

Luca Finadri, Ilenia Mappa, Asma Khalil, Giuseppe Rizzo*, Alessandro Lucidi, Daniele Di Mascio, Marco Liberati, Edwin Chandrachan and Francesco D'Antonio

Intra-partum and perinatal outcomes in fetuses exhibiting ZigZag pattern on cardiotocography trace: a systematic review and meta-analysis

<https://doi.org/10.1515/jpm-2025-0279>

Received June 15, 2025; accepted November 16, 2025;

published online December 29, 2025

Abstract

Objectives: Historically, baseline fetal heart rate variability (FHRV) with an amplitude of greater than 25 beats per minute, and lasting for more than 30 min, was defined as the saltatory pattern. Several experimental animal models have reported an association between saltatory pattern and poor perinatal outcomes. However, recent studies have suggested that the classically defined saltatory pattern is very uncommon during labor, and a new CTG pattern, called the “ZigZag” pattern (ZZP), has been reported. ZZP has been defined as a rapid, erratic repetitive oscillations in the FHR with an amplitude of >25 bpm and has been claimed as a potential marker to identify fetuses at risk of intra-partum and perinatal compromise during labour. A recent international expert consensus has recommended that ZZP persisting for >1 min requires an urgent intervention to avoid poor perinatal outcomes. The aim of the present systematic review was to determine the intra-partum and perinatal outcomes of fetuses with the ZZP compared to the control group not showing the ZZP during labor.

Methods: Medline, Embase and Cochrane databases were searched. Inclusion criteria were studies reporting the intra-partum and perinatal outcome of fetuses showing compared

to those not showing ZZP during labour. The outcomes observed were operative vaginal delivery, caesarean section, umbilical artery pH<7.1, base excess <-11, mean pH and base excess, admission to neonatal intensive care unit (NICU), abnormal post-natal brain imaging and occurrence of late decelerations later on the CTG trace. Random-effect meta-analyses were used to combine data and results reported as pooled odd ratios (OR) for categorical and pooled mean differences (MD) for continuous variables with their 95 % confidence intervals (CI).

Results: Six studies (18,136 fetuses) were included. Fetuses showing ZZP on CTG trace during labor had a higher risk of operative vaginal delivery (OR: 2.22, 95 % CI 1.69–2.91; $p<0.001$), cesarean delivery (OR: 1.71, 95 % CI 1.37–2.15; $p<0.001$), umbilical artery pH<7.1 (OR: 2.48, 95 % CI 1.56–3.94; $p<0.001$), Apgar score <7 at 5 min (OR: 2.13, 95 % CI 1.05–4.31; $p=0.004$) and the occurrence of late decelerations later on during labor (OR: 9.51, 95 % CI 7.80–11.61; $p<0.001$) compared to those not showing this pattern, while there was no difference in the risk of NICU admission ($p=0.209$) and respiratory support after birth ($p=0.755$). Likewise, umbilical artery pH was significantly lower in fetuses showing compared to those not showing ZZP during labour (pooled MD: -0.10, 95 % CI -0.11 to -0.09; $p<0.001$), while there was no difference in the value of mean base excess between the two groups ($p=0.156$).

Conclusions: Fetuses showing the ZZP on CTG trace during labour are at higher risk of operative vaginal delivery, caesarean section and adverse intrapartum and perinatal outcomes.

Keywords: cardiotocography; ZigZag; saltatory pattern

*Corresponding author: Prof. Giuseppe Rizzo, Department of Obstetrics and Gynecology, Policlinico Umberto I, Rome, Italy, E-mail: giuseppe.rizzo@uniroma1.it. <https://orcid.org/0000-0002-5525-4353>

Luca Finadri, Alessandro Lucidi, Marco Liberati and Francesco D'Antonio, Centre for Fetal Care and High-Risk Pregnancy, University of Chieti, Chieti, Italy

Ilenia Mappa and Daniele Di Mascio, Department of Obstetrics and Gynecology, Policlinico Umberto I, Rome, Italy. <https://orcid.org/0000-0002-9866-3050> (I. Mappa). <https://orcid.org/0000-0002-6560-3393> (D. Di Mascio)

Asma Khalil, Fetal Medicine Unit, St George's University Hospital, London, UK

Edwin Chandrachan, Department of Transformational Learning & Development, Global Academy of Medical Education & Training, London, UK

Introduction

Cardiotocography (CTG) is a widely utilized tool in obstetrics for monitoring fetal heart rate (FHR) and uterine contractions and was intended to allow clinicians to assess fetal well-being and make timely interventions to prevent adverse outcomes [1]. Since its development in the 1960s, CTG has been widely implemented into clinical practice to help identify potential

fetal compromise by providing a detailed information on FHR baseline, variability, accelerations, decelerations, and contraction patterns, each of which can offer insights into fetal oxygenation and health status [2–7].

The autonomic nervous system regulates FHR regulation and influences the patterns observed on CTG [8, 9]. While fetal heart rate variability is commonly attributed to a “push-pull” interaction between parasympathetic and beta-sympathetic branches, direct evidence supporting this model remains limited [10]. In an investigation by Dalton et al., autonomic blocking in fetal lambs demonstrated that beta-sympathetic blockade alone did not alter heart rate variability, while parasympathetic blockade reduced, but did not eliminate, variability. Interestingly, dual blockade of both autonomic branches left approximately 35–40 % of heart rate variability intact, implying a significant non-neural component in fetal heart rate modulation [10].

However, CTG interpretation remains challenging, with substantial subjectivity and complexity in assessing patterns, leading to variability in clinical decision-making [6, 11]. These interpretative challenges often result in either false positives, contributing to unnecessary interventions like operative vaginal delivery or emergency cesarean sections, potentially impacting neonatal outcomes [7, 12]. To address these limitations, recent efforts have focused on standardizing interpretation guidelines, which may improve both diagnostic accuracy and consistency in fetal monitoring [4, 7, 13–15].

Traditionally, a FHRV greater than 25 beats per minute lasting more than 30 min, was defined as saltatory pattern, is considered to carry an increased risk of poor perinatal outcomes [16–18]. However, recent studies have reported that the classically defined saltatory pattern is uncommon during labor and there is no international consensus yet regarding its definition, duration, interpretation and management [19].

More recently, a new CTG pattern, the “ZigZag” pattern (ZZP), has been reported and defined as a rapid, erratic, repetitive oscillations in the FHR baseline, most of the times at a variability above 25 bpm for at least 1 min [20–28]. This pattern has garnered attention for its potential association with fetal hypoxia and metabolic acidosis, conditions that warrant close monitoring and often requiring an urgent clinical intervention to improve fetal oxygenation [22–25]. Despite its potential clinical relevance, the ZZP remains a controversial marker due to limited consensus on its diagnostic accuracy and specificity. Some studies suggest that the ZZP reliably signals rapidly evolving hypoxic episodes, while others note its appearance in non-pathological scenarios, complicating its use as a definitive marker of fetal compromise [17, 20–26, 29, 30]. Therefore, the ZZP may represent an

important sign fetal compromise both during a rapidly evolving hypoxic stress, and in fetal inflammatory response syndrome (FIRS), as well as when there is a transfer of inflammatory cytokines from the maternal environment.

The aim of this systematic review and meta-analysis was to report the intra-partum and perinatal outcomes of fetuses with ZZP compared to those not showing ZZP during labor.

Methods

Protocol, information sources and literature search

This review was performed according to an *a-priori* designed protocol and recommended for systematic reviews and meta-analysis [31–33]. Medline, Embase and Cochrane databases were searched electronically on the 10/09/2024 utilizing combinations of the relevant medical subject heading (MeSH) terms, key words, and word variants for “ZigZag”, “Saltatory” patterns, “increased variability” and “outcome”. The search and selection criteria were restricted to the English language. Reference lists of relevant articles and reviews were hand-searched for additional reports. The PRISMA guidelines were followed [34].

Outcomes measures, study selection and data collection

We included studies reporting the intra-partum and perinatal outcome of fetuses showing compared to those not showing ZZP, defined as a rapid, repetitive oscillations in the FHR baseline, most of the times at a variability above 25bpm for at least 1 min, at CTG trace during labour (Figure 1).

The outcomes observed were:

- Operative vaginal delivery

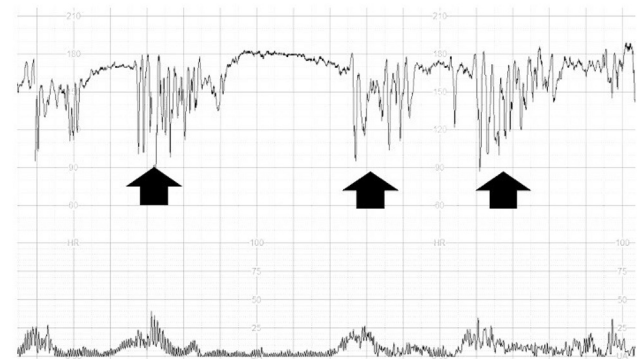


Figure 1: Zig-Zag pattern on a CTG trace during labour.

- Caesarean delivery
- Umbilical artery pH<7.1
- Base excess <-11
- Mean pH and base excess
- Admission to neonatal intensive care unit (NICU)
- Abnormal post-natal brain imaging, defined as the presence of intra-ventricular haemorrhage or periventricular leukomalacia or at post-natal imaging
- Occurrence of late decelerations later on the CTG trace

We also reported the distribution of different pregnancy and fetal characteristics including:

- Maternal age
- Gestational age at birth
- Nulliparity
- Spontaneous or induced labor
- Term pregnancies
- Prolonged or post-term pregnancies, defined as pregnancies progressing beyond 41 and 42 weeks of gestation respectively

Data extraction, quality assessment, risk of bias and statistical analysis

Two independent investigators (LF, GO) selected studies in two stages. The abstracts of all potentially relevant papers were examined individually for suitability. Papers were excluded at this stage only if they did not meet the inclusion criteria. The remaining papers were obtained in full text and were assessed independently for content, data extraction and analysis. Disagreements between the two original reviewers were resolved by discussion with a third investigator (FDA). Study characteristics were extracted using a predesigned data extraction protocol. If more than one study was published on the same cohort with identical endpoints, the report containing the most comprehensive information on the population was included to avoid overlapping populations.

Only full-text articles were considered eligible for inclusion. Studies not reporting the comparison between fetuses showing and those not showing ZZP on CTG trace during labour, those including only the role of CTG in specific pregnancy complications (such as those affected by infection or medical conditions complicating pregnancy) and those not reporting the occurrence of the observed outcomes were excluded. Case reports, conference abstracts and case series with <10 cases were also excluded to avoid publication bias. We excluded studies published before 2010 because we think that advances in the comprehension of CTG trace during labour make them less relevant.

Quality assessment of the included studies was performed using the Newcastle-Ottawa Scale (NOS) for case-control studies [35]. According to NOS, each study is judged on three broad perspectives: the selection of the study groups; the comparability of the groups; and the ascertainment of the outcome of interest.

Random-effect meta-analyses were used to combine data and results reported as pooled odd ratios (OR) and pooled mean differences (MD) for categorical continuous variables respectively [36, 37]. Funnel plots displaying the outcome rate from individual studies vs. their precision (1/standard error) were carried out with an exploratory aim, but were not used when the total number of publications included for each outcome was less than 10. In this case, the power of the tests is too low to distinguish chance from real asymmetry [37].

Between-study heterogeneity was explored using the I² statistic, which represents the percentage of between-study variation that is due to heterogeneity rather than chance. All analyses were performed using StatsDirect Statistical Software (StatsDirect Ltd Cambridge, United Kingdom).

Results

Study selection and characteristics

The literature search identified 320 articles, 10 of which were assessed for eligibility for inclusion, and six studies were included in the systematic review (Table 1, Figure 2, Supplementary Table 1) [19, 21–24, 30]. These six studies included (after removing the studies including overlapped cases) 18,136 fetuses.

The results of the quality assessment of the included studies using the NOS scale are presented in Table 2. Most of the included studies showed an overall moderate score regarding the selection and comparability of study groups, and for ascertainment of the outcome of interest. The main weaknesses of these studies were their retrospective design, and heterogeneity of outcomes observed.

Synthesis of the results

When comparing the maternal and pregnancy characteristics, there was no difference in maternal age ($p=0.878$) and term labor between cases showing and those not showing ZZP on CTG. Conversely, there was a higher prevalence of nulliparity ($p<0.001$), prolonged or post-term pregnancies ($p<0.001$) and women undergoing induction of labor

Table 1: General characteristics of the studies included in the systematic review.

Author	Year	Country	Study design	Period considered	Inclusion criteria	Inclusion of pregnancies complicated by placental insufficiency or pre-eclampsia	Definition of Zig-Zag pattern	Primary outcome	Pregnancies (n)
Loussert [21]	2022	France	Prospective	2019	All pregnancies ≥ 37 weeks	Yes	Definition of marked variability: variability greater than 25 beats per minute, with a minimum duration of 1 min	Neonatal acidosis	4,394
Tarvonen [24]	2020	Finland	Retrospective	2012	Pregnancies > 33 weeks of gestation	Yes	FHR baseline amplitude changes of > 25 bpm with a duration of 2–30 min	Umbilical artery (UA) blood gases, Apgar scores, neonatal respiratory distress, and neonatal encephalopathy	5,150
Tarvonen [25]	2020	Finland	Retrospective case control	2012	Pregnancies > 33 weeks of gestation	Yes	Definition of saltatory pattern: FHR baseline amplitude changes of > 25 bpm with an oscillatory frequency of > 6 /min with a minimum duration of 2 min	pH, base excess, pO ₂ and erythropoietin on umbilical cord	245
Gracia-Perez-Bonfils [30]	2020	Spain	Retrospective cohort	2020	Pregnancies in patients with symptomatic COVID-19 infection	Yes	Variability > 25 bpm during 1 min or more	Apgar score at 5 min and umbilical cord pH	12
Gracia-Perez-Bonfils [19]	2019	United Kingdom	Retrospective	2018–2019	Singleton term pregnancies between 37 and 42 weeks of gestation	No	Variability > 25 bpm during 1 min or more	Apgar scores, umbilical cord pH values and admission to NICU	500
Polnaszek [23]	2019	United States	Prospective cohort	2010–2015	All pregnancies ≥ 37 weeks	No	Definition of marked variability: fluctuations in FHR amplitude of > 25 beats per minute based on 10-min epochs	Neonatal morbidity and abnormal arterial cord gases	8,580

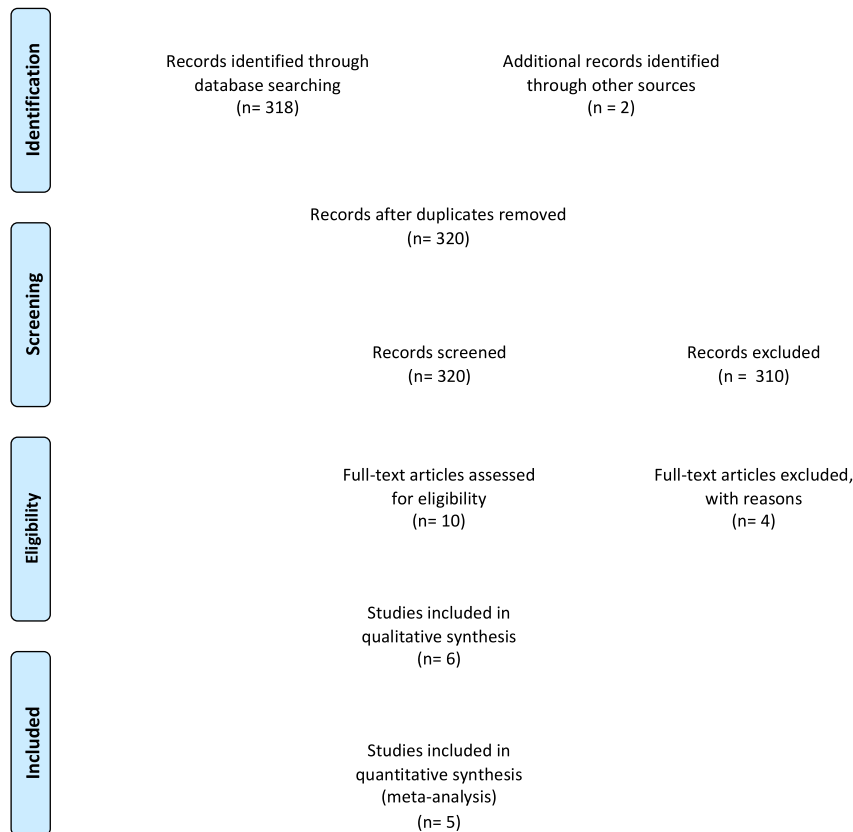


Figure 2: Prisma flow-diagram.

Table 2: Methodological assessment of included studies based on Newcastle – Ottawa Score (NOS).

Author	Year	Selection	Comparability	Outcome
Loussert	2023	★★★	★★	★★★
Tarvonen	2023	★★	★	★★
Gracia-Perez-Bonfils	2023	★★	★★	★★
Gracia-Perez-Bonfils	2023	★★	★	★★
Tarvonen	2022	★★	★★	★★
Polnaszek	2022	★★	★★	★★

($p=0.002$) between women showing compared to those not showing ZZP at CTG assessment during labor (Table 3).

Fetuses showing ZZP on CTG trace during labor had a higher risk of operative vaginal delivery (OR: 2.22, 95 % CI 1.69–2.91; $p<0.001$), cesarean delivery (OR: 1.71, 95 % CI 1.37–2.15; $p<0.001$), umbilical artery pH<7.1 (OR: 2.48, 95 % CI 1.56–3.94; $p<0.001$), Apgar score <7 at 5 min (OR: 2.13, 95 % CI 1.05–4.31; $p=0.004$) and the occurrence of late decelerations later on during labor (OR: 9.51, 95 % CI 7.80–11.61; $p<0.001$) compared to those not showing this pattern, while there was no difference in the risk of NICU admission ($p=0.209$) and respiratory support after birth ($p=0.755$), while it was not possible to performed a comprehensive pooled data synthesis for abnormal brain imaging as only

one study reported this outcome (Table 4). When considering the continuous variables, umbilical artery pH was significantly lower in fetuses showing compared to those not showing ZZP during labour (pooled MD: -0.10 , 95 % CI -0.11 to -0.09 ; $p<0.001$), while there was no difference in the value of mean base excess between the two groups ($p=0.156$) (Table 4).

Discussion

Summary of the main findings

The findings from this systematic review showed that fetuses showing ZZP on CTG trace during labor had a higher risk of operative vaginal delivery, cesarean section, abnormal Apgar score, pH<7.1 compared to those not showing this pattern during labour. The observed increase in the ZZP in post-term fetuses ($p<0.001$) who have reduced placental reserves and increased likelihood of umbilical cord compression due to relative reduction in amniotic fluid volume, and in fetuses who were exposed to induction of labor ($p=0.002$), supports the hypothesis that ZZP reflects a rapidly evolving hypoxic stress. This is because increased umbilical cord compression and reduced utero-placental

Table 3: Odd ratios and mean differences for the different maternal and pregnancy characteristics in the present systematic review in fetuses presenting compared to those not present ZZP at CTG during labor (95 % CI between parantheses).

Characteristics	Categorical variables				
	Studies	Patients (n/N vs. n/N)	Pooled odd ratio (95 % CI)	I ² (%)	p-Value
Nulliparity	3	750/1,149 vs. 7,727/16,975	2.40 (1.63–2.56)	65.4	<0.001
Spontaneous labor	3	734/1,149 vs. 11,090/16,975	0.78 (0.68–0.89)	0	0.002
Induced labor	3	415/1,149 vs. 5,585/16,975	1.28 (1.13–1.46)	0	0.002
Term labor	3	0/1,149 vs. 16,415/16,975	0.01 (0.001–1.79)	0	0.078
Post-term labor	2	84/972 vs. 398/12,758	1.76 (1.37–2.28)	0	<0.001
	Continuous variables				
	Studies	Raw mean (patients)	Pooled mean difference (95 % CI)	I ² (%)	p-Value
Maternal age	3	29.97 ± 3.93 (1,149) vs. 30.07 ± 3.70 (16,975)	−0.093 (−1.28 to 1.095)	97.23	0.878
Gestational age at birth	3	39.90 ± 1.27 (1,149) vs. 39.50 ± 1.13 (16,975)	0.363 (0.13 to 0.60)	92.93	0.003

insufficiency in the former and increased uterine activity in the latter would increase the likelihood of a rapidly evolving hypoxic stress in late first or second stage of labor, leading to the onset of ZZP on the CTG trace.

Comparison with other systematic reviews, strengths and limitations

The multitude of outcomes observed, and thorough literature search are main strengths of the present systematic review, while the small number of included cases, retrospective study design and lack of standardised criteria for intra-partum management in case of ZZP represents its main weaknesses. Furthermore, some maternal and pregnancy characteristics were unbalanced between the two different study groups, including nulliparity, induction of labour and post-term pregnancies, thus potentially representing a source of bias for the reported results.

Table 4: Pooled odd ratios and mean differences (95 % CI) for the different maternal and perinatal outcomes.

Categorical outcomes					
Outcome	Studies	Fetuses (n/N vs. n/N)	Pooled OR (95 % CI)	I ² , %	p-Value
Operative vaginal delivery	2	93/567 vs. 370/12,407	2.22 (1.69–2.91)	23.2	<0.001
Cesarean section	2	109/421 vs. 1,398/8,353	1.71 (1.37–2.15)	0	<0.001
Umbilical artery pH<7.1	3	49/717 vs. 386/12,757	2.48 (1.56–3.94)	39.6	<0.001
Apgar score<7 at 5 min	4	36/748 vs. 281/12,920	2.13 (1.05–4.31)	56.1	0.004
Respiratory support or intubation	2	29/567 vs. 637/12,407	0.67 (0.05–8.38)	94.2	0.755
Admission to NICU	2	21/327 vs. 148/4,576	3.14 (0.53–18.69)	85.7	0.209
Abnormal brain imaging	1	–	–	–	–
Late decelerations occurring later on the CTG trace	2	542/759 vs. 2,044/8,785	9.51 (7.80–11.61)	<0.001	<0.001
Continuous outcomes					
	Studies	Raw mean (patients)	Pooled mean difference (95 % CI)	I ² , %	p-Value
pH	3	7.19 ± 0.07 (571) vs. 7.23 ± 0.12 (8,703)	−0.10 (−0.11 to −0.094)	0	<0.001
Base excess	2	−8.08 ± 4.05 (421) vs. −6.24 ± 2.75 (8,353)	1.75 (−0.67 to 4.16)	92.3	0.156

Clinical and research implications

The American College of Obstetricians and Gynaecologists (ACOG) and the FIGO classification system [4, 7, 14] for CTG was developed to standardize the interpretation of FHR patterns during labor, grouping tracings into three primary categories based on specific criteria:

- Category I (FIGO=Normal): Patterns with a low risk of hypoxia, typically requiring no intervention.
- Category II (FIGO=Suspicious): Patterns that are inconclusive and warrant closer monitoring.
- Category III (FIGO=Pathological): Patterns with a high likelihood of fetal hypoxia, necessitating prompt intervention.

While these frameworks support labor management by establishing universal categories, these categories, being too rigid, may overlook the complexity of individual cases. For example, a growth restricted fetus may not have sufficient physiological reserves to be rigidly classified into these “fixed categories”. However, exposure to chronic uteroplacental insufficiency or an intraamniotic inflammation and/or chorioamnionitis may lead to multiple pathways of compromise. More importantly, its focus on technical criteria can limit a deeper understanding of the underlying pathophysiology, as it does not differentiate the causes of FHR variations or consider fetal adaptation to potentially hypoxic stress. This limitation may restrict clinicians’ insights into the physiological context of specific FHR patterns. These classification systems also do not address features of fetal inflammation, and therefore, may have some limitations when interpreting atypical patterns that do not fit neatly within these three categories.

The Saltatory pattern, for instance, has historically remained a controversial and poorly understood entity, with no established consensus on its pathophysiology and management. The saltatory pattern, as defined by FIGO guideline has been reported to occur rarely during labour. More recently, a new CTG feature during labor, the ZZZ, which has been defined as a rapid, erratic, oscillations in FHRV with an amplitude of >25 bpm has been reported to be a transient sign suggesting a higher risk of fetal hypoxemia and/or an ongoing fetal inflammation. Recently, an international expert consensus has provided the definition and the maximum duration of the ZZZ to be considered as abnormal [3]. Furthermore, the interpretation tools recommended by this international expert consensus panel classify the CTG traces based on the types of hypoxia and fetal inflammation and have included the ZZZ both in subacute hypoxia (rapidly evolving hypoxic stress) and in chorioamnionitis (neuroinflammation).

Although the pathophysiology of ZZZ has not been clearly described yet, it is likely to reflect a disordered or hyperactive autonomic response potentially triggered by rapidly evolving hypoxia or acidosis. When hypoxia progresses quickly, the fetus may not maintain baseline heart rate long enough to oxygenate critical organs, leading to erratic sympathovagal responses aimed at balancing oxygen delivery and cerebral perfusion. The sympathetic nervous system rapidly attempts to increase the FHR to obtain oxygenated blood while the parasympathetic nervous system tries to reduce the heart rate to protect the myocardial workload. This autonomic imbalance, likely caused by a sudden drop in oxygenation or acidosis, produces the pronounced FHR fluctuations seen as the ZZZ, signalling that the fetus’s regulatory system may be under strain.

This rapid increase and decrease in the FHR may be seen on the CTG as variability exceeding 25 bpm in a shape of an irregular ZZZ, defined by many authors as variability >25 bpm lasting at least 1 min. The appearance of this pattern during labor may represent an early sign of fetal hypoxia or acidosis, particularly when accompanied by other concerning signs, such as decreased long-term variability or late decelerations. A recent study has concluded that in the presence of features of fetal neuroinflammation on the CTG tracer which includes the ZZZ, the levels of IL-6 in the umbilical cord, which is a marker of ongoing fetal inflammation is increased approximately 4-fold [29]. Moreover, it has been shown that injection of boluses of LPS (bacterial toxins) in sheep was associated with increased fetal heart rate variability, which also coincided with episodes of fetal hypotension [37]. Therefore, ZZZ in chorioamnionitis may signify a late stage in fetal inflammatory response, requiring an urgent intervention.

We have reported a higher risk of operative delivery, abnormal Apgar score and umbilical artery pH in fetuses showing compared to those not showing ZZZ during labour, thus highlighting the potential role of such sign in identifying fetuses at higher risk of progressive hypoxemia and acidosis.

Identification of fetuses exposed to a rapidly evolving hypoxic stress during labour is crucial as potential interventions, stopping the oxytocic drugs, administration of tocolytics, and intra-venous fluids if appropriate, cessation of active maternal pushing and changing maternal position, may help restore fetal oxygenation. This may not only help avoid poor perinatal outcomes due to the progression of the rapidly evolving fetal hypoxemia leading to fetal metabolic acidosis, but also unnecessary intrapartum operative interventions by normalising the CTG trace. Therefore, our systematic review, first in our best knowledge which determined the association between the ZZZ and perinatal outcomes may have important clinical impact and help modify clinical practice.

Conclusions

Fetuses showing ZZZ during labour are at higher risk of operative vaginal delivery, caesarean section and adverse intrapartum and perinatal outcome. The results from this study support the use of the ZZZ as a sign for fetal compromise during labour. However, we acknowledge that further large studies showing objective shared protocols for intrapartum management of fetuses with ZZZ and including homogenous populations of women are needed to support the emerging consensus that ZZZ is an important marker for subsequent adverse perinatal outcomes.

Research ethics: Not applicable.

Informed consent: Not applicable, as this a systematic review of published studies.

Author contributions: Conceptualization: F. D'Antonio, L. Finadri. Data curation: F. D'Antonio, L. Finadri. Writing – original draft: F. D'Antonio, L. Finadri. Writing – review and editing: Asma Khalil, Ilenia Mappa, Giuseppe Rizzo, Alessandro Lucidi, Marco Liberati, Edwin Chandrachan. All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Use of Large Language Models, AI and Machine Learning Tools: None declared.

Conflict of interest: The authors state no conflict of interest.

Research funding: None declared.

Data availability: Data available on request.

References

- Steer PJ. Has electronic fetal heart rate monitoring made a difference. *Semin Fetal Neonatal Med* 2008;13:2–7.
- Chudáček V, Spilka J, Lhotská L, Janku P, Koucký M, Huptych M, et al. Assessment of features for automatic CTG analysis based on expert annotation. *Annu Int Conf IEEE Eng Med Biol Soc* 2011;2011:6051–4.
- Chandrachan E, Pereira S, Ghi T, Gracia Perez-Bonfils A, Fieni S, Jia YJ, et al. International expert consensus statement on physiological interpretation of cardiotocograph (CTG): first revision (2024). *Eur J Obstet Gynecol Reprod Biol* 2024;302:346–55.
- Ayres-de-Campos D, Spong CY, Chandrachan E. FIGO Intrapartum Fetal Monitoring Expert Consensus Panel. FIGO Intrapartum Fetal Monitoring Expert Consensus Panel. FIGO consensus guidelines on intrapartum fetal monitoring: cardiotocography. *Int J Gynaecol Obstet* 2015;131:13–24.
- Zanardo V, Straface G. Intrapartum cardiotocography. *Am J Obstet Gynecol* 2024;231:e114.
- Hernandez Engelhart C, Gundro Brurberg K, Aanstad KJ, Pay ASD, Kaasen A, Blix E, et al. Reliability and agreement in intrapartum fetal heart rate monitoring interpretation: a systematic review. *Acta Obstet Gynecol Scand* 2023;102:970–85.
- FIGO. Guidelines for the use of fetal monitoring. *Int J Gynecol Obstet* 1986;25:159–67.
- Schneider U, Bode F, Schmidt A, Nowack S, Rudolph A, Dölker EM, et al. Developmental milestones of the autonomic nervous system revealed via longitudinal monitoring of fetal heart rate variability. *PLoS One* 2018;13:e0200799.
- Assali NS, Brinkman CR 3rd., Woods JR Jr., Dandavino A, Nuwayhid B. Development of neurohumoral control of fetal, neonatal, and adult cardiovascular functions. *Am J Obstet Gynecol* 1977;129:748–59.
- Dalton KJ, Dawes GS, Patrick JE. The autonomic nervous system and fetal heart rate variability. *Am J Obstet Gynecol* 1983;146:456–62.
- Thellesen L, Bergholt T, Sorensen JL, Rosthoej S, Hvidman L, Eskenazi B, et al. The impact of a national cardiotocography education program on neonatal and maternal outcomes: a historical cohort study. *Acta Obstet Gynecol Scand* 2019;98:1258–67.
- Arnold JJ, Gawrys BL. Intrapartum fetal monitoring. *Am Fam Physician* 2020;102:158–67.
- Rei M, Tavares S, Pinto P, Machado AP, Monteiro S, Costa A, et al. Interobserver agreement in CTG interpretation using the 2015 FIGO guidelines for intrapartum fetal monitoring. *Eur J Obstet Gynecol Reprod Biol* 2016;205:27–31.
- ACOG Practice Bulletin No. 106. Intrapartum fetal heart rate monitoring: nomenclature, interpretation, and general management principles. *Obstet Gynecol* 2009;114:192–202.
- Chandrachan E, Pereira S, Ghi T, Gracia Perez-Bonfils A, Fieni S, Jia YJ, et al. International expert consensus statement on physiological interpretation of cardiotocograph (CTG): first revision (2024). *Eur J Obstet Gynecol Reprod Biol* 2024;302:346–55.
- Di Pasquo E, Fieni S, Chandrachan E, Dall'Asta A, Morganeli G, Spinelli M, et al. Correlation between intrapartum CTG findings and interleukin-6 levels in the umbilical cord arterial blood: a prospective cohort study. *Eur J Obstet Gynecol Reprod Biol* 2024;294:128–34.
- Magawa S, Lear CA, Beacom MJ, King VJ, Kasai M, Galinsky R, et al. Fetal heart rate variability is a biomarker of rapid but not progressive exacerbation of inflammation in preterm fetal sheep. *Sci Rep* 2022;12:1771.
- Nunes I, Ayres-de-Campos D, Kwee A, Rosén KGR. Prolonged saltatory fetal heart rate pattern leading to newborn metabolic acidosis. *Clin Exp Obstet Gynecol* 2014;41:507–11.
- Gracia-Perez-Bonfils A, Vigneswaran K, Cuadras D, Chandrachan E. Does the saltatory pattern on cardiotocograph (CTG) trace really exist? The ZigZag pattern as an alternative definition and its correlation with perinatal outcomes. *J Matern Fetal Neonatal Med* 2021;34:3537–45.
- Galli L, Dall'Asta A, Whelehan V, Archer A, Chandrachan E. Intrapartum cardiotocography patterns observed in suspected clinical and subclinical chorioamnionitis in term fetuses. *J Obstet Gynaecol Res* 2019;45:2343–50.
- Loussert L, Berveiller P, Magadoux A, Allouche M, Vayssiere C, Garabedian C, et al. Association between marked fetal heart rate variability and neonatal acidosis: a prospective cohort study. *BJOG* 2023;130:407–14.
- Nunes I, Ayres-de-Campos D, Kwee A, Rosén KG. Prolonged saltatory fetal heart rate pattern leading to newborn metabolic acidosis. *Clin Exp Obstet Gynecol* 2014;41:507–11.
- Polnaszek B, López JD, Clark R, Raghuraman N, Macones GA, Cahill AG. Marked variability in intrapartum electronic fetal heart rate patterns: association with neonatal morbidity and abnormal arterial cord gas. *J Perinatol* 2020;40:56–62.
- Tarvonen M, Sainio S, Hämäläinen E, Hiilesmaa V, Andersson S, Teramo K. Saltatory pattern of fetal heart rate during labor is a sign of fetal hypoxia. *Neonatology* 2020;117:111–17.
- Tarvonen M, Hovi P, Sainio S, Vuorela P, Andersson S, Teramo K. Factors associated with intrapartum ZigZag pattern of fetal heart rate: a retrospective one-year cohort study of 5150 singleton childbirths. *Eur J Obstet Gynecol Reprod Biol* 2021;258:118–25.
- Blix E, Maude R, Hals E, Kisa S, Karlén E, Nohr EA, et al. Intermittent auscultation fetal monitoring during labour: a systematic scoping review to identify methods, effects, and accuracy. *PLoS One* 2019;14:e0219573.
- Tarvonen MJ, Lear CA, Andersson S, Gunn AJ, Teramo KA. Increased variability of fetal heart rate during labour: a review of preclinical and clinical studies. *BJOG* 2022;129:2070–81.
- Sukumaran S, Pereira V, Mallur S, Chandrachan E. Cardiotocograph (CTG) changes and maternal and neonatal outcomes in chorioamnionitis and/or funisitis confirmed on histopathology. *Eur J Obstet Gynecol Reprod Biol* 2021;260:183–8.

29. Di Pasquo E, Fieni S, Chandraharan E, Dall'Asta A, Morganelli G, Spinelli M, et al. Correlation between intrapartum CTG findings and interleukin-6 levels in the umbilical cord arterial blood: a prospective cohort study. *Eur J Obstet Gynecol Reprod Biol* 2024;294:128–34.
 30. Gracia-Perez-Bonfils A, Martinez-Perez O, Llurba E, Chandraharan E. Fetal heart rate changes on the cardiotocograph trace secondary to maternal COVID-19 infection. *Eur J Obstet Gynecol Reprod Biol* 2020; 252:286–93.
 31. Henderson LK, Craig JC, Willis NS, Tovey D, Webster AC. How to write a Cochrane systematic review. *Nephrology (Carlton)* 2010;15:617–24.
 32. NHS Centre for Reviews and Dissemination. Systematic reviews: CRD's guidance for undertaking reviews in health care. York (UK): University of York; 2009. Available at: https://www.york.ac.uk/media/crd/Systematic_Reviews.pdf.
 33. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. *J Clin Epidemiol* 2021;134: 103–12.
 34. Newcastle-Ottawa Scale for assessing the quality of nonrandomised studies in meta- analyses. Available at: http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp.
 35. Manzoli L, De Vito C, Salanti G, D'Addario M, Villari P, Ioannidis JP. Meta-analysis of the immunogenicity and tolerability of pandemic influenza A 2009 (H1N1) vaccines. *PLoS One* 2011;6:e24384.
 36. Hunter JP, Saratzis A, Sutton AJ, Boucher RH, Sayers RD, Bown MJ. In meta-analyses of proportion studies, funnel plots were found to be an inaccurate method of assessing publication bias. *J Clin Epidemiol* 2014; 67:897–903.
 37. Lear CA, Davidson JO, Booth LC, Wassink G, Galinsky R, Drury PP, et al. Biphasic changes in fetal heart rate variability in preterm fetal sheep developing hypotension after acute on chronic lipopolysaccharide exposure. *Am J Physiol Regul Integr Comp Physiol* 2014;307:R387–95.
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- Supplementary Material:** This article contains supplementary material (<https://doi.org/10.1515/jpm-2025-0279>).