interventions from 1985 [4], FBS was continued to be recommended in the UK even in 2001 [1].

This approach of performing FBS for any pathological CTG trace after grouping arbitrary parameters into different categories resulted in clinicians *missing* fetuses who were experiencing intrapartum hypoxic stress with decompensation of their brain because the wrong, non-essential tissue (skin of the fetal scalp) was erroneously tested for metabolic acidosis. Catecholamine-mediated peripheral vasoconstriction to centralise blood flow to maintain oxygenation of the fetal brain was mistakenly considered as “fetal distress” due to the detection of low pH due to lactic acidosis in the skin of the fetal scalp as a result of this normal compensatory response to fetal stress. This illogical approach increased the likelihood of unnecessary intrapartum operative interventions.

It should have been very obvious in 2001 that the existing scientific evidence did not support the use of FBS to reduce caesarean sections, and that even the “normal values” were derived by analysing less than 80 babies at various stages of labour [5-8]. It was well known that contamination of amniotic fluid, blood and meconium, and even the presence of caput succedaneum and uterine contractions would alter the pH of

the sample of blood taken from the fetal scalp leading to erroneous FBS results [9-13] leading to poor perinatal outcomes. Moreover, it was also associated with an increased caesarean section rate due to over-reaction to detection of a low pH in a peripheral non-essential tissue without attempting to understand fetal physiological responses by scrutinising the features of fetal compensation on the CTG trace.

The beginning of the journey of physiological interpretation of the CTG

It was not surprising that the implementation of a flawed CTG guidelines and introduction of new technology such as the fetal ECG (STAN) without training all staff providing intrapartum care on fetal physiological responses resulted in poor perinatal outcomes at St George's maternity unit in 2004. It was obvious to many clinicians that the root cause of CTG misinterpretation was not the frontline midwife or the obstetrician who were making errors, but it was the error producing CTG tool which was being used nationally, without incorporating the knowledge of fetal physiology. The excessive rate of Hypoxic-Ischaemic Encephalopathy (HIE) and its long-term implications such as cerebral palsy as well as increased operative interventions due to a "pathological CTG" and resultant complications to the mother (postpartum haemorrhage, sepsis, venous thromboembolism, perineal trauma, uterine rupture and postpartum haemorrhage) as a result of CTG misinterpretation, provided the motivation to think outside the "historical obstetric practices" box in 2006.

Application of the existing knowledge of fetal physiology and different types of fetal hypoxia [14] during the real-time interpretation of CTG traces resulted in the concept of "*How is THIS Fetus?*" in many languages. This was followed by introduction of the mandatory competency testing of all midwives and obstetricians working in the labour ward with 85% as the minimum pass mark. St George's Hospital became the first hospital in the UK not only to stop the National (NICE) CTG Guideline which classified CTG traces into normal, suspicious and pathological and to stop FBS, but, it was the first hospital to introduce a mandatory competency testing on CTG interpretation. This CTG competency test was subsequently rolled out nationally by NHS England in their *Saving Babies' Lives: A Care Bundle for Reducing Stillbirths* initiative [15]. This competency testing implemented in 2006 was cited as an example of best practice in fetal monitoring by the NHS London Strategic Clinical Network in their "Fetal monitoring, competency and assessment: A best practice toolkit [16].

The initial findings after the introduction of physiological interpretation of the CTG confirmed a reduction of both the HIE rate and the emergency caesarean section rate following the introduction of physiological interpretation of CTG, and this was presented at the World Congress of the Royal College of Obstetricians and Gynaecologists (RCOG) in Athens in 2011 [17]. This was followed by the presentation of the results after 5 years of implementation of Physiological Interpretation of CTG showing approximately 50% reduction in neonatal acidosis at the RCOG World Congress in Liverpool in 2013 [18]. The impact of the mandatory competency testing in combination of physiological interpretation of CTG and the use of fetal ECG in reducing both the emergency intrapartum caesarean section and HIE rates was highlighted at the World Congress in Controversies in Obstetrics, Gynaecology & Infertility (COGI) in Vienna in 2013 [19]. This gave birth to the concept of GIMS (George's Intrapartum Monitoring Strategy), which comprised of an intense training of

physiological interpretation of CTG, the use of fetal ECG (STAN) and Mandatory Competency Testing [19,20].

Several basic (one day) and advanced (2-day) "Physiological CTG Masterclasses" were conducted in more than 20 countries over a 10-year period to disseminate the knowledge of physiological interpretation of CTG. As many maternity units discontinued the "pattern-based" clinical guidelines classifying CTG traces into "Normal, Suspicious and Pathological" and abandoned FBS due to better knowledge of fetal physiology by embracing the physiological interpretation of CTG, the first international consensus guideline on Physiological CTG interpretation, developed by 34 CTG experts from 14 countries, was published in 2018 [21]. Several novel concepts in physiological interpretation of CTG such as "*How is THIS Fetus?*", the "*ZigZag*" Pattern, the "*Poole Shark Teeth*" Pattern and the features of the "*Chorio Duck*" were developed to facilitate the seamless transformation of knowledge fetal pathophysiology into daily clinical practice. The "*Fetal Monitoring Checklist*" was developed in 2017 to recognise antenatal causes of fetal compromise prior to the onset of labour [22]. This resulted in "*Is THIS fetus FIT to undertake the progressively hypoxic journey of labour?*" and "*How is THIS Fetus?*" becoming two key concepts advocated by the International Consensus Guidelines on Physiological interpretation of CTG in 2018. Several review articles were published in several mainstream and other "open-access" journals and textbooks to disseminate the knowledge of fetal physiology to both well-resourced and resource-poor health care settings, to ensure democratisation of knowledge worldwide to improve maternal and perinatal outcomes [23-43].

What does the emerging scientific evidence on physiological interpretation of CTG indicate?

The first scientific paper on the outcomes following the application of Physiological interpretation of CTG was published by Jia et al in 2019 [44], and this confirmed the correlation between the stable baseline FHR and reassuring variability with perinatal outcomes. Since then, scientific papers supporting several physiological concepts such as the "*ZigZag pattern*" [45,46], "*cycling*" [47], "*mechanical effects*" on the fetal heart rate during operative vaginal births [48], and the CTG features of the "*Chorio Duck*" [49,50], as well as "*maternal COVID-19*" infection [51] have been published.

Cochrane Systemic Reviews have repeatedly highlighted that earlier studies using CTG guidelines classifying CTG traces as "normal, suspicious, pathological" had failed to show any correlation between abnormal CTG features and poor perinatal outcomes, and they concluded that the use of CTG did not reduce cerebral palsy and perinatal deaths but increased operative interventions [52]. However, recent evidence has shown that using different types of fetal hypoxia as recommended by the International Consensus Guidelines on Physiological interpretation of CTG enabled the correlation of observed type of hypoxia with neonatal acidosis [53,54]. Moreover, scientific studies have recently concluded that not only types of different intrapartum hypoxia correlated with the pattern of injury noted on the MRI scan of the brain in the neonatal period [55,56], but it also correlated with the neurological outcome at 2.8 years of age [56].

Recent evidence has also shown that a regional CTG training programme based on fetal physiology showed a significant improvement in the professionals' interpretation of CTG at short term and stable results at long term [57].

Is there any evidence of improvement in perinatal outcomes after the implementation of physiological interpretation of CTG?

In addition to the reports of improved perinatal outcomes from St George's maternity unit following the implementation of physiological interpretation of CTG, recent evidence from Mid and South Essex NHS Foundation Trust (MSE), which is one of the largest maternity services in the UK with approximately 12,500 births/year suggests that after replacing the NICE CTG Guidelines with International Consensus Guidelines on Physiological Interpretation of CTG, there was a 60% reduction in HIE across all 3 maternity units which constitute MSE [58,59]. The Maternity Unit at Basildon University Hospital was short-listed for the HSI National Patient Safety Award as a Finalist for "Reducing hypoxic brain injuries at birth by innovative Physiological Interpretation of Cardiotocograph" (<https://awards.hsj.co.uk/winners-2022>). In addition, Kingston Hospital (<https://www.hsj.co.uk/the-hsj-awards/improving-fetal-monitoring-skills/7025167.article>) and Peterborough Hospital have also been recognised by National Awards in the UK for demonstrating reduction in hypoxic ischaemic encephalopathy (HIE) rate after the implementation of physiological interpretation of CTG.

Several other hospitals both in the UK, Ireland (<https://www.limerickpost.ie/2019/02/11/limerick-leads-in-reducing-birth-brain-injury/>) have also demonstrated such improvement in perinatal outcomes (<https://youtu.be/tTUJA58QDjU>). Recently, Zamora Del Pozo C et al from Spain [60] analysed the predictive capacity of neonatal acidemia in the latest versions of four international cardiotocography guidelines: FIGO, ACOG, NICE and the Physiological CTG guideline in Madrid between January 2015 and June 2018. The last 30 min of 150 CTG records were analysed by three independent reviewers (blinded) over all the pH ranges. The authors found fetal cardiotocography guidelines have a variable sensitivity and specificity. The Classification recommended by the Physiological CTG guideline reached the highest sensitivity which was 78.79%, as compared to 24.24% for FIGO, 15.15% for ACOG and 39.39% for NICE. Moreover, the physiological CTG guideline which relies on understanding of the fetal physiological responses to ongoing hypoxic and mechanical stresses had the highest discrimination capacity for neonatal acidemia (AUC 0.66; 95%CI, 0.55-0.77) compared with FIGO (AUC 0.63; 95% CI, 0.52-0.73), ACOG (AUC 0.60; 95% CI, 0.49-0.70) and NICE (AUC 0.62; 95% CI, 0.517-0.729).

Samyraj et al from the UK reported an improvement of perinatal outcomes within two years of implementing physiological interpretation of CTG in Peterborough City Hospital North West Anglia, UK, which had approximately 5000 births/year [61]. This study demonstrated a progressive reduction in the number of severe (Grade 2/3) cases of hypoxic-ischaemic encephalopathy (HIE). The number of severe HIE cases in 2014-2015 was 22, and after conducting training on physiological CTG Masterclass in 2016, the number of severe HIE cases reduced from 19 in 2016-2017 to only 6 in 2018-2020, which demonstrated >60% reduction (compared to the average 10-12 cases to 2 cases per year after the implementation of physiological interpretation of CTG) in the number of severe HIE cases. In addition, Fetal Blood Sampling (FBS) was completely also abandoned.

In the light of 5 repetitive Each Baby Counts (EBC) reports produced by the Royal College of Obstetricians and Gynaecologists (RCOG) concluding that substandard care contributed to >70% of all cases of severe hypoxic-ischaemic brain injury and 33% of poor outcomes were due to CTG misinterpretation in

the UK (63), it may not be considered ethical to conduct a randomised controlled trial comparing the international consensus guideline on physiological interpretation of CTG with the error producing NICE CTG guideline. Therefore, analysing the outcomes "before and after" implementation of physiological interpretation of CTG from several maternity units may help frontline clinicians to make the right decision regarding optimal tools for intrapartum fetal heart rate monitoring to safeguard women and babies during labour.

Conclusion

In real life, lightning always precedes thunder because the speed of light is significantly higher than the speed of sound. In clinical medicine usually evidenced-based clinical guidelines are produced first (lightning) followed by implementation of the guideline and changes in clinical practice (thunder) to improve outcomes. However, in a hierarchical obstetric system with historical beliefs and entrenched cultural practices, it was not possible to replace the error producing national CTG guidelines with evidence-based guideline on physiological interpretation of CTG overnight. Unfortunately, many who practised non-evidence-based medicine by following CTG guidelines with arbitrary time limits were demanding robust scientific evidence prior to changing to physiological interpretation of CTG. This necessitated the "Thunder" (intense debates against the proponents of "normal, suspicious, pathological" and stopping of fetal blood sampling, individual discussions, dissemination of knowledge through intense physiological CTG Masterclasses, and the frontline midwives and obstetricians deviating from national guidelines in the interest of patient safety, thereby placing their own professional licence at risk) to precede the production of evidence-based physiological CTG guidelines (lightning), which was subsequently produced in 2018. It is hoped that the emerging scientific evidence in support of physiological interpretation of CTG will help change practice to individualise care to improve maternal and perinatal outcomes.

Conflicts of interest: The author has conducted several Master classes on CTG and fetal ECG in the UK, Europe, Asia, and Australia and has been the co-organizer of the Intrapartum Foetal Surveillance Course at the Royal College of Obstetricians and Gynaecologists (RCOG) and he was a member of the Editorial Board for NHS e-learning on CTG. He was the Course lead for the Neoventa Academy and the Baby Lifeline CTG Masterclasses. Organizers and hospitals of some of these Masterclasses have received sponsorships from Philips, Neoventa, Euroking, Huntleigh, K2, Cardiac Services, and other industry to support these Masterclasses. However, the author does not have any financial or managerial interests in any of these organisations. The author was one of the 3-member guideline development group which revised the international FIGO Guidelines on CTG in 2015, and he was on the Editorial Board which produced the first International Consensus Guidelines on Physiological Interpretation of CTGs in conjunction with 34 CTG Experts from 14 countries.

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