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ORIGINAL ARTICLE

Impact of nuchal cord on antenatal and intrapartum foetal heart rate surveillance and perinatal outcome

Salvatore Tagliaferri[a], Francesca Giovanna Esposito[a], Giuseppina Esposito[a], Gabriele Saccone[a], Maria Gabriella Signorini[b], Giovanni Magenes[c], Marta Campanile[a], Maurizio Guida[d] and Fulvio Zullo[a]

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ABSTRACT

Analysing antepartum and intrapartum computerised cardiotocographic (cCTG) parameters in physiological term pregnancies with nuchal (NC) or body cord (BC), in order to correlate them with labour events and neonatal outcome. We enrolled 808 pregnant women, composed of 264 with 'one NC', 121 with 'multiple NCs', 39 with BC and 384 with 'no NC', were monitored from the 37th week of gestation before labour, while 49 pregnant women with 'one or more NCs' and 47 with 'no NCs' were analysed during labour. No differences in maternal characteristics, foetal pH at birth and 5-min Apgar score were observed. The birth weight was significantly lower in the 'multiple NCs' group, while 1-minute Apgar score was lower in the BC group than the other groups, respectively. No relevant differences in cCTG parameters were observed, except for LTI, Delta and number of variable decelerations in antepartum period and only variable deceleration in intrapartum period.

IMPACT STATEMENT

- **What is already known on this subject?** Ultrasound cannot predict which foetuses with NCs are likely to have problem during labour. The question arose if single or multiple NC could affects FHR monitoring prior and during labour.
- **What do the results of this study add?** Computerised cardiotocography (cCTG) is a standardised method developed to reduce inter- and intra-observer variability and the poor reproducibility of visual analysis. Few studies have investigated the influence of NCs on FHR variability and, to our knowledge, no one has evaluated its linear and nonlinear characteristics in antepartum and intrapartum period using a computerised analysis system. No differences in maternal characteristics, foetal pH at birth and 5-min Apgar score were observed. Birth weight was significantly lower in the 'multiple NCs' group, while 1-min Apgar score was lower in the BC group than the other groups, respectively. Foetuses with 'one or more NCs' evidenced a larger number of prolonged second stage and meconium-stained liquor cases, while the operative vaginal delivery and emergency caesarean section rates were unchanged. No relevant differences in cCTG parameters were observed, except for LTI, Delta and number of variable decelerations in antepartum period and only variable deceleration in intrapartum period.
- **What are the implications of these findings for clinical practice and/or further research?** cCTG monitoring results confirmed their usefulness for assessing the state of good oxygenation for all foetuses investigated.

KEYWORDS

Foetal monitoring; labour; obstetric; nuchal cord; pregnancy outcome; signal interpretation; computer-assisted

1. Introduction

Nuchal cord (NC) is defined as the umbilical cord wrapped 360 degrees around the foetal neck at least once. It has an incidence ranging from 23 to 33% of all deliveries (Cunningham et al. 2010), but its clinical relevance is not entirely clear.

Antenatal detection of NC through ultrasound is low before labour with an accuracy of 37% at finding single loop and 60% at detecting multiple loops. Moreover, ultrasound cannot predict which foetuses are likely to have problem during labour (Peregrine et al. 2005). Therefore, the question arose if single or multiple NC could affects foetal heart rate (FHR) monitoring prior and during labour, and if so, how that depends on the number of NCs.

Cardiotocographic (CTG) monitoring is the diagnostic tool most commonly used to assess antepartum and intrapartum foetal well-being, even if its effect in decreasing foetal mortality and morbidity has not been established (Practice Bulletin 106, ACOG 2009). Computerised cardiotocography (cCTG) is a standardised method developed to reduce inter- and intra-observer variability and the poor reproducibility of visual analysis. In fact, it performs an automatic trace analysis

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to evaluate quantitative measures of linear and nonlinear indices of FHR variability, implementing diagnostic criteria accepted in clinical obstetric practice (Signorini et al. 2003). cCTG is a relatively new but promising technology when it is applied in intrapartum, even if it has been reported to have several limitations because of frequent occurrence of signal loss and artefacts, and greater signal instability resulting in more complicated baseline estimation (Lutomski et al. 2015).

Foetus suffers a physiologic stress during labour due to uterine contractions, head and cord compression. The impaired umbilical cord flow results into hypoxic environment for repeated circulation insufficiency and variable decelerations in FHR monitoring (Larson et al. 1995; Peregrine et al. 2005).

Interpretations of the significance of single or multiple NCs vary widely in the current literature. Some studies point out that NCs may be associated with lower birth weight (Schaffer et al. 2005), some degree of foetal distress (Hashimoto and Clapp 2003; Bernad et al. 2012) and short term morbidity (Reed et al. 2009). Indeed, many other studies (Mastrobattista et al. 2005; Peregrine et al. 2005; Sheiner et al. 2006) consider NC as a common finding at birth without any association with adverse perinatal outcomes.

Few studies have investigated the influence of NCs on FHR variability and, to our knowledge, no one has evaluated its linear and nonlinear characteristics in antepartum and intrapartum period using a computerised analysis system.

Our aim was to evaluate differences in antepartum and intrapartum cCTG parameters in foetuses with and without NCs, in order to detect early signs of foetal compromise and to enhance the prediction of neonatal outcome.

2. Methods

This retrospective study was carried out at the Department of Obstetrical-Gynecological and Urological Science and Reproductive Medicine of the Federico II University (Italy) in a period of 4 years.

The principles of the Helsinki Declaration were followed, and all participants gave their written informed consent.

Cases were enrolled if they were confirmed to have a Body Cord (BC), 'one NC' or 'multiple NCs' at the time of delivery and if they fulfilled the following inclusion criteria: singleton Caucasian low-risk pregnancy; foetus in the cephalic presentation; an amniotic fluid volume greater than 2 cm and less than 8 cm in the deepest vertical pocket; cCTGs with a signal loss of less than 15% over the whole record; gestational age at the cCTG recording greater than 37th and less than 41st week; certain pregnancy dating (calculated from the first day of the last menstrual period and confirmed by ultrasound measurements, according to the population nomograms) (Butt and Lim 2014); absence of pre-existing maternal diseases and pregnancy-related diseases, drug abuse and cigarette smoking; a body mass index (BMI) greater than 20 and less than 30 at the beginning of pregnancy; time between the last meal and the FHR recording <4 h (Zimmer et al. 2000; Zeskind and Gingras 2006; Costa et al. 2009). The body cord group included cases with the umbilical cord wrapped around the trunk, excluding the neck. Cases with umbilical cord entanglement around multiple parts, such as entanglement around both the neck and trunk or around both the neck and upper/lower limbs, were excluded.

Newborn baby data (sex, weight, Apgar score, malformation at birth, access to neonatal intensive care, and umbilical artery pH at birth) were also collected. We excluded foetuses with chromosomal and major congenital anomalies, abnormal umbilical artery Doppler, birth weight less than the 10th and greater than the 90th percentile according to the population nomograms, and inadequate umbilical cord samples at birth (Kessous et al. 2014; Wang et al. 2016).

The antepartum cCTG traces were recorded with the same frequency in all cases. For each patient we considered the last cCTG trace performed 24 h before the onset of delivery.

The control group was randomly sampled from patients without cord entanglements with the same inclusion and exclusion criteria of the case group.

Starting from a population of 9534 pregnant women was selected a sample of 808 pregnant women composed of 264 cases with 'one NC', 121 cases with 'multiple NCs', 39 cases with BC and 384 controls with 'no NC'.

Moreover, for each patient we evaluated labour and perinatal outcome after excluding: elective caesarean section in pre-labour and intrapartum cCTGs with a signal loss greater than 15% over the whole recording. Therefore, the cCTGs of 49 pregnant women with 'one or more NCs' (excluded 121 with elective caesarean section in pre-labour and 254 with intrapartum cCTGs with a signal loss greater than 15% over the whole recording) and 47 pregnant women with 'no NC' (excluded 102 with elective caesarean section in pre-labour and 235 with intrapartum cCTGs with a signal loss greater than 15% over the whole recording) were analysed during labour, no pregnant woman with BC fulfilled the selection criteria. The incidence of prolonged second stage, meconium-stained liquor, operative vaginal delivery, and emergency caesarean section were also recorded. Second stage was considered as prolonged if >1 h in multipara women or >2 h in primipara women.

2.1. Signal acquisition

The antepartum and intrapartum cCTGs were performed in a controlled clinical environment with the patient lying in a semi-Fowler's position in a relaxed condition. The cCTG records were obtained using Corometrics 170 (General Electrics), equipped with an ultrasound transducer and a transabdominal tocodynamometer connected to 2CTG2 system (SEA, Italy) (Arduini et al. 1993), that acts as processing unit. The FHR records were performed according to ACOG guidelines (Practice Bulletin 106, ACOG 2009) and the FHR analysis was carried out using segments of 10 minutes without missing data, in order to prevent influences of incorrect heart rates and to assume the same length of analysis segment for all parameters investigated, irrespective of the traces length. Initial and final 10 min of each trace were averaged, in order to obtain a single analysis segment for each trace.

The ultrasound probe registers the echoes generated by movements of foetal heart valves opening and closing. These inputs are the basis of the reconstruction of FHR signal, which is obtained by applying an autocorrelation technique, in order to demodulate peaks corresponding to FHRs. The final results are a sequence of peaks identifying the occurrence of a beat in the foetal heart. Measurement of the beat to beat distance provides RR signal. Each Doppler signal is sampled at 200 Hz (5 ms). The time window over which the autocorrelation function is computed is 1.2 s, corresponding to a FHR lower bound of 50 bpm.

The cardiotocograph produces one FHR value in bpm every 250 ms. In the commercially available system, the 2CTG2 software reads 10 consecutive values from the monitor every 2.5 s and determines the actual FHR as the average of the 10 values (corresponding to an equivalent sampling frequency of 0.4 Hz). Our CTG equipment uses a modified software in order to read the FHR at 2 Hz (every 0.5 s). The choice of reading the FHR values each 0.5 sec represents a reasonable compromise to have a bandwidth large enough (Nyquist Frequency 1 Hz) and an acceptable accuracy of the FHR signal. A quality index classifies three different levels of the FHR signal (optimal, acceptable, and insufficient quality). After this step, each FHR series underwent a subdivision into 3-min segments (360 data points) and the programme computes the parameters on the entire signal. During the acquisition, parameters are updated every one or three minutes according to their computing time. After the preprocessing stage, the 2CTG2 software provides a set of linear and non-linear parameters to quantify complexity characteristics of FHR series.

Linear FHR parameters investigated were time domain parameters (FHR baseline, baseline; Accelerations, Acc; Decelerations, Dec; Short-Term Variability, STV; Long-Term Irregularity, LTI; Delta; Interval Index, II) and frequency domain parameters (Low Frequency, LF; Movement Frequency, MF; High Frequency, HF; LF/(HF + MF) ratio, LF/(HF + MF)). Non-linear FHR parameter investigated was Approximate Entropy (ApEn) (Fanelli et al. 2013; Signorini et al. 2014).

2.2. Time domain parameters

2.2.1. Baseline, accelerations, decelerations

A real-time version of Mantel's algorithm (Mantel et al. 1990) was used for the determination of baseline, which is a running average of the heart rate where accelerations are positive deviations and decelerations are negative deviations of the FHR from the baseline lasting 15 bpm for 15 s for them both.

2.2.2. STV

STV quantifies FHR variability over a very short-time scale on a beat-to-beat basis (Arduini et al. 1993). Considering one minute of interbeat sequence, T24 (i) in ms, $i_{\in}$[1; 24], we defined STV as

$$STV = mean\left[|T_{24}(i+1) - T_{24}(i)|\right]_i = \frac{\sum_{i=1}^{23} |T_{24}(i+1) - T_{24}(i)|}{23} \quad (1)$$

where T_{24} (i) is the value of the signal T (i) taken each 2.5 s.

2.2.3. LTI

LTI is computed on a three-minute segment of interbeat sequence in milliseconds. Given a signal $T_{24}(i)$ with $i_{\in}$[1; 72], LTI is defined as the interquartile range (1/4; 3/4) of the distribution of the modula m_{24} (j) with $i_{\in}$[1; 71]

$$m_{24}(j) = \left(T_{24}{}^2(j+1) + T_{24}{}^2(j)\right)^{1/2} \quad (2)$$

The definition is the same provided by De Haan (ACOG 1989), with the exception of a window of 72 (and not 512) samples long. As proposed by Arduini et al. (1993), we exclude from the calculation big accelerations and decelerations.

2.2.4. Delta

Given a minute of signal in millisecond $T_{24}(i)$ with $i_{\in}$[1; 24], Delta is defined as the difference between the maximum and minimum FHR value

$$Delta = \max T_{24}(i) - \min T_{24}(i) \quad (3)$$

Even in this case (Arduini et al. 1993), we exclude from the calculation big accelerations and decelerations.

2.2.5. Interval index (II)

II is calculated as the coefficient of variation between the differences of all FHR values in one minute of interbeat sequence, taken each 2.5 s. It was proposed by Yeh et al. (1973) as a long-term variability statistic. We adopted the formulation used by Arduini et al. (1993) with $i_{\in}$[1; 23]

$$II = \frac{std|T_{24}(i+1) - T_{24}(i)|}{STV} \quad (4)$$

2.3. Frequency domain parameters

The power spectrum of FHR variability can be quantified both during activity period and foetal sleep by the use of mathematical algorithms. Frequency ranges were set as follows: Low Frequency (LF: 0.03–0.15 Hz), Movement Frequency (MF: 0.15–0.50 Hz, not present in adult human subjects), and High Frequency (HF: 0.50–1.00 Hz) ranges. LF and HF bands are mainly associated with autonomic nervous system (ANS) activity (sympathetic and parasympathetic branches, respectively) while the MF band is connected to foetal movements and maternal respiratory frequency. The LF/(HF + MF) ratio quantifies the autonomic balance between neural control mechanisms from different origin (in accordance with the LF/HF ratio normally estimated in adults). A detailed description of how these parameters are computed is reported in Signorini et al. (2003).

2.4. Non-linear parameters

Non-linear FHR parameters quantify the complexity in time series. *Approximate Entropy (ApEn)* is a non-linear measure obtained through direct signal estimation. Among entropy estimators, ApEn is able to quantify the complexity (or irregularity) of FHR variability over windows of FHR signal 3 min

long: small values indicate reduced signal irregularity. We use the original definition by Pincus (1995):

$$\mathrm{ApEn}_{(m,\ r)} = \frac{\sum_{i=1}^{N-m+1} \log C_i(m,r)}{N-m+1} - \frac{\sum_{i=1}^{N-m} \log C_i(m+1,r)}{N-m} \quad (5)$$

For an experimental time series of a fixed length N, m is the length of runs compared in the time series, r is the percentage of signal std (working as a filter) and C_i measures the regularity of patterns comparing them to a given pattern of length m.

2.5. Statistics

Data statistical analysis was performed using version 19.0 SPSS for windows statistical package.

The Kolmogorov–Smirnov test confirmed the Gaussian distributions in each population for all parameters investigated. *T*-test was applied for continuous variables while the Chi-square test was used for categorical variables. cCTG parameters were compared among groups using the one-way Anova test. The Anova test with the Bonferroni adjusted α was used for pairwise comparisons between groups. Moreover, some cCTG parameters were correlated each other using the Pearson correlation test. Statistical significance was fixed at p value $<.05$ for all the tests performed.

3. Results

The aim of the study was to identify which cCTG parameter or parameter set is most efficient in the discrimination among foetuses with 'no NC' ($n = 384$), BC ($n = 39$), 'one NC' ($n = 264$), and 'multiple NCs' ($n = 121$). No correlation was found between cord entanglements and maternal and perinatal characteristics, including body mass index, parity, week of delivery, mode of delivery, foetal pH at birth and 5-min Apgar score <7. Instead, birth weight was significantly lower in the 'multiple NCs' group while 1-min Apgar score was lower in BC group than other groups, respectively (Table 1).

In the antepartum period, the one-way Anova test evidenced statistical significant differences only for some linear cCTG parameters investigated: Acc ($F = 3,64$; $p = .013$), LTI ($F = 93,99$; $p < .001$), Delta ($F = 47,74$; $p < .001$), and Dec ($F = 4,62$; $p = .003$). Pairwise comparisons, using the one-way Anova test with the Bonferroni adjusted α evidenced: a higher number of Acc in the 'one NC' than the 'no NC' group; a statistical significant difference between the 'no NC' group compared to each one of the other two ('no NC' versus BC; 'no NC' versus 'one NC'; 'no NC' versus 'multiple NCs' groups) for LTI and Delta; a higher number of Dec in 'one NC' and 'multiple NCs' than the 'no NC' group, respectively (Table 2).

In order to improve the diagnostic ability of our set of parameters we quantified the correlation between cCTG parameters for each group investigated. Table 3 shows some of the most significant results. No significant results were found in the 'no NC' group, while Acc showed a positive correlation with LTI, Delta and Dec in the BC group. Moreover, Acc was positively correlated with LTI and Delta in 'one NC' and 'multiple NCs' groups, respectively. Finally, LTI was positively correlated with Delta in 'one NC', 'multiple NCs', and BC groups, respectively.

3.1. Intrapartum findings

However, if some difference in FHR variability analysis according to cord entanglements was observed in antepartum period, none of the cCTG parameters investigated during labour exhibited statistically significant differences, except a larger number of variable decelerations ($F = 8,63$; $p = .004$) in 'one or more NCs' than the 'no NCs' group (data not shown).

Therefore, we focussed on the presence or absence of intrapartum events most commonly associated with nuchal cords during labour. Our findings showed that the 'one or more NCs' group exhibited a larger number of cases with prolonged second stage (32.7% versus 8.5%) and meconium-stained liquor (16.3% versus 6.4%) than foetuses with 'no NCs' at birth. Instead, the rate of operative vaginal delivery (20.4% versus 14.9%) and emergency caesarean section (16.3% versus 14.3%) were similar in both groups (Figure 1).

Moreover, we looked for a potential correlation between the need for emergency caesarean section with intrapartum cCTG parameters in both groups. Also in this case, no statistically significant differences were observed, except the largest number of variable decelerations ($F = 5,38$; $p = .025$) for

Table 1. Maternal and perinatal characteristics.

Characteristics	No nuchal cord[a]	Body cord[a]	One nuchal cord[a]	Multiple nuchal cords[a]	*p*-value
Age, year	31.73 ± 5.0	32.29 ± 6.2	31.84 ± 6.0	31.60 ± 5.4	.5
Body mass index (kg/m^2)	25.2 ± 4.7	26.4 ± 3.5	25.7 ± 4.2	26.3 ± 3.6	.3
Weight gain (kg)	8.6 ± 7.3	8.8 ± 8.2	9.2 ± 7.1	9.5 ± 7.8	.2
Gravidity	1.70 ± 1.0	1.64 ± 0.8	1.62 ± 0.9	1.63 ± 1.1	.9
Parity	0.33 ± 0.7	0.36 ± 0.7	0.23 ± 0.5	0.27 ± 0.6	.7
Week of delivery (weeks)	39.4 ± 1.4	39.6 ± 1.6	39.2 ± 1.7	38.7 ± 2.2	.07
Vaginal delivery (%)	85.2	84.7	84.1	83.5	.4
Neonatal data					
Foetal pH at birth	7.28 ± 0.07	7.26 ± 0.07	7.28 ± 0.08	7.31 ± 0.05	.5
1 min Apgar score <7 (%)	2.8	7.6	3.1	3.4	**<.01**
5 min Apgar score <7 (%)	0.5	0.9	0.6	0.7	.2
Female (%)	48.8	54.5	44.0	53.2	.3
Birth weight. gr	3265 ± 421	3100 ± 651	3040 ± 710	2908 ± 347	**<.01**

[a]Values above are expressed as mean value ± SD.
Bold values are statistical significant.

Table 2. Comparison between cCTG parameters stratified by nuchal cords in antepartum period.

Variable		No nuchal cord	Body cord	One nuchal cord	Multiple nuchal cords	*p*-value
Baseline (bpm)						.05**
	Mean	138.61	136.71	137.44	136.00	1.0^{A,B,**}
	SD	9.41	13.10	12.06	14.61	.434$^{A–C}$
						.166$^{A–D}$
Acc (*n*)						**.013**
	Mean	9.66	10.96	11.09	10.55	1.0^{A,B}
	SD	5.46	8.49	5.84	5.78	**.007**$^{A–C}$
						.829$^{A–D}$
STV (ms)						.198
	Mean	6.37	5.98	6.59	6.44	.841$^{A–B}$
	SD	2.18	2.55	4.09	2.70	1.0$^{A–C}$
						1.0$^{A–D}$
LTI (ms)						**<.001**
	Mean	33.62	20.58	21.48	21.23	**<.001**^{A,B}
	SD	13.64	7.04	5.92	6.12	**<.001**$^{A–C}$
						<.001$^{A–D}$
Delta (ms)						**<.001**
	Mean	30.05	40.81	40.03	40.41	**<.001**^{A,B}
	SD	12.32	15.51	11.22	12.36	**<.001**$^{A–C}$
						<.001$^{A–D}$
II						.904
	Mean	0.87	0.86	0.86	0.84	1.0^{A,B}
	SD	0.46	0.06	0.30	0.06	1.0$^{A–C}$
						1.0$^{A–D}$
ApEn						.570
	Mean	1.31	1.23	1.36	1.32	1.0^{A,B}
	SD	0.15	0.14	0.75	0.16	1.0$^{A–C}$
						1.0$^{A–D}$
LF (ms^2)						.593
	Mean	82.36	83.39	84.57	82.12	1.0^{A,B}
	SD	4.61	4.76	42.23	4.67	1.0$^{A–C}$
						1.0$^{A–D}$
MF (ms^2)						.543
	Mean	12.27	10.98	12.55	12.17	1.0^{A,B}
	SD	3.33	3.53	3.40	2.93	1.0$^{A–C}$
						1.0$^{A–D}$
HF (ms^2)						.120
	Mean	5.35	5.62	5.34	5.70	.344^{A,B}
	SD	2.82	2.92	2.98	3.10	1.0$^{A–C}$
						1.0$^{A–D}$
LF/(HF + MF)						.274
	Mean	4.18	3.97	4.16	3.92	.971^{A,B}
	SD	1.99	1.80	1.85	1.97	1.0$^{A–C}$
						1.0$^{A–D}$
Dec (*n*)						**.003**
	Mean	0.05	0.10	0.14	0.17	.149^{A,B}
	SD	0.24	0.66	0.47	0.54	**.031**$^{A–C}$
						.047$^{A–D}$

CTG: computerised Cardiotocography; Baseline: FHR baseline; Acc: accelerations; STV: short-term variability; LTI: long-term irregularity; Delta: Delta Index; II: Interval Index; ApEn: Approximate Entropy; LF: low frequency; MF: movement frequency; HF: high frequency; LF/(HF + MF): the LF/(HF + MF) ratio; Dec: decelerations.
SD: standard deviation.
Values in bold are statistically significant.
Variables are calculated using initial and final 10 min of each trace.
**p Value for comparison among groups using the one-way Anova test.
***p Value for the one-way Anova test with the Bonferroni adjusted α are indicated with A,B (no nuchal cord versus body cord). A–C (no nuchal cord versus one nuchal cord). A–D (no nuchal cord versus multiple nuchal cords) groups.

Table 3. Correlation coefficients between the variables evaluated.

Group		Acc	LTI	Delta	Dec
No nuchal cord	ACC	1	−0.033	−0.022	0.104
	p		.525	.670	.041*
	LTI	−0.033	1	−0.156	−0.044
	p	.525		.002	.389
Body cord	Acc	1	**0.615**	**0.596**	**0.576**
	p		<.001	<.001	<.001
	LTI	**0.615**	1	**0.858**	0.195
	p	<.001		<.001	.235
One nuchal cord	Acc	1	0.481	0.416	0.161
	p		.001	<.001	.009
	LTI	0.481	1	**0.752**	0.060
	p	<.001		<.001	.335
Multiple nuchal cord	Acc	1	**0.618**	**0.583**	0.048
	p		<.001	<.001	.601
	LTI	**0.618**	1	**0.895**	−0.003
	p	<.001		<.001	.971

Acc: accelerations; LTI: long-term irregularity; Delta: Delta Index; Dec: decelerations.
Values in bold are statistically significant.
*p Value for comparison between parameters for each group using the Pearson correlation test.

foetuses of women who had an emergency caesarean section in 'one or more NCs' group (data not shown).

As further investigation, we assumed that the loss of amniotic fluid following the rupture of membranes could cause more compression of the umbilical cord vessels during labour, with an increased risk of foetal hypoxia. Therefore, we looked for the differences between before and after the rupture of membranes during labour in the two groups of foetuses. When membranes were intact, foetuses in the 'one or more NCs' group showed higher values for ApEn ($F = 4,65$; $p = .036$) and MF ($F = 5,20$; $p = .027$) than foetuses with 'no NCs'. After the rupture of membranes, foetuses in the 'one or more NCs' group showed a very large number of variable decelerations ($F = 7,09$; $p = .011$), lower 5-min Apgar score ($F = 5,07$; $p = .03$) values than foetuses with 'no NCs'.

Finally, we considered a stratified analysis based on the gender-specific differences, but no differences were observed in antepartum and intrapartum FHR parameters.

4. Discussion

In this study, the percentage of vaginal delivery was similar in all groups investigated. According to the current literature, NC did not influence the mode of delivery with no significantly increased risk of operative vaginal delivery or caesarean section (Schaffer et al. 2005; Ogueh et al. 2006; Narang et al. 2014; Kobayashi et al. 2015). Instead, Larson et al. (1995) reported that multiple loops of the umbilical cord may be associated with a greater risk of operative vaginal delivery, but not in the rate of caesarean deliveries, while Jauniaux et al. (1995) reported a significant increase in the rate of caesarean section in multiple nuchal cords. According to some studies (Larson et al. 1995; Narang et al. 2014), our results showed a higher number of meconium-stained liquor and prolonged second stage cases in association with 'one or more NCs', while for other studies (Schaffer et al. 2005; Ogueh et al. 2006), the frequency of these two intrapartum events was unchanged. These differences between studies may be explained by different numbers of umbilical cord loops considered or due to the amount of cases examined. Another key variable was the different management protocols adopted during labour in case of intrapartum events related to NC (e.g. change in maternal posture, stopping of oxytocin infusions, correction of maternal hypotension), because they may have influenced decision making.

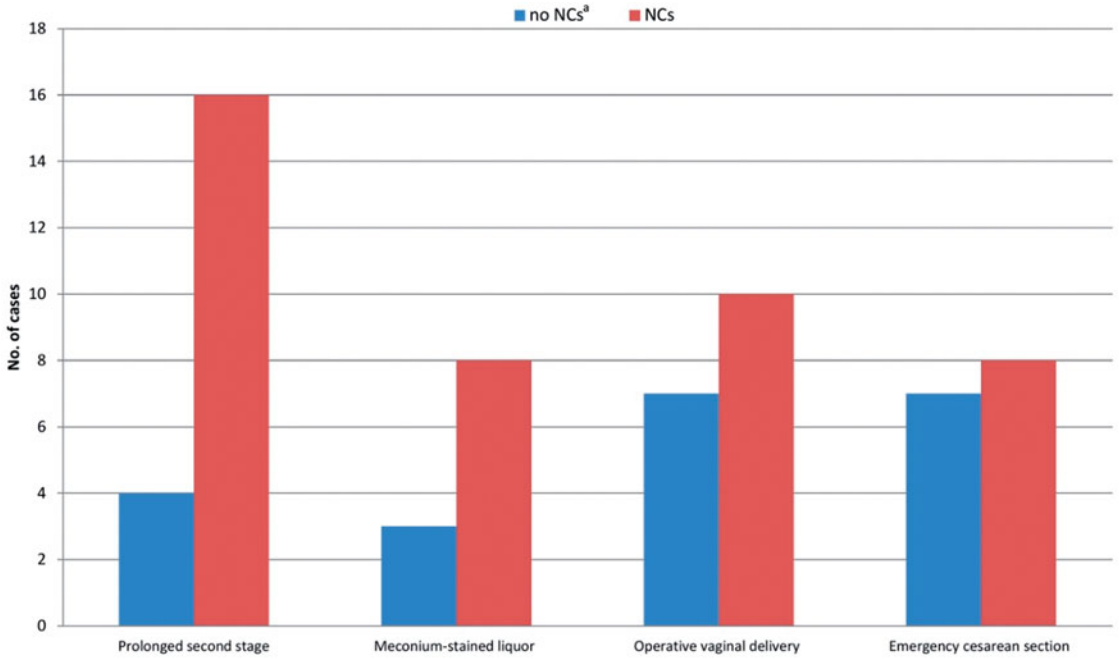

Figure 1. Schematic association of no NCs and NCs with intrapartum events. [a]NC: Nuchal Cord.

4.1. Neonatal outcomes

On comparing neonatal primary adaptation data, UA pH values and 5-min Apgar scores <7 were similar among groups investigated, while 1-min Apgar scores <7 were lower in BC than other three groups. Instead, Kobayashi et al. (2015) reported both lower UA pH and 1-min and 5-min Apgar scores in the BC group than in the NC cord ones. However, the pathophysiological mechanism underlying these differences is identical, because the absence of space between uterus and foetal body during contractions causes a stronger umbilical cord compression in body cord than nuchal cord. Even if most studies (Assimakopoulos et al. 2005; Schaffer et al. 2005; Narang et al. 2014) reported lower UA pH in NC groups, the overall rate of pathological pH values at birth is relatively low. This finding probably suggests that the presence of cord entanglements interrupts umbilical blood flow to some extent causing some biochemical alteration, but a term physiological foetus with adequately functioning placenta is able to compensate quickly. According to Narang et al. (2014), our neonatal outcome data suggested that foetuses with single or multiple NCs were able to compensate intermittent umbilical cord compression during pregnancy and to undergone vaginal delivery without the occurrence of metabolic acidosis.

Although foetuses with growth restriction were initially excluded, our findings revealed a significant association between foetal weight decrease and cord entanglements. It might reflect chronic intermittent cord compression in foetus with prolonged nuchal cord existence, as often it happened in presence of multiple cord entanglements. It is also true that a constitutionally small foetus is more likely to move around in the uterus and to generate a cord loop around the neck or body (Ogueh et al. 2006; Kobayashi et al. 2015).

4.2. Nuchal cords and cCTG parameters

Our results showed that umbilical cord entanglements around the body or neck did not seem to influence most of linear and non-linear cCTG parameters investigated, such as FHR baseline, STV, II, ApEn, and spectral components of FHR variability. Instead, Delta and LTI were different for all pairwise comparisons in antepartum period, reflecting the adaptability of the foetus to internal and external stimuli through the activation of parasympathetic and sympathetic branches of the autonomic nervous system (ANS). However, medium- and long-term variabilities are less reliable indicators of the foetal homeostasis than STV. In fact, STV is the most extensively studied parameter of cCTG, because it is able to assess the integrity of the ANS and its connections with the central nervous system (CNS). High STV values reflect an healthy ANS, normal activity of chemoreceptors, baroreceptors and cardiac responsiveness, while low STV values are associated with impending deterioration of foetal oxygen supply and therefore foetal distress (Anceschi et al. 2003; Serra et al. 2008).

Similarly, ApEn was considered to provide a measurement of feedback and regularity, so that time series containing many repetitive patterns have relatively low ApEn, and a less predictable process has higher ApEn (Pincus 1995, 2001). Li et al. (2005) suggested that the lower ApEn of FHR was associated not only with foetal distress and hypoxia, but also with respiratory and metabolic acidosis in women at term pregnancy.

Also spectral analysis of the FHR variability provides quantitative and non-invasive measures of ANS activity, extracting information related to the heart and to the cardiovascular control even from systolic and diastolic values in arterial blood pressure, on a beat-to-beat basis (Signorini et al. 2003).

Therefore, the absence of statistical significant differences in STV, ApEn and spectral analysis values showed that the

presence of cord entanglements did not affect the foetal well-being state.

Antepartum cCTG records showed a higher number of Acc in the 'one NC' than the 'no NC' group. Most of accelerations showed the typical pattern of double-form accelerations. The appearance is that of the single-form uniform acceleration with the addition of a notch that is central or eccentric in location. This pattern is usually indicative of partial cord compression. The notch is believed to represent very transient umbilical artery impingement, flanked by the tachycardic response that is produced by isolated umbilical vein impingement. It usually represents a protective reflex of a well-oxygenated foetus (Cabaniss and Ross 2010).

Single or multiple NCs were also associated with an increased prevalence of variable FHR decelerations in antepartum and intrapartum period, as reported in several studies (Hankins et al. 1987; Misser 1992).

However, we did not find clinically significant differences in outcomes for the newborn infant. Therefore, both antepartum and intrapartum cCTG monitoring results emphasise the state of good oxygenation of all foetuses, regardless of nuchal or body cords. This conclusion is consistent with the current literature (Schaffer et al. 2005; Narang et al. 2014; Kobayashi et al. 2015).

In summary, we have investigated several linear and nonlinear cCTG parameters in presence of NC and BC, but no significant differences were observed. Despite increased meconium-stained liquor and prolonged second stage cases, cord entanglements do not alter the mode of delivery. The primary adaptation of neonates is not impaired and no additional neonatal care is necessary. Clearly, there remains a need for further studies in the management of patients with cord entanglements using FHR monitoring as a means of antenatal and intrapartum surveillance.

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