The quality of intrapartum cardiotocography in preterm labour

Zohal Faiz*, Eline M. Van ’t Hof, Gerard J. Colenbrander, Ralf Lippes and Petra C.A.M. Bakker

Abstract

Objectives: The aim of this study is to determine the quality of the foetal heart rate (FHR) recording, defined as signal loss, during preterm labour below 28 weeks gestational age (GA) and contribute to the discussion if cardiotocography (CTG) is of value for the extreme preterm foetus.

Methods: From January 2010 to December 2019 a retrospective study was conducted with data of 95 FHR recordings of singletons born between 24 and 28 weeks GA at the Amsterdam University Medical Centre, location VUmc. FHR tracings had a duration of at least 30 min and were obtained via external ultrasound mode. Data of all recordings were divided in two groups according to gestation (24–26 weeks and 26–28 weeks). Signal loss was analysed. Statistical significance was calculated by non-parametric tests and chi-square tests. The median signal loss and the proportion of cases exceeding the International Federation of Gynaecology and Obstetrics Guidelines (FIGO) threshold of 20% signal loss were calculated.

Results: One-third of the recordings exceeded the 20% FIGO-criterion for adequate signal quality during the first stage of labour. In the second stage, this was nearly 75%. Similarly, the median signal loss was 13% during the first and 30% during the second stage of labour (p<0.01).

Conclusions: The quality of FHR monitoring in the extreme preterm foetus is inadequate in a large proportion of the foetuses, especially during the second stage. FHR monitoring is therefore controversial and should be used with caution.

Introduction

A worldwide shift in the threshold for active treatment in preterm infants is seen. In the Netherlands, the threshold shifted in 2010 from 26 weeks gestational age (GA) to 24 weeks GA whereas in other countries, a term of 22 weeks GA is now the norm [1]. This global change in guidelines is due to the shift in the threshold of viability in the preterm infants, attributed to the improvement of neonatal intensive care [2]. How these births should be managed in terms of mode of delivery is under debate. Although some countries perform a caesarean section (CS), in many countries around the world a vaginal delivery with CTG monitoring is still the preferred mode of delivery. Particularly for spontaneous preterm deliveries with foetus in a good condition at the beginning of delivery and the intention for active neonatal support after delivery. Consequently, monitoring of the foetal heart rate (FHR) with cardiotocography (CTG) is also applied to foetuses of lower GA.

The main goal of FHR monitoring is to detect imminent foetal hypoxia, so that a well-timed, appropriate intervention can be started and perinatal outcome will improve [3]. The value of electronic foetal monitoring (EFM) in term foetuses is extensively studied over the past decades. These studies do not ascertain the benefits of EFM and give rise to controversy [4–6]. Rates of obstetric interventions have increased with a limited effect on perinatal mortality and morbidity [7]. The value of EFM in preterm foetuses and its contribution to improving outcome still needs to be studied [8]. Notwithstanding this, EFM is currently the clinical standard for monitoring foetal well-being in both term and preterm infants during labour. Furthermore EFM is limited by the high intra- and inter observer variability in interpretation of the FHR of term foetuses, even when international guidelines, like for instance the International Federation of Gynaecology and Obstetrics (FIGO) are used [9]. It is expected that interpretation of the FHR is even more challenging in preterm foetuses.

A less noticeable challenge is obtaining adequate signal quality, as seen in Figure 1. Several guidelines state that FHR recordings need to be of high quality so that basic

Keywords: cardiotocography; foetal heart rate monitoring; International Federation of Gynaecology and Obstetrics; preterm labour; signal quality.
FHR features can be assessed for evaluation of foetal well-being. However, a clear definition and quantification of adequate quality is lacking [10, 11]. FIGO guidelines are an exception. They quantify adequate quality as signal loss with an acceptable level up to 20%, although this is arbitrary [12]. Several studies have examined signal quality of FHR recordings. The quality of antepartum EFM in preterm foetuses found a mean signal loss of 28–55% [13, 14]. To our knowledge, no study examined signal quality for preterm foetuses during labour.

The aim of this study is to determine the quality of the FHR recording during preterm labour, and contribute to the discussion whether CTG is valuable for foetuses below 28 weeks GA.

Materials and methods

FHR recordings of preterm labour between 24 and 28 weeks GA were obtained at the Amsterdam University Medical Centre, location VUmc, from January 2010 to December 2019. A total of 265 preterm singleton deliveries took place.

Approval was obtained by the Medical Ethics Review Committee of VUmc. Eligible patients received an information letter. Informed consent was obtained by opting out. Patients had six weeks to opt out via e-mail or post and informed consent was implied after this period. After opting out, 259 cases were examined for inclusion. Exclusion criteria were twin deliveries, foetal death, foetal congenital anomalies including cardiac arrhythmia, absence of the CTG recording, duration of the last recording prior to birth <30 min and if the program was unable to compute the amount of signal loss (in case of a recording time longer than 15 h). The final database consisted of 95 singleton deliveries (Figure 2).

The FHR recordings were all obtained via external ultrasound mode only. The Philips M2736A Avalon ultrasound transducer (Philips Healthcare, Amsterdam, The Netherlands), was used, with a sampling rate of the FHR at a frequency of 4 Hz. The data was acquired and archived by the MOSOS centralized monitoring system (ICT Healthcare Technology Solutions, Houten, The Netherlands). FHR recordings were obtained and analysed with a computer program, specially developed for this purpose, to calculate signal loss for the first and second stage of labour. The reliability and reproducibility of the software were validated in previous studies from our research group, on signal loss in singletons and twins [15, 16]. See supplementary material for the algorithm of the computer program. Three levels of signal quality are defined: low, medium and high signal quality. In this study signal loss was defined by low quality, meaning that no signal was visible and available on the FHR trace. We have combined high and medium signal quality to one category: as a signal seen and available, and thus as no signal loss.

Primary outcome measures

The quality of the FHR recordings during labour was determined by the median signal loss and by the percentage of cases exceeding the FIGO-criterion (>20% signal loss) for adequate quality, for both stages of labour [17]. The first stage of labour was defined as the time period after the beginning of the FHR recording and lasts until the beginning of the second stage. The starting point of the second stage of labour, defined as the moment of active maternal pushing, was looked up in the patient’s chart and compared with the patterns of increased uterine activity on the CTG when available [18]. If the time mentioned in the patient’s charts did not correspond with the changed patterns of uterine activity, the latter was used to determine the beginning of the second stage. The analysis of the FHR ended with the birth of the infant, or when the recording ended prior to birth, due to premature ending of the recording or operative intervention. In case a CS was performed, foetal monitoring continued until the mother was transferred to the operating room, which is standard procedure in Amsterdam UMC.

Secondary outcome measures

Detection of the maternal heart rate (MHR) instead of the FHR can occur during labour and was defined as the proportion of heart rate tracings with a sudden drop below 100 BPM or more than 20 BPM from the baseline for more than 30 s and a direct return to the baseline. MHR detection was determined through eyeballing meaning that MHR was measured roughly by sight, without the help of software. The total amount of MHR detection was counted and divided by the total duration of the recording. MHR detection is hard to distinguish from decelerations during the second stage and was therefore only examined during the first stage.

The time the foetus was unmonitored, was defined by the time between the ending of the recording and the time of birth and was calculated in case of operative interventions and premature ending of the FHR recording.

Figure 1: A cardiotocograph of a foetus (25 + 1 week’s gestational age) during the first stage of labour. The infant was delivered vaginally approximately 1 h later with a pH of 7.28 and birth weight of 740 g. The Apgar score was 4-6-7. During the first stage of labour, there was 26% (100 min) signal loss.
Determinants

We examined whether the quality of the FHR recordings was associated with GA, mode of delivery (MOD) and maternal overweight. GA was divided between 24–26 weeks and 26–28 weeks. MOD by vaginal delivery (VD) or secondary caesarean delivery (CS). Maternal overweight was considered a BMI > 25 kg/m², calculated from prepregnancy weight.

Clinical characteristics

The following baseline characteristics were collected: maternal age (years), gravidity, parity, foetal birth weight (g), Apgar score after one and 5 min, pH of the foetal umbilical artery and duration of the second stage of labour.

Statistical analysis

Statistical analyses were carried out using SPSS Statistics 26.0 software. The Mann-Whitney U test, the Wilcoxon signed ranks test and the Chi-square test were used to compare baseline differences and significance. Data are presented as medians and interquartile ranges (IQR) and proportion of cases exceeding the FIGO-criterion. A p-value < 0.05 for a two-tailed test was considered statistically significant.

Results

Baseline characteristics

Patient characteristics are presented in Table 1 and were equal for both groups. The numbers of recordings per mode of delivery are presented in Figure 3.

Signal quality of the FHR recordings

A median signal loss of 13% for the first stage of labour was found. The median signal loss for the second stage was significantly higher, with 30% signal loss, see Table 2. Furthermore, approximately one third of the cases did not fulfil the FIGO-criterion for adequate quality during the first stage. This was 72% during the second stage of labour.
MHR registration did not contribute to foetal signal loss. The median unmonitored time for VD was 1 min. In 10 cases, the unmonitored time was more than 10 min. This premature ending of the recording was mainly due to excessive signal loss, with a median signal loss of 23% for the first stage of labour. Consequently, the FHR was monitored with ultrasound instead of CTG. Data for the second stage of labour could not be retrieved for this reason.

Signal quality and gestational age

The quality of the FHR during the first stage of labour was almost identical between both GA groups (Table 2). Although not significant, signal loss during the second

| Maternal and foetal characteristics | 24–26 weeks (n=25) | 26–28 weeks (n=70) |
|------------------------------------|-------------------|-------------------|
| Maternal age, years               | 31 ± 5            | 32 ± 6            |
| Gravida                            | 2 ± 2             | 2 ± 2             |
| Parity                             | 1 ± 1             | 1 ± 1             |
| Gestational age, days              | 177 ± 3           | 189 ± 4           |
| Birth weight, g                    | 792 ± 62          | 1,000 ± 183       |
| Apgar score 1 min                  | 4 ± 2             | 5 ± 2             |
| Apgar score 5 min                  | 6 ± 2             | 7 ± 1             |
| pH umbical artery                  | 7.28 ± 0.15       | 7.29 ± 0.13       |
| Duration second stage of labour, min | 16 ± 8           | 16 ± 11           |

*P* values: first stage versus second stage. *P*-value*²*: 24–26 weeks versus 26–28 weeks. A bold value indicates a significant *p*-value.
stage of labour was worse in the 24–26 weeks group in comparison to the 26–28 weeks group (38 vs. 28%, p-value = 0.34). For both GA groups, a statistical difference was seen in signal loss during the first versus the second stage of labour, at the expense of the second stage.

The proportion of cases not fulfilling the FIGO-criterion during the first stage of labour was lower in the 24–26 weeks group compared to the 26–28 weeks group (24 vs. 33%, p-value < 0.41). For the second stage, it was just the opposite, (80 vs. 69%, p-value = 0.50).

**Signal quality and mode of delivery**

CTG monitoring was performed until the mother was transferred to the operating room in case a CS was performed. No significant differences were seen in signal quality with respect to MOD, see Table 3. Of all CS, 40% were performed based on a non-reassuring FHR pattern, of which 41% did not fulfill the FIGO-criterion. In contrary, this was 20% in the other indications, which included infections (7.5%, n=4), alternative foetal presentation (13%, n=10) and abruptio placentae (18%, n=8). None were statistically significant.

**Signal quality and maternal weight**

For the first stage of labour, data on maternal weight was available for 29 mothers, see Table 3. Signal loss was more common in the overweight mothers (18 vs. 12%), however not significant. In the second stage of labour, data on maternal weight were available for only 12 mothers. Significance for the second stage of labour could not be analysed due to limited data on maternal BMI.

| Table 3: Foetal signal loss divided by maternal weight and mode of delivery. |
|---------------------------------------------------------------|
| **First stage of labour**                                    | **Vaginal delivery** | **Secondary caesarean delivery** |
|                                                               | (n=53)              | Non-reassuring FHR pattern (n=17) | Other indications (n=25) |
| Foetal signal loss                                           |                     | 13 (14)                          | 11 (22)                  |
| Median (IQR)                                                 |                     | 17/53 (32)                       | 7/17 (41)                |
| Not fulfilling FIGO-criterion (>20%)                         |                     | 5/25 (20)                        |                          |
| Cases/total, %                                               |                     |                                   |                          |
| Second stage of labour                                       | (n=37)              | (n=1)                            | (n=1)                    |
| Foetal signal loss                                           |                     | 30 (30)                          | 7 (7)                    |
| Median (IQR)                                                 |                     | 28/37 (76)                       | 0/1 (0)                  |
| Not fulfilling FIGO-criterion (>20%)                         |                     | 0/1 (0)                          | 0/1 (0)                  |
| Cases/total, %                                               |                     |                                   |                          |
| **First stage of labour**                                    | Normal maternal weight^a (n=17) | Maternal overweight^b (n=12) | p-Value |
| Foetal signal loss, %                                        | 12 (16)             | 18 (12)                          | 0.22                   |
| Median (IQR)                                                 |                     |                                   |                         |
| Not fulfilling FIGO-criterion (>20%)                         | 5/17 (29)           | 4/12 (33)                        | 0.83                   |
| Cases/total, %                                               | 5/8 (63)            | 4/4 (100)                        |                         |
| Second stage of labour                                       | (n=8)               | (n=4)                            |                         |
| Foetal signal loss, %                                        | 37 (30)             | 29 (19)                          |                         |
| Median (IQR)                                                 |                     |                                   |                         |
| Not fulfilling FIGO-criterion (>20%)                         | 5/8 (63)            | 4/4 (100)                        |                         |
| Cases/total, %                                               | 5/8 (63)            | 4/4 (100)                        |                         |

^aNormal maternal weight: a pre-pregnancy BMI of <25 kg/m². ^bMaternal overweight: a pre-pregnancy BMI of >25 kg/m². Mode of delivery is divided by vaginal delivery and secondary caesarean delivery. Secondary caesarean delivery is stratified by indication.
Discussion

Principal findings

In this unique retrospective study, the quality of intrapartum cardiotocography in preterm labour before 28 weeks was studied. Our data demonstrate that FHR recordings of preterm foetuses are susceptible to signal loss during labour, particularly during the second stage of labour. This leads to an unmonitored foetus during a major part of labour.

Interpretation in light of other evidence

Although no other studies have examined intrapartum signal quality in preterm labour, studies have examined the quality in term foetuses. Signal loss for the external mode, in the first stage of labour varied between 5–13% vs. 10–19% during the second stage of labour. Direct mode proved to be of far better quality, with percentage of signal loss below 4% for both stages of labour [15, 19]. Our study demonstrated more signal loss, especially during the second stage of labour. Moreover, the direct mode cannot be applied in preterm foetuses since placement of the electrode at the delicate foetal skull should be avoided [12].

Two studies have examined signal quality in preterm foetuses during pregnancy. The first study examined preterm foetuses with a GA of 24–34 weeks and found that in 28% of the time the foetus was not continuously monitored [13]. The second study included pregnancies with a lower GA, 21–26 weeks, and found 55% signal loss with the external mode. Interestingly, when abdominal f-ECG was applied, signal loss decreased to 25% [14]. Unfortunately, it is still unknown if f-ECG can be used in preterm labour. Both studies correlate signal quality in pregnancy to gestation. The inadequate quality of FHR monitoring at younger gestation can be explained by the large volume of the uterine space in relation to the smaller foetus and foetal movements. However, our study cannot confirm this, most likely due to the small study population.

Signal quality with respect to MOD has not been studied before. Our study found that caesarean deliveries are frequently performed while the quality of the trace is inadequate. Notably, signal quality was even worse in the non-reassuring FHR pattern group compared to other indications. Almost half of the FHR recordings were classified as inadequate quality. This is distressing since the rising incidence in CS worldwide contributes to high maternal and foetal mortality and morbidity and should be avoided [20].

Other reasons for signal loss are due to the Doppler technique, which is susceptibility to noise. Main causes include improper placement of the transducer, maternal and foetal movement and detection of the MHR instead of the FHR. Some studies correlate signal quality to maternal BMI, as a result of increased distance between the transducer and foetal cardiac structures [14, 21]. Other reasons for inadequate signal quality include foetal cardiac arrhythmias and complicated decelerations [22].

Strengths and limitations

This is the first study investigating signal quality during preterm labour. Only few other studies explored signal quality of EFM in preterm foetuses. These studies addressed signal quality during pregnancy. Presumably, signal quality will be better during pregnancy since factors contributing to signal loss during labour, like maternal movement and contractions, are lacking. The opposite is true, compared to EFM in pregnancy, our results show superiority with remarkably higher quality signals [13, 14]. This can be explained by the support of a dedicated midwife with vast experience in monitoring. Another explanation might be the high-quality monitors and ultrasound transducers, as quality control is conducted every year. Two previous studies from our research group also demonstrated remarkably better-quality traces in term foetus and twins compared to similar studies, verifying this hypothesis [15, 16]. Nevertheless, signal loss is still impressively high and we can only assume signal quality in preterm foetuses during labour, with inferior quality transducers and a less experienced team, to be lower.

Unfortunately, our study was limited due to a small sample size. This explains why the correlation of signal loss with gestation and maternal overweight could not be confirmed, as expected from previous studies that do demonstrate a relationship [13, 14, 23].

Moreover, the median signal loss in our study was not evidently affected by recording of the MHR. Nonetheless, this does not mean that the MHR was not recorded since we were limited to eyeballing. Consecutive MHR recording for more than 30 s did not occur and therefore did not contribute to signal loss. MHR registration during second stage of labour was not measured. During this stage it is difficult to distinguish the MHR from foetal decelerations. However, monitoring the MHR instead of the FHR is likely to increase when the foetus descends. Previous studies found a median MHR registration of 0.70% for the first stage, up to 6% for the second stage of labour [23].
Practical and research recommendations

Worldwide, there is no consensus on labour management for extreme preterm birth considering mode of delivery and the application of foetal heart rate monitoring. Although a few low grade observational studies have been performed on this subject, strong evidence is lacking. The mode of delivery in spontaneous preterm birth did not affect neonatal mortality or morbidity, short and long term, in these studies. Since the incidence of perinatal asphyxia in extreme preterm infants is unclear, and the consequences of a CS for subsequent pregnancies are considerable, a vaginal delivery is still the preferred mode of delivery in the Netherlands and many other countries around the world [24, 25].

EFM is currently the only method to monitor the preterm foetus during labour and therefore is used worldwide as the standard method for monitoring. CTG opens for clinicians the option for additional information about foetal wellbeing and is therefore used in some countries as a tool to decide the optimal timing of intervention. However, clinicians must be aware that a non-reassuring FHR pattern is common during preterm labour and usually does not affect mortality rates [26]. Additionally, the quality of the FHR trace during labour is poor in a large proportion and signal quality cannot be improved with the direct mode. Other monitoring methods in the preterm foetus still needs to be explored, such as f-ECG [27].

In term foetuses the second stage of labour is most crucial phase, when the risk for perinatal asphyxia is the highest [28]. In preterm foetuses the incidence and contribution of perinatal asphyxia to the high mortality and morbidity rates remains unclear. Therefore, EFM in preterm labour is debatable as the standard method to monitor the foetal condition. Future research should focus on these subjects and is crucial to establish the value of FHR monitoring for the preterm foetus and the clinician.

Conclusions

The quality of cardiotocography during extreme preterm labour is poor in a large proportion of the recordings, especially in the second stage. Cardiotocography is the golden standard to monitor the well-being of the term foetus, even though we are aware of its limitations. Clinicians should also be aware that FHR monitoring in the preterm foetus is controversial and should be used with caution.

Acknowledgments: Lisa van Zutphen, MD, Department of Epidemiology and Data Science, is acknowledged for assistance related to the statistical aspects. She was not sponsored for the assistance.

Research funding: None declared.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Competing interests: Authors state no conflict of interest.

Informed consent: Informed consent was obtained from all individuals included in this study.

Ethical approval: Research involving human subjects complied with all relevant national regulations, institutional policies and is in accordance with the tenets of the Helsinki Declaration (as revised in 2013), and has been approved by the Medical Ethics Review Committee of the Amsterdam UMC, location VUmc.

References

1. Wilkinson D, Verhagen E, Johansson S. Thresholds for resuscitation of extremely preterm infants in the UK, Sweden, and Netherlands. Pediatrics 2018;142:e5574–84.
2. de Laat MWM, Wiegerink MM, Walther FJ, Boluyt N, Mol BWJ, van der Post JAM, et al. Practise guideline ‘perinatal management of extremely preterm delivery’. Ned Tijdschr Geneeskd 2010;154: A2701.
3. Stout MJ, Cahill AG. Electronic fetal monitoring: past, present, and future. Clin Perinatol 2011;38:127–42.
4. Brocklehurst P, Field D, Greene K, Juszczak E, Keith R, Kenyon S, et al. Quantitative cardiotocography to improve fetal assessment during labor: a preliminary randomized controlled trial. Eur J Obstet Gynecol Reprod Biol 2016;205:91–7.
5. Brocklehurst P, Field D, Greene K, Juszczak E, Kenyon S, Linsell L, et al. Computerised interpretation of fetal heart rate during labour (INFANT): a randomised controlled trial. Lancet 2017;389:1719–29.
6. Smith V, Begley C, Newell J, Higgins S, Murphy DJ, White MJ, et al. Admission cardiotocography versus intermittent auscultation of the fetal heart in low-risk pregnancy during evaluation for possible labour admission – a multicentre randomised trial: the ADCAR trial. BJOG An Int J Obstet Gynaecol 2019;126:114–21.
7. Alfivreic Z, Devane D, Gyte GML, Cuthbert A. Continuous cardiotocography (CTG) as a form of electronic fetal monitoring (EFM) for fetal assessment during labour. Cochrane Database Syst Rev 2017;2. https://doi.org/10.1002/14651858.CD006066.pub3.
8. Afors K, Chandraharan E. Use of continuous electronic fetal monitoring in a preterm fetus: clinical dilemmas and recommendations for practice. J Pregnancy 2011;2011. https://doi.org/10.1155/2011/848794.
9. Schiermeier S, Westhof G, Leven A, Hatzmann H, Reinhard J. Intra- and interobserver variability of intrapartum cardiotocography: a multicenter study comparing the FIGO classification with computer analysis software. Gynecol Obstet Invest 2011;72: 169–73.

10. National Institute for Health and Care Excellence (UK). Intrapartum care for healthy women and babies: clinical Guideline. National Institute for Health and Care Excellence: Guidelines 2017.

11. American College of Obstetricians. Practice bulletin no. 116: management of intrapartum fetal heart rate tracings. Obstet Gynecol 2010;116:1232–40.

12. Ayres-De-Campos D, Spong CY, Chandrakaran E. FIGO consensus guidelines on intrapartum fetal monitoring: Cardiotocography. Int J Gynecol Obstet 2015;131:13–24.

13. Li Y, Gonik B. Continuous fetal heart rate monitoring in patients with preterm premature rupture of membranes undergoing expectant management. J Matern Neonatal Med 2009;22: 589–92.

14. Sänger N, Hayes-Gill BR, Schiermeier S, Hatzmann W, Yuan J, Herrmann E, et al. Prenatal foetal non-invasive ECG instead of Doppler CTG – a better alternative? Geburtshilfe Frauenheilkd 2012;72:630–3.

15. Bakker PCAM, Colenbrander GJ, Verstraeten AA, Van Geijn HP. The quality of intrapartum fetal heart rate monitoring. Eur J Obstet Gynecol Reprod Biol 2004;116:22–7.

16. Bakker PCAM, Colenbrander GJ, Verstraeten AA, Van Geijn HP. Quality of intrapartum cardiotocography in twin deliveries. Am J Obstet Gynecol 2004;191:2114–9.

17. Rooth G, Huch A, Huch R. Guidelines for the use of fetal monitoring. Int J Gynecol Obstet 1987;25:159–67.

18. Nederlandse Vereniging voor Obstetrie en Gynaecologie (NVOG). Spontaneous vaginal delivery [in Dutch]. NVOG Guideline 2013.

19. Reinhard J, Hayes-Gill BR, Schiermeier S, Hatzmann W, Herrmann E, Heinrich TM, et al. Intrapartum signal quality with external fetal heart rate monitoring: a two way trial of external Doppler CTG ultrasound and the abdominal fetal electrocardiogram. Arch Gynecol Obstet 2012;286: 1103–7.

20. Betran AP, Torloni MR, Zhang JJ, Gülmezoglu AM. WHO statement on caesarean section rates. BJOG 2016;123:667–70.

21. Spencer JAD, Belcher R, Dawes GS. The influence of signal loss on the comparison between computer analyses of the fetal heart rate in labour using pulsed Doppler ultrasound (with autocorrelation) and simultaneous scalp electrocardiogram. Eur J Obstet Gynecol Reprod Biol 1987;25:29–34.

22. Van Geijn HP, Lomsinga HW, De Haan J, Eskes TKAB. Analysis of heart rate and beat-to-beat variability: interval difference index. Am J Obstet Gynecol 1980;138:246–52.

23. Reinhard J, Hayes-Gill BR, Schiermeier S, Hatzmann H, Heinrich TM, Louwen F. Intrapartum heart rate ambiguity: a comparison of cardiotocogram and abdominal fetal electrocardiogram with maternal electrocardiogram. Gynecol Obstet Invest 2013;75:101–8.

24. Morgan AS, Marlow N, Costeloe K, Draper ES. Investigating increased admissions to neonatal intensive care in England between 1995 and 2006: data linkage study using Hospital Episode Statistics. BMC Med Res Methodol 2016;16. https://doi.org/10.1186/s12874-016-0152-0.

25. Högberg U, Holmgren PA. Infant mortality of very preterm infants by mode of delivery, institutional policies and maternal diagnosis. Acta Obstet Gynecol Scand 2007;86:693–700.

26. Ayoubi JM, Audibert F, Vial M, Pons JC, Taylor S, Frydman R. Fetal heart rate and survival of the very premature newborn. Am J Obstet Gynecol 2002;187:1026–30.

27. Peters CHL, van Laar JOEH, Vullings R, Oei SG, Wijn PFF. Beat-to-beat heart rate detection in multi-lead abdominal fetal ECG recordings. Med Eng Phys 2012;34:333–8.

28. Sandström A, Altmann M, Cnattingius S, Johansson S, Ahlberg M, Stephansson O. Durations of second stage of labor and pushing, and adverse neonatal outcomes: a population-based cohort study. J Perinatol 2017;37:236–42.

Supplementary Material: The online version of this article offers supplementary material (https://doi.org/10.1515/jpm-2021-0214).