## Computerized cardiotocography and Dawes-Redman criteria: how should we interpret criteria not-met?

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## Abstract

Antenatal computerized cardiotocography, often abbreviated to cCTG, provides an objective way of assessing the fetal heart rate (FHR), most commonly analyzed according to the Dawes-Redman criteria. First described four decades ago, various components of the FHR were associated with adverse perinatal outcomes and poor fetal acid-base balance. While various proprietary devices offer analysis based on Dawes-Redman criteria, little evidence-based guidance exists from prospective studies outside of the specific area of hypoxia related to fetal growth restriction. Objective assessment of the CTG is an important step towards reducing variable interpretation. However, the widespread adoption of antenatal cCTG and its categorization of traces as ‘criteria met’ and ‘criteria not met’ has led to genuine uncertainty regarding situations where cCTG criteria for fetal wellbeing are not met. Many women undergoing monitoring in modern obstetric practice are at low-risk of perinatal adverse outcome, hence, the potential for obstetric over-intervention exists where cCTG criteria are not met, without clear evidence of benefit. This opinion piece seeks to establish where there is consensus, and where evidence is lacking in relation to antenatal fetal monitoring using the cCTG and Dawes-Redman criteria.

## Introduction

Antepartum cardiotocography (CTG) was introduced in the 1970s to allow continuous fetal monitoring. Initially it was received with enthusiasm but little rigorous testing and validation. Over time, criticisms have emerged regarding the interpretation, reproducibility, and clinical significance of CTG, particularly in relation to interpretation of the CTG trace, which is necessarily subjective. However, despite these concerns, the CTG remains in widespread use in antenatal care, in no small part, because it is impossible to ‘un invent’ technology.

The development of antepartum computerized CTG (cCTG) began in 1978 based on criteria developed by Geoffrey Dawes and Chris Redman (Dawes-Redman criteria) (1)(2). Since then, the algorithm has been constantly upgraded and improved, now reportedly based on approximately 100,000 CTG traces linked to clinical outcome data spanning 20 years (3). The main advantage of cCTG with Dawes-Redman criteria over ‘conventional’ CTG is that it expresses components of fetal heart rate (FHR) in an objective and numerically quantifiable way. This has led to cCTG being adopted as a recommendation for antepartum monitoring over CTG in United Kingdom by NHS “Saving Babies’ Lives Care Bundle” (https://www.england.nhs.uk/wp-content/uploads/2019/07/saving-babies-lives-care-bundle-version-two-v5.pdf), which states, not unreasonably: “*Human error in antepartum CTG interpretation has been identified as a significant root cause of stillbirth and serious brain injury. A failure to meet the Dawes-Redman criteria usually prompts even the most experienced clinician to re-evaluate their clinical assessment. It provides a second line of defence when a less experienced doctor or midwife interprets a CTG. Therefore, with a recognition that the evidence is inconclusive, SBLCBv2 recommends the antepartum use of computerized CTG over and above visualized CTG due to the potential to reduce the risks of human error”.*

Despite advantages of cCTG in relation to objective assessment, controversies remain regarding the introduction of Dawes-Redman criteria in clinical practice. In this opinion paper we: 1) explain how Dawes-Redman criteria are computed; 2) discuss the evidence that supports the use of the algorithm in clinical practice; 3) compare cCTG with CTG; and 4) consider some controversies, particularly regarding the clinical management when the criteria are not met.

## The computation of Dawes-Redman cCTG criteria explained

A technical description of the Dawes-Redman criteria and cCTG algorithm is beyond the scope of this manuscript. The computation of the Dawes-Redman criteria remains proprietary knowledge and the main components are described in Figure 1 and in the Appendix (4,5).



*Figure 1. An example of cCTG and Dawes-Redman criteria report. On the right, the process of analysis is represented. cCTG recording of the fetal heart is divided into 16 epochs in each minute, corresponding to 3.75 seconds in which the average FHR is expressed both as beats per minute (bpm) or as pulse intervals (ms) and used for further analysis. The minimum duration of fetal monitoring is 10 minutes; the analysis is performed at 10 minutes and every 2 minutes thereafter up to a maximum of 60 minutes. In the presence of enough elements to be classified as normal (in other words ‘criteria met’), the monitoring can be stopped. On the left, an example of Dawes-Redman criteria report is represented.*

Table 1 represents the description of Dawes-Redman criteria. The first eight parameters specify FHR recording features that either must or must not be met, while the last two refer to conditions during which the recording should not be stopped.

At the end of the monitoring period, a detailed report with Dawes-Redman criteria is produced together with number of fetal movements, uterine contractions and overall signal loss percentage (Figure 1). Finally, abnormalities are highlighted.

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| 1. | The recording must contain at least one episode of high variation |
| 2. | The STV must be >3 ms, but if it is <4.5 ms the LTV averaged across all episodes of high variation must be >3rd percentile for gestational age |
| 3. | There must be no evidence of a high-frequency sinusoidal rhythm |
| 4. | There must be at least one acceleration, or a fetal movement rate ≥20 per hour and an LTV averaged across all episodes of high variation that is >10th percentile for gestational age |
| 5. | There must be at least one fetal movement or three accelerations |
| 6. | There must be no decelerations >20 lost beats if the recording <30 minutes, no more than one deceleration of 21-100 lost beats if it is >30 minutes, and no decelerations at all >100 lost beats |
| 7. | The basal heart rate must be 116-160 bpm if the recording is <30 minutes |
| 8. | The LTV must be within 3SD of its estimated value or (a) the STV must be >5 ms, (b) there must be an episode of high variation with ≥5 fetal movements per min, (c) the basal heart rate must be ≥120 bpm, and (d) the signal loss must be <30% |
| 9. | The final epoch of the recording must not be part of a deceleration if the recording is <60 minutes, or a deceleration at 60 minutes must not be >20 lost beats |
| 10. | There must be no suspected artefacts at the end of the recording if the recording is <60 minutes |

*Table 1. Dawes-Redman criteria (Oxford system) for normality (from Pardey AJOG 2002)*(5)*. STV, short term variation; LTV, long term variation.*

When interpreting the FHR for computation of Dawes-Redman criteria, it is important to consider the physiological cycling of fetal behavioral states. Episodes of high FHR variation are present during active fetal sleep together with accelerations and fetal movements, implying fetal wellbeing. Episodes of active sleep, thus of high FHR long term variation (LTV), represent a better index of fetal normality than reactivity represented by accelerations (6).

Episodes of low FHR variation characterize fetal quiet sleep, as do a paucity of fetal movements. Characteristics of the FHR during quiet sleep may be difficult to distinguish from those of a compromised fetus with low variation (7,8). Cycling of fetal behavioral states can be identified from 28 weeks’ gestation onwards and in the healthy fetus episodes of quiet sleep, and thus low FHR variation, last up to 50 minutes (9,10). Thus, the length of recording should be sufficient to allow for the detection of active sleep and to differentiate between quiet sleep and fetal compromise - usually taken as one hour.

One of the most important cCTG parameters is short term variation, STV (see Appendix). The lower limit of STV normality is influenced by lower gestational age and shorter recording duration (11). Reduced STV associated with physiological fetal quiet (non-REM) sleep should last no longer than 45-50 minutes. In cases of reduced STV for >60 minutes other conditions should be considered, such as fetal hypoxemia or acidemia (in the presence of non-reactive FHR), medications (corticosteroids, MgSO4), fetal neurological anomalies, arrhythmia, or infection (usually in association with tachycardia) (12). Finally, special attention is reserved for the presence of a sinusoidal rhythm. This rare FHR pattern, identified by visual inspection (13) or by computerized analysis (14), is associated with a compromised fetus, particularly in the case of fetal anemia.

## Computerized CTG in fetal hypoxia/hypoxemia, metabolic acidosis and fetal growth restriction

Antepartum CTG analysis reflects the current fetal state at the moment of monitoring. As such, it cannot be regarded as a universal prediction tool or a screening test for stillbirth because unpredictable acute events such as placental abruption or intrapartum events also contribute to stillbirth. Nevertheless, low STV and LTV are good predictors of fetal metabolic acidosis at the time of monitoring.

LTV is correlated with umbilical blood gas analysis obtained by cordocentesis in severely small for gestational age fetuses: LTV <20 ms was always associated with severe fetal hypoxemia and acidemia (15). A similar association was reported between FHR recordings before cesarean delivery in pregnancies at high risk of fetal growth restriction (FGR) where umbilical cord blood gases were examined at delivery (16).

In high-risk pregnancies, STV <2.5 ms identified all terminal cases and three of four cases with metabolic acidemia at birth (12). In the same study, STV was proposed as a better marker of fetal compromise than LTV, with fetal compromise associated with slow sinusoidal FHR rhythm with increased LTV (12). Where a one-hour cCTG was performed within 4 hours of cesarean section in FGR with abnormal uterine and/or umbilical artery Doppler, low STV and LTV were significantly associated with umbilical artery pH and predicted acidemia at birth (17–19). It is important to note that these STV thresholds do not consider gestational age (STV increases with gestational age).

In summary, there is a strong association between STV and LTV cCTG parameters and fetal hypoxemia and/or acidemia in high-risk pregnancies (particularly FGR).

Longitudinal studies showed a gradual reduction in LTV FHR variation (20), and that reduced FHR variability and late decelerations appear approximately at the same time, as a late sign of fetal impairment (20). This should not be surprising considering that both indicate the presence of fetal hypoxemia or metabolic acidemia.

In severely growth restricted fetuses the prevalence of metabolic acidosis with an STV of <4.0 msecs was 35% (19), however wide gestational age of pregnancies (26-41 weeks) made analysis of an STV cut-off problematic given its change with gestational age. Seliger et al showed that a single recording of STV <4.0 msecs is not sufficient to justify intervention if the background risk is not particularly high and suggest that a repeat recording demonstrating a low STV is required (21).

These studies set the scene for the only randomized controlled trial (RCT) where cCTG was used within a management algorithm in the TRUFFLE-1 study of FGR at 26-32 weeks’ gestation (Figure 2) (22). Dawes-Redman criteria were not used, 1-hour STV and the presence of decelerations were.

Graphical user interface

Description automatically generated

*Figure 2. The figure represents the randomization arms in TRUFFLE 1 randomized controlled trial. REDF, reverse end diastolic flow; AEDF, absent end diastolic flow.*

The TRUFFLE-1 RCT concluded that the timing of delivery based on ductus venosus Doppler in conjunction with a gestational age related STV cut-off results in the best 2-year neurodevelopmental outcome in surviving infants (22,24,25).

## Evidence to support cCTG Dawes-Redman criteria in other pathological conditions

Abnormal findings on Dawes-Redman criteria have also been associated with other pathological conditions.

*Anemia.* In 19,506 predominantly high-risk pregnancies, a high frequency sinusoidal rhythm was encountered in 8 cases (0.41/1000) and in 5/8 (62.5%) there was confirmed neonatal anemia (mean 5.5 +/-1.2 g/dL) (14).

In case of suspected anemia, an additional assessment of peak systolic velocity in middle cerebral artery is indicated (26). This is particularly important, as sinusoidal rhythm may be present during physiological conditions such as fetal mouthing movements (27). The presence of reduced fetal movements in association with sinusoidal trace implies a more severe condition and prognosis.

*Reduced fetal movement*. In 524 women with reduced fetal movements (RFM) Daly et al. found CTG abnormalities are evident in 8% of cases, in 2% of cases these abnormalities persisted and women with non-reassuring CTG traces were more likely to have emergency delivery, Apgar score <7, resuscitation or neonatal intensive care unit (NICU) admission (28). Similarly, in 3,014 Norwegian women with RFM 3.2% had CTG abnormalities (29). Women with RFM and CTG abnormalities had a 7-fold increased risk of adverse pregnancy outcome (30). Despite this association there has been much less investigation of cCTG after maternal perception of RFM. A case report of a woman with FGR and preeclampsia noted normal STV in a woman with 5 days history of RFM, and birth was prompted by the presence of decelerations. The fetus had evidence of short-term asphyxia but not longer-term compromise (umbilical artery pH 7.16, BE -2.4) (31). Notably, some cCTG machines contain an actograph which objectively records low frequency fetal movements, related to accelerations, but not STV (32). A study of 435 women with RFM and cCTG compared to those who did not have cCTG, showed no difference in Apgar score <7, neonatal unit admission or preterm birth (33). Therefore, at present there is no evidence that cCTG improves outcome after RFM, but components could provide objective evidence of fetal movements and wellbeing.

*Brain damage*. FHR variability is a result of maturation of autonomic nervous system control. A significant reduction of STV, with normal blood gases and without decelerations, can occur in cases of severe brain damage (i.e. anencephaly, brain death, decerebration) shown in human and animal experimental studies (34–36).

## Is antenatal assessment with cCTG better than CTG?

One argument in favor of cCTG is that conventional CTG is interpreted through learned subjective visual interpretation, which lacks standardization. Indeed, several studies showed a low intra- and inter-observer reproducibility in CTG interpretation and have underlined this as a clinical problem (37–40). The application of a computer assisted device and its advices (i.e. signal loss) reduces monitoring duration (4).

An objective numerical assessment of STV is not possible from visual CTG assessment. In cases of already low FHR variation, it is difficult without measurement to estimate a decreasing trend day-by-day (4). Similarly, a correct interpretation of STV in early gestational age epochs is difficult without a quantitative evaluation. Other studies have suggested advantages in cCTG over CTG in terms of improved perinatal outcome, the number of diagnostic interventions required and time used for monitoring (41,42).

While the interpretation of the extreme (normal vs terminal (43)) CTG traces is not contentious, it is the ‘grey zone’ in between that represents the problem. Thus, the main advantages of computer assisted analysis of antepartum CTG over visual interpretation is its objective nature, that it eliminates intra- and inter-observer variation and enables the identification of trends in monitoring. Table 2 summarizes pros and cons of cCTG versus CTG.

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|  | cCTG  (Dawes-Redman criteria) | CTG |
| Availability in high-resource settings | Not available everywhere | Available almost everywhere |
| Duration of monitoring | Minimizes recording time | Longer recording time required |
| Intra- and inter-observer variability | None | Substantial |
| Interpretation | Objective | Subjective |
| Experience | Important: but little data on which to guide management outside FGR | May be a problem for inexperienced staff |
| Period of use | Only antepartum | Ante and intrapartum |

*Table 2. Pros and cons of cCTG and CTG are listed.*

## How to interpret “criteria met” and “criteria not met”

In the case of cCTG, the first analysis is performed after 10 minutes and every two minutes thereafter. The recording can be stopped when criteria have been met, as fetal wellbeing has been ascertained and the risk of fetal hypoxemia/acidosis is very low (1,44). Unless there are clear abnormal patterns such as repetitive decelerations or prolonged severe bradycardia or criteria have been met, the recording should continue for at least 60 minutes. Abnormally low variability is not conclusive unless the monitoring duration is at least 60 minutes. Unless clearly abnormal, the recording should not be stopped prematurely because the results are invalid. For example, a state of quite sleep may take a longer recording time for criteria to be met. The possible reasons for the criteria to be not met are listed in Table 3.

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| Possible reasons for Dawes-Redman criteria not met | |
| 1. | Basal heart rate <110 or >160 bpm |
| 2. | Baseline fitting uncertain |
| 3. | No episodes of high variation |
| 4. | No movements and <3 accelerations |
| 5. | No accelerations |
| 6. | LTV in high episodes < cut-off for gestational age |
| 7. | STV <3 ms |
| 8. | Large decelerations |
| 9. | High- frequency or suspected sinusoidal rhythm |
| 10. | Possible error or deceleration at the end of record |

*Table 3. Possible reasons for criteria not to be met are listed.*

The next question is how frequently does criteria “not-met” occur. The reported proportion of criteria “not-met” is around 6-10% (4)(45) (46). Roberts et al. found that 20% of recordings at 24-28 weeks’ gestation showed no accelerations >15 bpm, while 13% of recordings did not meet the criteria due to lack of episodes of high variation (45). Indeed, the mean number of accelerations per record increases with gestation (11) and the absence of episodes of high variation or accelerations is not an abnormal finding at lower gestations. In a more recent prospective study at median gestation 39+6 weeks’ in a mixed high and low-risk population that underwent induction or had a spontaneous labor, Dawes-Redman criteria were “not-met” in 9.6% (21/218) before labor or induction (46). There was no significant association between criteria “not-met” and prediction of arterial cord pH or composite neonatal morbidities. Finally, some specific categories of patients might have a higher proportion of criteria “not-met”. In women with type I diabetes, 20% of recordings failed to meet the criteria, in 11% due to the absence of episodes of high variation (47). There were no differences in the outcome between fetuses that did and did not meet the criteria suggesting that caution should be exercised in interpreting the Dawes-Redman criteria in this group of women.

Overall, these data suggest that where criteria are “not-met” after 60 minutes of recording, normality has not been demonstrated, not that the situation is *de facto* abnormal. In a recent article, Redman and Moulden suggest that when the criteria are “not-met” and in the presence of normal STV there is an increased risk of perinatal death and birth asphyxia, particularly at earlier gestational age epochs (3). However, they do not reference any outcome data and, to our knowledge, there are no formally reported data. Hence, in the absence of evidence, the question is how to manage the patient where criteria are ‘not-met’ and where there are no clear signs of pathology (sinusoidal rhythm, decelerations, prolonged severe bradycardia, STV <3 ms). There is anecdotal evidence of women undergoing induction of labor, admission for repeat cCTG until they meet criteria and intravenous fluid replacement in an effort for criteria to ‘meet’.

Thus, in the absence of large datasets that report on cCTG criteria “not-met” and the perinatal outcome, the authors of this review give the following practical advice based on their own clinical expertise and consensus as represented in Figure 3.



*Figure 3. The figure represents a flow-chart to follow in case of Dawes-Redman criteria “not-met”.*

## Conclusions

The cCTG is a widely-used antepartum monitoring tool. Despite that, there is a paucity of prospective data regarding the outcome of pregnancies when Dawes-Redman cCTG criteria are “not-met”. Outside the use of STV in FGR and clearly evident pathological FHR findings, such as fetal decelerations or bradycardia, management is difficult and not evidence based. Most studies of cCTG involve high-risk pregnancies with attendant confirmation bias in respect of abnormal outcome. However, the use of cCTG in medium and low-risk women risks over-interpretation in a large proportion of women where criteria are “not-met”, and there is the potential for over-medicalization, based on little or no data. The Dawes-Redman algorithm probably performs best where there is a pre-existing condition associated with fetal hypoxia/acidemia for example FGR, where its use has been shown to be adjunctive to Doppler.

It is prudent until further data becomes available to restrict the use of cCTG to specific conditions known to be associated with hypoxia and hypoxemia, for example anaemia and FGR, given the risk of false positive criteria not-met results leading to unwarranted clinical intervention. In the meantime, we call on those with large datasets to publish their outcome data taking into consideration background risk pertaining to the pregnancy, the gestational age and whether management was indicated, hence confounded, by the findings from cCTG analysis.

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