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Does the saltatory pattern on cardiotocograph (CTG) trace really exist? The ZigZag pattern as an alternative definition and its correlation with perinatal outcomes

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ABSTRACT

Background: The saltatory pattern (SP) has been defined by guidelines as a uniformly increased bandwidth of >25 beats per min lasting for 30 min. However, previous research suggest that it is very unusual to observe such a “uniform” increase in the bandwidth persisting for >30 min. Baseline fetal heart rate variability (FHRV) on cardiotocography reflects the integrity of the central nervous system. During labor, in the presence of a gradually-evolving hypoxia associated with the onset of metabolic acidosis, FHRV may be reduced. However, if a fetus is exposed to rapidly-evolving hypoxia, it may not have sufficient time to release catecholamines and the perfusion of central organs can be impaired. In such cases, simultaneous increased activity of the sympathetic nervous system to obtain more oxygen as well as enhanced parasympathetic activity to reduce the myocardial workload can lead to autonomic instability. This exaggerated autonomic response can be seen frequently on the cardiotocograph as a rapid, irregular, abrupt “up and down” fluctuation across the baseline (amplitude >25 beats per min). The authors have termed this pattern as “ZigZag” when apparent for a minimum of 1 min. It differs from the SP in terms of duration and uniformity of the bandwidth.

Objective: To determine the incidence of the SP during labor as well as a shorter and less uniform version of the SP newly called “ZigZag pattern” (ZZP). The intention was to correlate them with perinatal outcomes, taking into account the duration of the ZZP.

Study design: A retrospective analysis of 500 consecutive cardiotocograph traces was performed to identify saltatory patterns and ZigZag patterns of 1 and 2 min of duration. Apgar scores, umbilical cord pH values and admission to the Neonatal Unit were evaluated and correlated with the cardiotocograph findings.

Results: Not a single case of the SP was observed. A ZZP of 1 min of duration (ZZP1) was identified in 30.1% of the CTG during the last hour prior to delivery; ZZP lasting for 2 min (ZZP2) were identified in 8.9% of cases during the same period. Apgar scores at 1 min of ≤ 7 were significantly more frequent in newborns where the ZZP was observed (36.7% in ZZP1 and 54.5% in ZZP2 versus 9.5% in fetuses without); similarly, the Apgar scores at 5 min of ≤ 7 were also more frequent when ZZP was observed (6.7% in ZZP1 and 13.6% in ZZP2 versus 1.1% in controls). Moderate acidosis (pH 7.0–7.10) was more common in fetuses with the ZZP (14.3% in ZZP1 and 15% in ZZP2) compared to those without (4.6 and 7.2%, respectively). Similarly, mild acidosis (pH 7.1–7.2) was more common with the ZZP (40.3% in ZZP1 and 35% in ZZP2 versus 27.6 and 31.7%, respectively without ZZP). The neonatal admission rate was significantly higher in fetuses with the ZZP (8.7% in ZZP1 and 11.4% in ZZP2 versus 1.1% in controls).

Conclusions: In line with previous research, our study suggest that SP is an almost nonexistent phenomenon. Alternatively, the ZigZag pattern (ZZP) has been defined as an exaggerated, irregular, “up and down” fluctuation of the baseline variability with an amplitude of >25 beats per min, lasting for 1 min or longer. It represents autonomic instability during human labor and it differs from the SP in terms of uniformity and length. Newborns with a ZZP during active maternal pushing were found to have statistically-significant lower Apgar scores at the 1st and 5th min, moderate and mild acidosis in the umbilical artery and an 8.7–11.4-fold higher neonatal admission rate. Clinicians should stop oxytocin infusion and/or active maternal pushing to improve fetal oxygenation if the ZZP is observed.

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Introduction

On the cardiocotograph (CTG) trace, the fetal heart rate variability (FHRV) reflects in part the complex interaction between the sympathetic and the parasympathetic nervous systems, which are constantly interacting with each other. The sympathetic nervous system exerts a positive inotropic effect on the heart increasing the fetal heart rate (FHR), whereas the parasympathetic system attempts to reduce the FHR in order to maintain a positive energy balance in the heart. This “push-pull” interaction between the autonomic nervous system modified by other factors such as the cardiac volume receptor-reflex still remain poorly understood [1–5] and it creates a bandwidth that is observed on the CTG trace as the FHRV [5].

Traditionally, the FHRV greater than 25 beats per min (bpm) has been called the saltatory pattern (SP). Nevertheless, there is no international consensus regarding its definition, duration, interpretation and management. The International Federation of Obstetrics and Gynecology (FIGO) guidelines of 2015 define SP as a bandwidth value exceeding 25 beats per min lasting more than 30 min [6]. Other international Committees such as the Royal College of Obstetricians & Gynecologists (RCOG), the National Institute of Clinical Excellence (NICE) and the American College of Obstetricians & Gynecologists (ACOG) do not mention the minimum duration necessary to consider it as a significant feature.

According to the FIGO's definition, SP should be persistent for 30 min, and is considered as an extremely unusual phenomenon. A study conducted in 2014 by Nunes et al. [7] reviewed three research databases with 13,859 intrapartum internally monitored FHR records, searching for saltatory patterns towards the end of labor. Four cases lasting between 23 and 44 min could be found (only three of them lasted longer than 30 min). They all were associated with umbilical cord metabolic acidosis (defined as $\text{pH} < 7.05$). No cases of hypoxic-ischemic encephalopathy were found.

Cibils [8] conducted a prospective study in 1976 with a cohort of 1304 term fetuses and reported an incidence of SP of 7.8%, but he did not establish a minimum duration for the SP to be considered significant to warrant an intervention. A smaller study regarding saltatory pattern was published as a case report in 1991 with poor perinatal outcomes [9].

In 1992 O'Brien-Abel and Benedetti [10] conducted a retrospective observational study reviewing 433 intrapartum CTG searching for SP defined as variability >25 bpm with an oscillatory frequency of greater than 6 per min for a minimum duration of 1 min. They

concluded that the incidence of SP was 2.3%, and all the cases of SP were detected in active second stage of labor. Apgar scores were 8/9 or 9/9 but umbilical cord gases were not studied.

The pathophysiology of the SP pattern is poorly understood. It is presumed to be caused by fetal autonomic instability/hyperactive autonomic system in relation with hypoxia or acidosis that evolves very rapidly [6].

When a fetus is exposed to hypoxia, unlike adults, it cannot increase the rate and depth of respiration to increase the atmospheric oxygen supply to maintain the myocardium in a positive aerobic balance. Instead, the parasympathetic system rapidly reduces the FHR to decrease the myocardial workload to sustain a positive energy balance in the heart [11,12]. This reflex response is seen in the CTG as decelerations [13–15].

Therefore, if a fetus is exposed to a gradually evolving hypoxia it would start to show decelerations to protect its myocardial workload so as to maintain the myocardium in a positive aerobic energy balance. This would be followed by absence of accelerations (conservation of somatic body movements). If the hypoxia continues, a gradual increase in the baseline FHR will be seen secondary to the release of catecholamines by the sympathetic nervous system [12]. If this compensatory mechanism fails, there is the onset of anaerobic metabolism in the brain leading to metabolic acidosis. This is reflected in the CTG as reduced FHRV [16,17].

However, several experimental studies in sheep have shown that the earliest response to an acutely evolving hypoxia is in fact an increase in FHRV rather than a decrease in FHRV [1,5,18–20]. Moreover, if the hypoxic insult is maintained, the FHRV progressively shows suppression [21,22].

Therefore, it is logical to expect that if the hypoxia evolves rapidly (i.e., second stage of labor with active maternal pushing, oxytocin infusion with repetitive and sustained compression of the umbilical cord or reduction *in utero*-placental oxygenation), a fetus may not have sufficient time spent at the baseline to successively increase the baseline heart rate to oxygenate vital organs [23]. The sympathetic nervous system rapidly attempts to increase the FHR to obtain oxygenated blood whilst the parasympathetic nervous system attempts to reduce the heart rate to protect the myocardial workload. In this situation, owing to an abrupt reduction in oxygenation *via* the carotid arteries, autonomic instability may occur.

This rapid increase and decrease in the FHR may be seen on the CTG as variability >25 bpm in a shape of

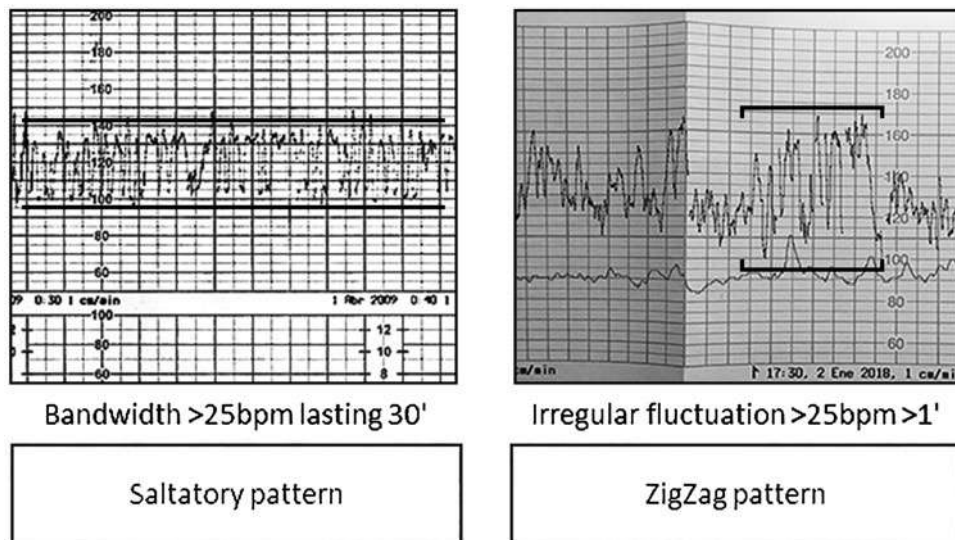


Figure 1. The Saltatory pattern and the Zigzag pattern.

an irregular zigzag, but it will not last necessarily for 30 min. This pattern has been called by the authors as the “ZigZag pattern” and is defined by variability >25 bpm during 1 min or longer. It differs from the SP that has been defined as a uniformly increased bandwidth of >25 beats per min lasting for 30 min (see Figure 1).

The aim of our study was to retrospectively analyze 500 intrapartum CTG traces looking for SP as well as to determine the incidence of a shorter and less uniform version of it, newly called the “ZigZag pattern” (ZZP). Moreover, we wanted to correlate the presence of these CTG characteristics and their duration with perinatal outcomes in order to study the potential effect of the autonomic instability on the neonates.

Materials and methods

This was a retrospective study of 500 consecutive CTG traces of fetuses (please see inclusion criteria) delivered at St. George’s Hospital (London) during a 12-month period.

The inclusion criteria were: Singleton term pregnancies between 37 and 42 weeks of gestation with a continuously recorded trace for at least 30 min of an interpretable quality. 16 CTG traces were discarded due to the poor quality of the recording.

The exclusion criteria were:

- Length of the recorded trace shorter than 30 min, poor quality of recording, rendering it uninterpretable
- Multiple gestation
- Preterm delivery
- Preeclampsia

- Fetal growth restriction: EFW and confirmed birth-weight <3 rd percentile
- Fetal anomalies including chromosomal abnormalities or structural malformations detected by ultrasound
- Chorioamnionitis confirmed by the histopathological result
- Chronic maternal conditions such as lupus erythematosus, cholestasis, diabetes mellitus or HIV infection

No identifiable patient data were used and approval for our study was obtained from the St. George’s Joint Research Enterprise Office of St. George’s University, London.

Analysis of the whole CTG trace and specifically during the second stage of labor was performed, looking for ZZP (variability >25 bpm), taking into consideration the duration of the pattern. The CTG traces were independently verified by two assessors blinded to the outcome, who had undergone extensive training in CTG interpretation. Perinatal outcomes were analyzed to establish whether a correlation existed between the presence of the ZZP (lasting for 1 or 2 min), and lower Apgar scores, umbilical cord pH values as well as admission to the neonatal unit.

According to the local unit policy, which was in line with the standard of obstetric practice in the United Kingdom, Apgar scores were calculated in all cases and umbilical cord pH values were performed in cases with pathological CTGs, operative vaginal births and poor neonatal condition at birth. Umbilical cord pH values were available in 81 cases out of 150 with ZZP during the last hour prior to birth (81 venous samples,

Table 1. Apgar score results at the first and fifth minute in relation to presence of ZigZag pattern lasting for 1 or 2 min, during the last hour of CTG.

APGAR	ZZP lasting for 1 min			ZZP lasting for 2 min		
	No	Yes	Total	No	Yes	Total
Apgar 1 min						
7–	33 (9.5%)	55 (36.7%)	88 (17.7%)	64 (14.1%)	24 (54.5%)	88 (17.7%)
8+	315 (90.5%)	95 (63.3%)	410 (82.3%)	389 (85.9%)	20 (45.5%)	409 (82.3%)
Total	348 (100.0%)	150 (100.0%)	498 (100.0%)	453 (100.0%)	44 (100.0%)	497 (100.0%)
Apgar 5 min						
7–	4 (1.1%)	10 (6.7%)	14 (2.8%)	8 (1.8%)	6 (13.6%)	14 (2.8%)
8+	344 (98.9%)	140 (93.3%)	484 (97.2%)	445 (98.2%)	38 (86.4%)	483 (97.2%)
Total	348 (100.0%)	150 (100.0%)	498 (100.0%)	453 (100.0%)	44 (100.0%)	497 (100.0%)

77 of which also included arterial samples). Out of the 350 cases without ZPP detected on the CTG, 170 specimens of umbilical blood samples were collected (170 from vein only, and 152 cases from both the umbilical vein and the umbilical artery).

Chi-square test with odds ratio (OR) and its 95% confidence interval was used to compare a binary outcome between groups, while Student's *t*-test or Mann–Whitney *U* test (nonparametric) were used to compare a numerical variable between them. Spearman's correlation was used to check the relationship between two numerical variables. Statistical analysis was performed with SPSS 19.0 (IBM Corp, Armonk, NY) and $p < .05$ was considered statistically significant.

Results

Not a single case of the SP was detected in the 500 consecutive CTG traces analyzed. In contrast, ZPP of 1 min of duration was observed within the entire CTG trace in 168 cases (33.6% of the CTG), the vast majority of which (89%) occurred during the last hour prior to delivery. Our study analyzed only the cases in the last hour of CTG, observed in 30% of traces, which generally occurred in the second stage of labor during active maternal pushing. During this time ZPP of 2 min of duration was detected in 8.9% of cases.

Apgar score results are reported in Table 1. As it can be seen, 36.7% of the newborns who demonstrated ZPP lasting for 1 min during last hour prior to birth (ZPP1) were found to have an Apgar score at 1 min of ≤ 7 , whereas only 9.9% of newborns who had not shown the ZPP had an Apgar score of ≤ 7 . When the ZPP lasted for 2 min (ZPP2) the percentage of Apgar score at first minute of ≤ 7 increased to 54.5%. Both differences were statistically significant ($p < .001$ chi-square test), OR = 5.53, 95%CI (3.39, 9.01); and ($p < .001$ chi-square test), OR = 5.549, 95%CI (3.381, 9.105), respectively.

At 5 min of life, 6.7% of newborns with ZPP1 had an Apgar score of ≤ 7 compared to 1.1% without it.

Table 2. pH cord gas results in relation to the presence of ZigZag pattern lasting for 1 or 2 min, during the last hour of CTG.

pH result	ZZP lasting for 1 min		ZZP lasting for 2 min	
	No	Yes	No	Yes
pH artery				
≤ 7	2 (1.3%)	1 (1.3%)	3 (1.4%)	0 (0%)
7–7.1	7 (4.6%)	11 (14.3%)	15 (7.2%)	3 (15%)
7.1–7.2	42 (27.6%)	31 (40.3%)	66 (31.7%)	7 (35%)
> 7.2	101 (66.4%)	34 (44.2%)	124 (59.6%)	10 (50%)
pH vein				
≤ 7	1 (0.6%)	0 (0%)	1 (0.4%)	0 (0%)
7–7.1	2 (1.2%)	1 (1.2%)	3 (1.3%)	0 (0%)
7.1–7.2	9 (5.3%)	12 (14.8%)	19 (8.4%)	2 (8.7%)
> 7.2	158 (92.9%)	68 (84.0%)	204 (89.9%)	21 (91.3%)

When ZPP2 was observed the percentage increased to 13.6%. Both differences were statistically significant ($p = .00$ chi-square test) OR 6.143, 95% CI (1.89, 19.9); and ($p = .007$ Fisher test) OR 5.110, 95% CI (1.578, 16.546), respectively.

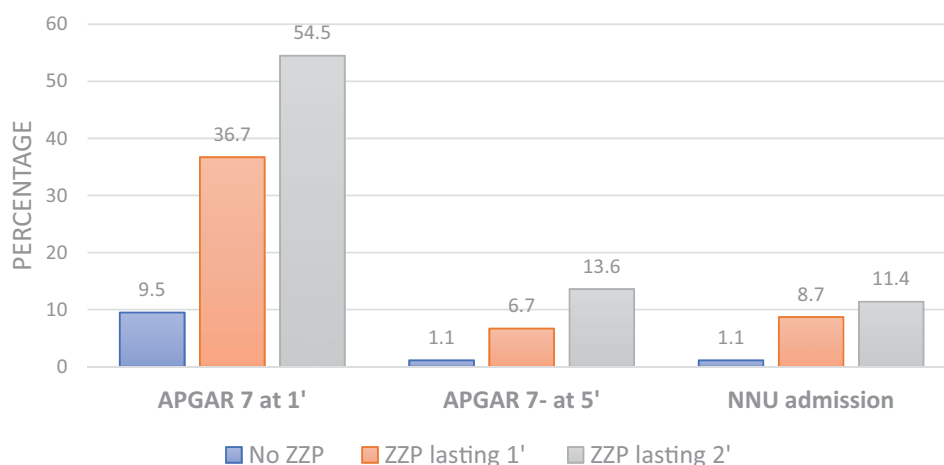
The umbilical cord pH results are shown in Table 2. As illustrated, pH arterial cord cases between 7.0 and 7.1 as well as between 7.1 and 7.2 were more frequently detected in the newborns that showed the ZPP that lasted either for 1 or 2 min. This was statistically significant ($p = .001$ gamma ordinal test). Mean \pm SD umbilical arterial pH in newborns with the ZPP was 7.19 ± 0.08 compared to 7.23 ± 0.08 in those without ZPP. This difference was also statistically significant ($p < .001$ Student's *t*-test).

Umbilical venous pH results can also be seen in Table 2. No statistically-significant differences were found between groups ($p = .052$ gamma ordinal test when lasted for 1 min and $p = .057$ when longer). Nevertheless, mean \pm SD umbilical venous pH in newborns with the ZPP was 7.28 ± 0.07 compared to 7.31 ± 0.07 in controls; this difference was statistically significant ($p = .007$ Student's *t*-test).

Overall, the neonatal admission rate (for all causes including hypoxia, infections, presence of meconium and any other cause that requires close observation of the neonate) was 3.4%. However, 8.7% of fetuses with

Table 3. Admission to Neonatal Unit in relation to presence of ZigZag pattern of 1 or 2 min of duration, in last hour of CTG.

APGAR	ZZP lasting for 1 min			ZZP lasting for 2 min		
	No	Yes	Total	No	Yes	Total
NNU admission						
No	344 (98.9%)	137 (91.3%)	481 (96.6%)	441 (97.4%)	39 (88.6%)	480 (96.6%)
Yes	4 (1.1%)	13 (8.7%)	17 (3.4%)	12 (2.6%)	5 (11.4%)	17 (3.4%)
Total	348 (100.0%)	150 (100.0%)	498 (100.0%)	453 (100.0%)	44 (100.0%)	497 (100.0%)

**Figure 2.** Percentage of APGAR ≤ 7 at first and fifth minutes and admission to NNU, according to presence and duration of ZZP.

ZZP1 were admitted to the neonatal unit, compared to 1.1% without a ZZP during the last hour prior to birth. This percentage increased to 11.4% when ZZP2 was detected. This difference was statistically significant ($p < .001$ chi-square test), OR = 8.161, 95% CI (2.61, 25.4) (Table 3).

Figure 2 illustrates the percentage of Apgar score results of ≤ 7 and NNU admission according to presence of ZZP.

Discussion

The SP has been defined as an increased “bandwidth” of the baseline (>25 bpm) lasting more than 30 min, and has been considered a pathologic feature by International guidelines on CTG interpretation [24]. Our review of 500 CTG yielded not a single case of SP. In line with previous studies on the subject, our study suggests that SP is a very rare phenomenon in human labor. Therefore, it would appear that fetuses rarely demonstrate such a uniformly increased “bandwidth” consistently for 30 min, as stipulated by guidelines on CTG interpretation.

In contrast, we found that 30.1% of fetuses showed the ZZP (an irregular, “up and down” fluctuation across the baseline with an amplitude >25 bpm lasting at least 1 min) during the active second stage of labor. This incidence is higher than the incidence

detected by O’Brien-Abel and Benedetti [10] (2.3%). It is very likely that the previous authors had used the “bandwidth” rather than the abrupt up and down oscillation across the baseline whilst defining the ZZP.

Patterns earlier in time were excluded from the final analysis due to their insignificant incidence and the lack of reliable indicator of hypoxia (pH cord gases).

Several animal studies demonstrated that rapidly-evolving hypoxia secondary to compression of the umbilical cord leads to autonomic instability and the occurrence of increased baseline FHR variability [5,20,21,25]. In a study published in 1980, Parer et al. [20] determined the FHR, oxygen consumption and FHR variability in 20 chronically instrumented, normoxic sheep. They found that during 26 min of isocapnic hypoxia, there was an increase in variability that was visually evident and statistically significant. It is suggested that the increased variability may be due to increased alfa-adrenergic activity [20].

In 1999 Westgate et al. [21] designed a study monitoring 14 chronically instrumented fetal sheep divided into two groups that were exposed to a repeated umbilical cord occlusions every 5 min or every 2.5 min, respectively. In the latter group, FHR variation increased with the onset of occlusions and then progressively fell with continued occlusions. From the

third occlusion there was progressive hypotension and severe progressive metabolic acidaemia.

In 2004, George [5] et al. studied the effect of the exposure to hypoxia and asphyxia in 27 near-term and preterm sheep fetus. They also found that immediately after the hypoxic insult there was a transient but pronounced increase in the FHRV. In the fetus exposed to complete occlusion of the cord, after 20 min showed epileptiform body movements. Histological assessment after 72 h demonstrated severe brain stem injury in the sheep exposed to 30 min of asphyxia.

Moreover, increased FHR variability has been related to the risk of developing periventricular leukomalacia (PVL), which is associated with cerebral palsy [26,27]. Kurahashi et al. [27] conducted a study comparing the FHRV in 124 CTG and the subsequent development of periventricular leukomalacia (PVL). They found that the total fluctuation of the FHRV was significantly higher in those fetuses that showed PVL after birth [7]. Furthermore, a recent study has reported that increased variability during the second stage of labor was associated with neonatal metabolic acidosis at term [28].

On another note, CTG changes during instrumental deliveries were recently studied by Xie et al. [29]. Increased variability of greater than 25 bpm was found in 34% of forceps and 15% of vacuum deliveries. It is suggested that the fetal head's compression exerted by the instruments and consequent augmented intracranial pressure might also be a cause of sympathetic and parasympathetic nervous systems' instability.

Our study suggests that the ZPP is likely due to autonomic instability secondary to rapidly-evolving hypoxia arising from active maternal pushing and occurs in approximately 30% of fetuses at this stage. Thus, it is essential to recognize such rapidly-fluctuating baseline fetal heart rate (FHR) variability (i.e., ZPP) even without an increase in the "bandwidth" according to the current definition. This ZPP is associated with a progressive drop in umbilical artery pH and a higher incidence of lower Apgar scores (<7).

The normal values observed in the umbilical vein suggest that the ZPP reflects a rapidly-evolving hypoxic process with lower pH values in the umbilical artery as opposed to the umbilical vein.

The control group (i.e., without the ZPP during the last hour of active maternal pushing) had a lower incidence of umbilical arterial cord pH <7.20 and better Apgar scores (>7) compared to cases with the ZPP. These results were more evident when the ZPP lasted for 2 min compared to one. The neonatal unit

admission rate was also over eight-fold higher in the ZPP group of 1 min of duration (8.7 versus 1.1%) and 11-fold higher when lasted for 2 min (11.4%). More studies need to be done to determine the potential impact of a longer ZPP on perinatal outcomes.

None of the fetuses developed metabolic acidosis according to the current definition (umbilical arterial pH < 7.0), in line with previous findings [7]. This can be explained by the duration of the hypoxic insult being short-lasting and, consequently, there was insufficient time for the pH to drop significantly. Nevertheless, a trend was observed towards a reduction in pH in the ZPP of 1 min as well as 2 min of duration (with 14.3% having umbilical arterial pH between 7.0 and 7.10 in newborns that had ZPP lasting for 1-min compared with 4.6% without; and 15% compared to 7.2% at the same group when lasted for 2 min). Continuation of active maternal pushing leading to prolongation of the ZPP may lead to a further reduction in pH.

Our study suggests that approximately three in ten fetuses would show a ZPP with the onset of active maternal pushing, which may be secondary to autonomic instability resulting from rapidly-evolving hypoxia. If the ZPP is observed during the last hour of active maternal pushing, the likelihood of lower umbilical cord gases (pH 7.05–7.10), lower Apgar scores (≤ 7) at 1 and 5 min and a 8–11-fold higher neonatal unit admission rate is greater compared to the group without the ZPP.

Based on our findings, we recommend consideration of the ZPP during the active second stage of labor, even if the strict criteria for the SP are not met, since not all fetuses would demonstrate a uniformly "increased bandwidth" that lasts for 30 min. Any fluctuation in the baseline variability >25 bpm, which lasts for more than 60 s (i.e., ZPP), should be taken seriously as it is associated with lower Apgar scores, lower umbilical arterial pH and a greater likelihood of Neonatal Unit admission.

Zigzag pattern occurs due to an acutely evolving hypoxia, usually in the second stage of labor during active maternal pushing. Therefore, active maternal pushing should be immediately stopped to normalize fetal oxygenation and to avoid autonomic instability, unless a spontaneous vaginal birth is imminent (i.e., the fetal vertex is visible).

If a spontaneous vaginal birth is not imminent and if oxytocin infusion is being used to augment labor, then, this should be immediately stopped to relieve ongoing repetitive and sustained umbilical cord compression, and to improve utero-placental oxygenation.

If these conservative measures resolve the observed ZigZag pattern leading to the fetus spending more time on the stable baseline with reassuring variability, then, active pushing could be recommenced without the concomitant use of oxytocin infusion.

If there is no resolution of the ZigZag pattern within 5 min of the interventions to improve fetal oxygenation, then an immediate operative vaginal delivery should be performed to avoid the risks of continuing acutely evolving hypoxia. An emergency cesarean section during second stage of labor has significantly increased risks to the woman and her fetus, if the vertex is at or below the ischial spines and therefore, an operative vaginal birth should always be the preferred option, if the ZigZag pattern persists despite attempts to improve fetal oxygenation.

The main strength of our study is that, to the best of our knowledge, it is the first to analyze the incidence of the SP and the ZZP and its relationship with perinatal outcomes with cord gases results. Considering that the second stage of labor is the most perilous time for a fetus to suffer hypoxic-ischemic brain injury, we believe that understanding of additional features on the CTG trace such as the ZZP and measures to rapidly correct evolving hypoxic stress to prevent fetal neurologic injury, may help to avoid poor perinatal outcomes. The CTG traces were reviewed by two assessors to avoid intraobserver variability in CTG interpretation, and the ZZP was clearly defined to avoid confusion with the existing definition of the SP which is rarely seen in human labor.

The limitations of our study include its retrospective nature. However, at St. George's Maternity Unit, every CTG is recorded and maintained in an electronic database along with its perinatal outcomes. Five hundred consecutive CTG traces were analyzed from this prospectively-maintained electronic database.

The second drawback of our study was that, like other maternity units in the UK, umbilical cord gases were not universally performed, except in cases with pathological CTGs, operative vaginal deliveries and cases of unexpected poor perinatal outcomes. Cord pH values were available in 81 cases where the ZZP was observed and 170 without it. This is because current obstetric practice in the UK does not involve measuring umbilical cord pH in all fetuses. Whilst it may be argued that this might have caused a selection bias, we consider that the fact the pH analysis was performed according to perinatal outcomes or instrumental delivery instead of the presence or not of the ZZP (which was reviewed 4 years later) might have minimized the impact.

However, Apgar scores were available for all cases and our study showed a significant difference in lower Apgar scores in fetuses with the ZZP compared to the control group. This is similar to our observation regarding umbilical arterial cord pH values.

Despite the ZZP lasting for more than 2 min, none of the fetuses had evidence of metabolic acidosis as per the current internationally agreed definition (umbilical cord arterial pH 7.0) [24]. Nevertheless, 54.5% of cases and 14.1% of controls had an Apgar score of 7 or lower at the 1st min.

We recommend that clinicians actively scrutinize the CTG trace for the onset and continuation of the ZZP during labor, especially during the second stage, when hypoxic stress may evolve rapidly. Repetitive maternal active pushing may not provide sufficient time for a fetus to release catecholamines to raise the baseline FHR to obtain more oxygenated blood from the placenta and perfuse the central organs. By contrast, during the first stage of labor (when hypoxic stress gradually evolves), a fetus has sufficient time to mobilize its resources, increase its heart rate and redistribute blood to its vital organs *via* a catecholamine-induced stress response.

Conclusion

Rapidly-evolving hypoxia during active maternal pushing in the second stage of labor may cause instability of the autonomic nervous system. This may result in a ZigZag pattern (ZZP) on the CTG trace. Fetuses with an ongoing ZZP during the last hour prior to birth appeared to have lower Apgar scores at 1 and 5 min, a trend towards lower umbilical arterial pH (<7.2) and an increased likelihood of neonatal unit admission (8.7 if ZZP1 was detected and 11.4-fold in case of ZZP2) compared to controls without the ZZP. These findings may have a significant clinical application since onset of the ZZP during active maternal pushing may need urgent interventions to improve oxygenation to the fetal central nervous system. These include stopping oxytocin infusion and halting active maternal pushing. Considering the fact that 10% of fetuses with the ZZP of 1 min of duration showed a trend towards lower umbilical arterial pH compared to the control group there might be a greater likelihood of umbilical cord pH falling below 7.0 if maternal active pushing is continued in the presence of the ZZP. Therefore, the ZZP should be actively sought and recognized on the CTG trace during the active second stage of labor so that immediate steps can be taken to improve oxygenation to the fetal autonomic nervous system (i.e., the brain).

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Disclosure statement

No potential conflict of interest was reported by the authors.

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