

Prevalence of Abnormal Cerebroplacental Ratio in Uncomplicated Full-term Pregnancy and Correlation with Adverse Perinatal Outcomes

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ABSTRACT

Objective: To investigate the prevalence of abnormal cerebroplacental ratio (CPR) and predicting values for adverse perinatal outcomes in uncomplicated full-term pregnancies.

Materials and Methods: This prospective cross-sectional study was conducted at Bhumibol Adulyadej Hospital, Royal Thai Air Force, Thailand between July and December 2023. The study population comprised pregnant women between the ages 18 and 45 presenting uncomplicated full-term pregnancies. Transabdominal ultrasonography in Doppler color mode was performed on all participants. Umbilical artery pulsatility index (UAPI) and middle cerebral artery pulsatility index (MCAPI) were both measured. CPR was calculated by MCAPI divided by UAPI. A CPR value was considered low if it was less than 1.03. Obstetric and perinatal outcomes were recorded including route of delivery, gestational age (GA) at delivery, obstetric complications, Apgar score, neonatal birth weight, neonatal intensive care unit (NICU) admission, and fetal non-reassuring tracing (FNR).

Results: A total of 250 pregnant women were recruited. The mean maternal age and GA was 27.7 years, 39.6 weeks, respectively. Low CPR prevalence was recorded at 16.4 percent. There were 41 and 209 cases in low (<1.03) and normal (≥ 1.03) CPR groups, respectively. UAPI and MCAPI of the normal/low CPR group were 0.8/1.3 and 1.1/0.9 with statistical significance. CPR for predicted value of FNR (1.03) gave sensitivity, specificity, PPV, and NPV at 95.5, 91.2, 51.2 and 99.5 percent, respectively. This study presented no adverse perinatal outcomes.

Conclusion: Low CPR prevalence was 16.4 percent. Normal CPR values measured within a week before birth was a good indicator of normal perinatal outcomes.

Keywords: Umbilical artery; middle cerebral artery; cerebroplacental ratio (Siriraj Med J 2024; 76: 514-521)

INTRODUCTION

The umbilical artery (UA) is responsible for outflow in fetal circulation and carries deoxygenated blood to the placenta and can indicate placental vascular resistance.¹ The middle cerebral artery (MCA) of the fetus is one of

the main fetal cerebral blood vessels. When the blood flow to the fetus is reduced, the resistance of MCA is lowered to divert blood flow to supply the fetal brain.² Resistance of MCA is generally used as an indicator of intrapartum fetal hypoxia (IFH).³

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Cerebroplacental ratio (CPR) is a hemodynamic parameter measurement derived from dividing the MCA by the UA Doppler pulsatility index ratio.⁴ CPR is a reflection of the arterial redistribution that occurs during preferential brain perfusion in response of fetal hypoxia.⁵ A low CPR value demonstrates impaired fetal oxygenation and brain hypoxemia.⁶ It is believed that a low CPR is associated with adverse perinatal outcomes such as low neonatal birth weight, low Apgar score, and fetal non-reassuring tracing (FNR).⁷

Currently, there is no recommendation for antenatal surveillance in uncomplicated full-term (39–40 weeks and 6 days) pregnancies according to ACOG guidelines.^{8,9} Previous literatures reported correlation between low CPR and fetal non-reassuring among pregnant women with intrauterine fetal growth restriction.^{10–12} It has been suggested that the use of Doppler ultrasound in pregnancies with normal-sized fetuses at term could potentially identify those at risk of subclinical placental impairment.⁷ The aim of this study is to analyze the prevalence of low CPR in uncomplicated full-term pregnancies and establish correlation with adverse perinatal outcomes.

MATERIALS AND METHODS

This prospective cross-sectional study was conducted between July and December 2023. Pregnant women who attended antenatal care unit (ANC) at the Maternal and fetal medicine unit at Bhumibol Adulyadej Hospital (BAH) during the study period were recruited. The study was approved by the Bhumibol Adulyadej Institutional review board (BAIRB) (Registration number 33/66). The clinical trial registration number was TCTR20230602002. All participants were first comprehensively counseled regarding the study and its procedures before informed consent was established and signed for enrollment.

Pregnant women aged between 18 and 45 years old with gestational ages (GA) between 39 to 40 weeks and 6 days were recruited. Accurate GA was confirmed by the first day of the last menstrual period and first trimester ultrasound. For purposes of this study; an uncomplicated pregnancy was defined as pregnancy displaying an absence of maternal medical disorders such as diabetes mellitus, hypertension, renal disease, autoimmune diseases. Our exclusion criteria were maternal medical disorders and multiple gestations.

At a GA of 39 weeks, pregnant women were required to attend weekly antenatal care until delivery. Color Doppler ultrasonography was performed at 39 weeks and repeated weekly until delivery via transabdominal technique based on International Society of Ultrasound in Obstetrics and Gynecology 2021 guidelines.⁵ Non-stress

test and amniotic fluid index measurement (modified biophysical profiles) were also performed weekly to all participants until delivery.^{13,14} Doppler ultrasound was performed within one week before delivery. Obstetrics and perinatal outcomes were followed up and data was collected at delivery date. A flow chart of the study is displayed in Fig 1.

Umbilical artery pulsatility index (UAPI) was measured by transabdominal ultrasonography in color Doppler mode by using an ultrasound machine (Voluson E10 model: GE healthcare, Zipf, Austria). Point of UAPI measurement was the free loop of the umbilical cord. The acceptable velocity waveform of UAPI was presented in Fig 2A. Middle cerebral artery pulsatility index (MCAP) was measured at the axial section of the brain including the thalami and the sphenoid bone wings. The circle of Willis was identified by the color flow Doppler mode. Point of pulse wave measurement was placed at the proximal third of the MCA closing to its origin (internal carotid artery) as shown in Fig 2B. Acceptable Doppler waveform of MCA and the angle of insonation was adjusted to be at nearly zero degrees.⁵ Each Doppler ultrasound was performed by a single operator. Three waveforms were selected for measurement of UAPI and MCAP in autotrace mode. When a CPR value measured less than 1.03, it was classified as abnormal or low CPR.

When subjects approached the active phase of labor, routine intrapartum care was attended. Standard labor protocol including nothing by mouth, intravenous fluid infusion and continuous external fetal monitoring were applied. Labor progression, namely uterine contraction, cervical progression and vital sign were monitored by an on-duty expert obstetrician. Cesarean delivery was performed as needed as decided under obstetrics indication.

Obstetric and perinatal outcomes were recorded including route of delivery, GA, obstetric complications, Apgar score, neonatal birth weight, neonatal intensive care unit (NICU) admission, and FNR. FNR was classified in subjects who had intrapartum fetal heart rate monitoring with category two or three. The National Institute of Child Health and Human Development terminology (revised in 2008) classified continuous electronic fetal monitoring tracings into a three-tiered system.¹⁵

When Apgar score at 5 minutes was 7 or greater it was unlikely to indicate peripartum hypoxia.¹⁶ Adverse perinatal outcomes being described as: Apgar score less than 7, low birth weight (lower than 2,500 gram) and NICU admission.¹⁷

A pilot study was conducted among ten subjects. Prevalence of low CPR was 10 percent. Precision of estimation was set as level of 0.04. Appropriate sample

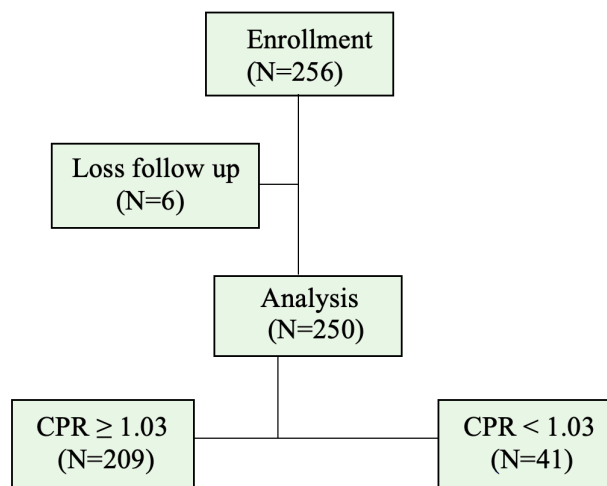


Fig 1. Flow chart of study.

Abbreviation: CPR: cerebroplacental ratio

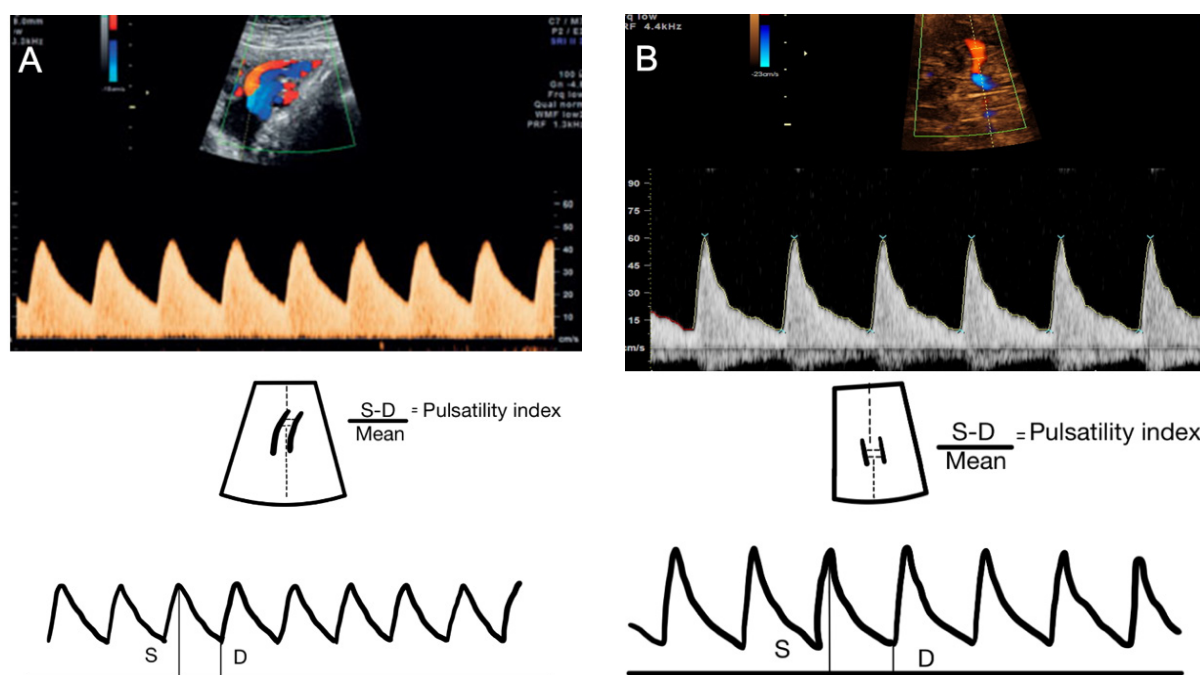


Fig 2. Ultrasonography image demonstrating the measurement of Umbilical artery and Middle cerebral artery.

Fig 2A: Umbilical artery Doppler, **Fig 2B:** Middle cerebral artery Doppler

size was at least 217 cases. Ten percent for data lost was added. The sample size in the current study was approximately 240 cases.

The commercial statistical package for social science version 22 program (IBM Inc., NY USA) was used for data analysis. Descriptive data was presented in percentages. Continuous and category variables between groups were presented as mean $\pm$ standard deviation and chi square or Fisher exact with appropriate application, respectively. Cut-off points for Doppler indices and FNR prediction were calculated using receiver operative curve (ROC) plotting. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of UA and MCA Doppler indices and CPR were

evaluated. A *p*-value less than 0.05 was considered as statistical significance.

RESULTS

During the study period, 256 pregnant women were enrolled. A total of 250 pregnant women were recruited for the study as presented in Fig 1. The prevalence of low CPR in this study was 16.4 percent (41/250). Doppler ultrasound was performed within one week before delivery. The velocity waveform of UAPI and MCAPI was presented in Fig 2.

The participants' average age was 27.7 years old. Their average body mass index (BMI) was 27.8 kg/m² with a mean GA at delivery of 39.6 weeks. Two thirds of

subjects (155/250) were nulliparous. Low and normal CPR were defined as $\text{CPR} < 1.03$ and ≥ 1.03 , respectively. There were 41 and 209 cases in the low and normal CPR groups, respectively. Subjects in the low CPR group were significantly older, with higher BMI, higher cesarean delivery (CS) rate, higher oligohydramnios and FNR (21 vs 1 cases) than those in normal CPR group. All subjects with FNR were evaluated for appropriate delivery according to obstetrics indication. One fourth (5/22) of FNR cases had vaginal delivery. Average neonatal birth weight from the low CPR group was significantly lower than those from the normal CPR group (3.1 vs 3.3 kg, respectively, $p = 0.01$). Average GA at delivery and parity of both groups were comparable as shown in Table 1. There was no newborn with low Apgar scores or any who required NICU admission among all subjects in this study.

The different cut-off values for predicting FNR including UAPI, MCAPI and CPR were presented in Fig 3. Receiver operative curve (ROC) was generated for appropriate cut-off value. Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were shown in Table 2. CPR for predicted value of FNR (1.03) gave sensitivity, specificity, PPV, and NPV at 95.5, 91.2, 51.2 and 99.5 percent, respectively.

DISCUSSION

This prospective cohort study was to evaluate the use of Doppler indices for the prediction of abnormal intrapartum fetal tracing. FNR condition was recommended for the rapid fetus delivery to prevent IFH. CS was usually performed in FNR cases with slow cervical progression.¹⁸

The prevalence of low CPR in the current study was 16.4 percent. Previous studies from Italy and Türkiye reported incidence of low CPR were 15.7 and 19.3 percent, respectively.^{19,20} While Mecke from Germany and Chinaron from Thailand reported incidence rates of 5.7 and 2.3 percent, respectively.^{21,22} Study participants within Mecke and Chinaron's studies underwent Doppler ultrasound for CPR measurement at 22 and 37 weeks of pregnancy. Dall'Asta's study, Gunuy's, and the current study start Doppler ultrasound measurement at GA of 39 weeks. Increasing GA was a dominant factor for low CPR due to impairment of placental blood flow.²³ However, adverse perinatal outcomes fell short of statistical significance.

The CS rate of subjects in this study averaged approximately 20 percent (55/250). Half of subjects who had low CPR underwent CS (19/41). UAPI and MCAPI were Doppler indices used for predicting FNR.¹⁸ High UAPI levels indicated that resistance of the umbilical

TABLE 1. Maternal characteristic, perinatal outcomes and Doppler indices of high CPR (n=209) and low CPR (n=41) total pregnant women (n= 250).

	Total*	CPR		p-value
		$\geq 1.03^*$	$< 1.03^*$	
Age (year)	27.7 $\pm$ 5.4	27.4 $\pm$ 5.4	29.5 $\pm$ 5.6	0.02
BMI (kg/m ²)	27.8 $\pm$ 4.6	27.5 $\pm$ 4.6	29.3 $\pm$ 4.6	0.02
GA at delivery (weeks)	39.6 $\pm$ 0.6	39.6 $\pm$ 0.6	39.6 $\pm$ 0.6	0.64
Nulliparity**	155 (62)	129 (61.7)	26(63.4)	0.84
Cesarean delivery**	55 (22)	36 (17.2)	19 (46.3)	<0.001
Oligohydramnios**	7 (2.8)	0 (0.0)	7 (17.1)	<0.001
EFW (kg)**	3.2 $\pm$ 0.3	3.3 $\pm$ 0.3	3.1 $\pm$ 0.3	0.01
Fetal non-reassuring**	22 (8.80)	1 (0.48)	21 (51.2)	<0.001
UAPI	0.9 $\pm$ 0.2	0.8 $\pm$ 0.2	1.1 $\pm$ 0.3	<0.001
MCAPI	1.2 $\pm$ 0.3	1.3 $\pm$ 0.3	0.9 $\pm$ 0.2	<0.001
CPR ratio	1.5 $\pm$ 0.4	1.6 $\pm$ 0.4	0.9 $\pm$ 0.2	<0.001

* Mean $\pm$ standard deviation (SD), ** n (%)

Abbreviations: UAPI: umbilical artery pulsatility index, MCAPI: middle cerebral artery pulsatility index, CPR: Cerebroplacental ratio

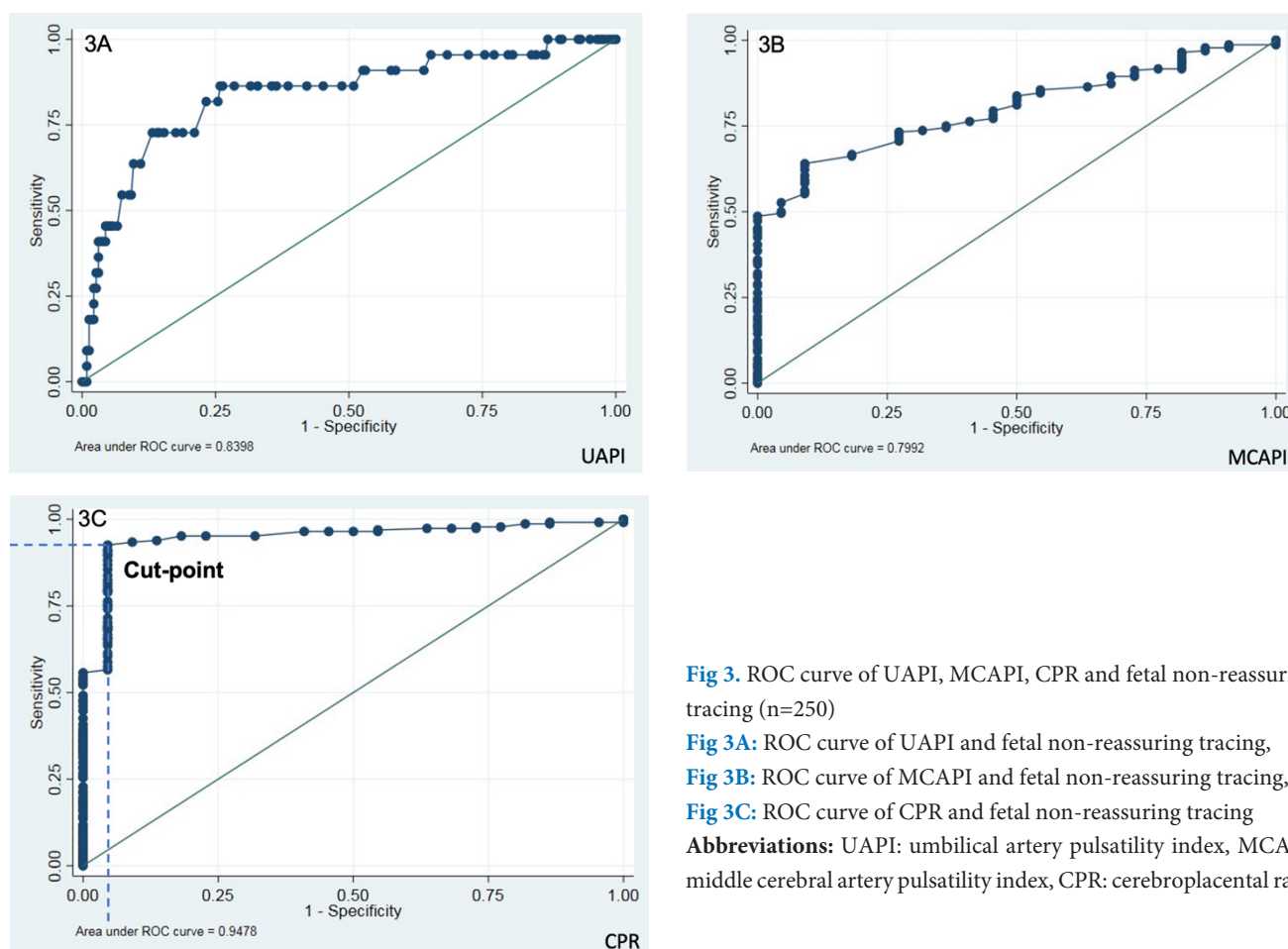


Fig 3. ROC curve of UAPI, MCAPI, CPR and fetal non-reassuring tracing (n=250)

Fig 3A: ROC curve of UAPI and fetal non-reassuring tracing,

Fig 3B: ROC curve of MCAPI and fetal non-reassuring tracing,

Fig 3C: ROC curve of CPR and fetal non-reassuring tracing

Abbreviations: UAPI: umbilical artery pulsatility index, MCAPI: middle cerebral artery pulsatility index, CPR: cerebroplacental ratio

TABLE 2. The performance of the different testing parameters.

	AUC	Cut off value	Sensitivity*	Specificity*	PPV*	NPV*
UAPI	0.80	1.05	72.7 (49.8-89.3)	86.8 (81.8-90.9)	34.8 (21.4-50.2)	97.1 (93.7-98.9)
MCAPI	0.77	1.13	90.9 (70.8-98.9)	64.0 (57.4-70.3)	19.6 (12.4-28.6)	98.6 (95.2-99.8)
CPR	0.93	1.03	95.5 (77.2-99.9)	91.2 (86.8-94.6)	51.2 (35.1-67.1)	99.5 (97.4-100)

* 95% confidence interval

Abbreviations: UAPI: umbilical artery pulsatility index, MCAPI: middle cerebral artery pulsatility index, CPR: cerebroplacental ratio, PPV: positive predictive value, NPV: negative predictive value

vessel was high. This implicated that placental vascular was higher resistance and dysfunction.²³

In this study, FNR was classified as fetal heart rate tracing in category two or three. Category two was defined as absent baseline variability and late or variable deceleration of intrapartum fetal heart rate monitoring. While category two along with recurrent late or variable decelerations, bradycardia and sinusoidal pattern was classified as category three.¹⁵ UAPI of more than 1.05 was

proposed as allowing FNR prediction with sensitivity, specificity, PPV and NPV at a percentage of 72.7, 86.8, 34.8 and 97.1, respectively. When UAPI indicated a healthy fetus, the diagnosis accuracy was 97.1 percent. However, when UAPI indicated FNR, the diagnosis accuracy was only 34.8 percent. When UAPI was high, the unnecessary CS might be performed.

MCAPI indicated intracerebral resistance. In healthy fetuses, MCAPI was seen at high levels, indicating transport

of high oxygenation blood to peripheral and visceral organs.²⁴ When the fetus was FNR, the MCAPI appeared at low levels to shift blood flow to the brain to allow appropriate levels of oxygenation.²⁵ In this study, MCAPI lower than 1.13 could be used to predict FNR with sensitivity, specificity, PPV and NPV at a percentage of 90.9, 64.0, 19.6 and 98.6, respectively. When MCAPI indicated a healthy fetus, the correct diagnosis was comparable to the use of UAPI. The sensitivity of MCAPI was better than UAPI (90.9 and 72.7, respectively). However, the PPV of MCAPI was lower than UAPI (19.6 and 34.8). MCAPI alone was not a good validation of FNR when compared to the use of UAPI.

CPR was the ratio of MCA and UAPI. It was used for improving the predictive value of FNR and hence reducing unnecessary cesarean delivery.²⁶ (26). From the current study, CPR of less than 1.03 could be used to predict FNR with sensitivity, specificity, PPV and NPV at the percentage of 95.5, 91.2, 51.2 and 99.5, respectively. Sensitivity for the detection of FNR by CPR was better

than the sensitivity of MCA and UAPI (95.5, 90.9 and 72.7%). When CPR was used to ensure healthy fetus, it yielded a better result than the use of MCA and UAPI (99.5, 98.6 and 97.1%, respectively). When CPR was used to indicate FNR, the correct diagnosis of FNR was only 51.2 percent. CPR of less than 1.03 could be the appropriate Doppler index for prediction of FNR. The CPR cut-off point used in literature varied between 1.0 to 1.08 had been used as a predictor of FNR and applied for assessment of fetal well-being as summarized in [Table 3](#).¹⁹⁻²²

The cesarean delivery rate in Thailand, Turkiye, Germany, as of the current study were 46.1, 42.8, 36.9 and 22 percent, respectively.¹⁹⁻²² However, the cesarean delivery rate of the Italian study was only 14.6 percent.¹⁹ FNR prevalence in Thailand, Turkiye, Germany, Italy and the current study were 31.5, 16.7, 10.1, 6.6 and 8.8, respectively, see: [Table 4](#).¹⁹⁻²² FNR was shown not to be the indication for rapid delivery, but the CS rate seemed to be higher in the high prevalence of FNR cases.

TABLE 3. Comparison of Maternal characteristic, perinatal outcomes and Doppler indices.

	Gunay		Chainarong		Mecke		Dall'Asta		Present	
Year	2022		2018		2022		2019		2024	
Country	Turkiye		Thailand		Germany		Italy		Thailand	
CPR	≥1	< 1	≥ 1	< 1	≥ 1.08	< 1.08	≥ 10 th	< 10 th	≥ 1.03	< 1.03
Cases (n)	117	28	375	9	669	41	290	54	209	41
Prev**		19.3		2.3		5.7		15.7		16.4
Age (year)*	27.0	28.0	29.0		30.5	30.4	30.5	30.3	27.4	29.5
GA (weeks)*	39.4	38.1	39.3		39.4	38.9	39.6	39.1	39.6	39.6
BMI (kg/m ²) *	30.0	29.0	21.8			28.9	29.1	27.5	29.3	
Nulliparity**	57.0	15.0	72.0			57.1	51.9	61.7	63.4	
CS**	37.6	64.3	46.1		36.9		14.6		17.2	46.3
Oligo**	14.5	10.7	35	37.5					0	17
EFW (kg)*	3.4	3.2	3.1	3.0	3.4	3.0	3.4	3.2	3.3	3.1
FNR**	12.8	32.1	13.3	33.3	9.0	29.3	5.5	16.7	0.5	51.2
UAPI*	0.8	1.3					0.9		0.8	1.1
MCAPI*	1.4	1.2					1.3		1.3	0.9
CPR*	1.8	0.9			1.9	0.9	1.6		1.6	0.9

*Mean, **(%)

Abbreviations: Prev: prevalence of low CPR, UAPI: umbilical artery pulsatility index, MCAPI: middle cerebral artery pulsatility index, CPR: cerebroplacental ratio, GA: gestational age at delivery, BMI: body mass index, CS: cesarean delivery, Oligo: oligohydramnios, EFW: estimate fetal weight, FNR: fetal non-reassuring tracing

TABLE 4. Comparison of the performance of the different testing parameters.

Studies	Prev*	Cut off value	Sensitivity	Specificity	PPV	NPV
Gunay, Turkiye, 2022	16.7 (24/145)	< 1	37.5 (9/24)	84.3 (102/121)	32.4 (9/28)	87.0 (102/117)
Chinarong, Thailand, 2018	31.5 (121/384)	< 1	4.7 (6/121)	98.9 (260/263)	66.7 (6/9)	69.3 (260/375)
Mecke, Germany, 2022	10.1 (72/710)	< 1.08	16.7 (12/72)	95.5 (609/638)	29.3 (12/41)	91.0 (609/669)
Dall'Asta, Italy, 2019	6.6 (37/562)	< 10 th	24.3 (9/37)	91.4 (480/525)	16.7 (9/54)	94.5 (480/508)
Present, Thailand, 2024	8.8 (22/250)	< 1.03	95.5 (21/22)	91.2 (208/228)	51.2 (21/41)	99.5 (208/209)

*%

Abbreviations: Prev: Prevalence of fetal non-reassuring tracing, PPV: Positive predictive value, NPV: Negative predictive value

NPV for detection of FNR in the current study, Dall'Asta', Mecke', Gunay' and Chainarong' studies were 99.5, 94.5, 91.0, 87.0 and 69.3 percent.¹⁹⁻²² NPV from the current study was comparable to those from the mentioned studies. PPV in the current work, Chainarong', Gunay', Mecke' and Dall'Asta' studies were 51.2, 66.7, 34.4, 29.3 and 16.7 percent¹⁹⁻²², respectively. PPV indicated high probability of FNR. When CPR predicts FNR, rapid delivery should be considered.

From the current finding, CPR of higher than 1.03 suggested the high probability of healthy fetus. When CPR was less than 1.03, the intrauterine surveillance and appropriate intervention should be performed. Immediate cesarean delivery among those who had CPR lower than 1.03 was not recommended. These fetuses should be treated as high-risk pregnancies and received close observation in intrapartum fetal monitoring.

Present study showed CPR as a method for antepartum fetal surveillance with high sensitivity (95.5%) to screen FNR. CPR of less than 1.03 was useful to encourage the attending obstetrician to closely survey the parturient. Low CPR (less than 1.03) was not an indication for cesarean delivery but was an indicator for intensive intrapartum monitoring. This could be used to potentially reduce rapid cesarean delivery with improved maternal perinatal outcomes.

CONCLUSION

Low CPR prevalence was presented at 16.4 percent. Normal CPR values measured within one week before delivery was a good predictor for normal perinatal outcome.

What is already known on this topic?

The umbilical artery (UA) is responsible for outflow

in fetal circulation and carries deoxygenated blood to the placenta and can indicate placental vascular resistance. Resistance to MCA is generally used as an indicator of intrapartum fetal hypoxia. Cerebroplacental ratio (CPR) is a hemodynamic parameter derived by dividing the MCA by the UA Doppler pulsatility index ratio. A low CPR value demonstrates impaired fetal oxygenation.

What does this study add?

CPR of higher than 1.03 suggested the high probability of healthy fetus. When CPR of less than 1.03 was useful to encourage the attending obstetrician to closely survey the parturient. Low CPR (less than 1.03) was not an indication for cesarean delivery but was an indicator for intensive intrapartum monitoring.

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Conflict of Interest

There was no conflict of interest.

Author Contributions

Study concept and designed (NO, WL), analysis and interpretation of data (NO, WL, NO, MP, KP, SM, BP). Study supervision (KB, KS) provided critical revision and approved the final version of manuscript.

REFERENCES

1. Rocha AS, Andrade ARA, Moleiro ML, Guedes-Martins L. Doppler Ultrasound of the Umbilical Artery: Clinical Application. *Rev Bras Ginecol Obstet.* 2022;44(5):519-31.
2. Buca D, Liberati M, Rizzo G, Gazzolo D, Chiarelli F, Giannini C, et al. Pre- and postnatal brain hemodynamics in pregnancies

- at term: correlation with Doppler ultrasound, birthweight, and adverse perinatal outcome. *J Matern Fetal Neonatal Med.* 2022;35(4):713-9.
3. Fiolna M, Kostiv V, Anthoulakis C, Akolekar R, Nicolaides KH. Prediction of adverse perinatal outcome by cerebroplacental ratio in women undergoing induction of labor. *Ultrasound Obstet Gynecol.* 2019;53(4):473-80.
 4. Vollgraff Heidweiller-Schreurs CA, De Boer MA, Heymans MW, Schoonmade LJ, Bossuyt PMM, Mol BWJ, et al. Prognostic accuracy of cerebroplacental ratio and middle cerebral artery Doppler for adverse perinatal outcome: systematic review and meta-analysis. *Ultrasound Obstet Gynecol.* 2018;51(3):313-22.
 5. Bhide A, Acharya G, Baschat A, Bilardo CM, Brezinka C, Cafici D, et al. ISUOG Practice Guidelines (updated): use of Doppler velocimetry in obstetrics. *Ultrasound Obstet Gynecol.* 2021;58(2):331-9.
 6. Yin Q, Zhang Y, Ma Q, Gao L, Li P, Chen X. The clinical value of blood flow parameters of the umbilical artery and middle cerebral artery for assessing fetal distress. *Am J Transl Res.* 2021; 13(5):5280-6.
 7. Di Mascio D, Rizzo G, Buca D, D'Amico A, Leombroni M, Tinari S, et al. Comparison between cerebroplacental ratio and umbilicocerebral ratio in predicting adverse perinatal outcome at term. *Eur J Obstet Gynecol Reprod Biol.* 2020;252:439-43.
 8. Antepartum Fetal Surveillance: ACOG Practice Bulletin, Number 229. *Obstet Gynecol.* 2021;137(6):e116-e27.
 9. Gilroy LC, Al-Kouatly HB, Minkoff HL, McLaren RA, Jr. Changes in obstetrical practices and pregnancy outcomes following the ARRIVE trial. *Am J Obstet Gynecol.* 2022;226(5): 716.e1- e12.
 10. Besimoglu B, Uyan Hendem D, Atalay A, Goncu Ayhan S, Sinaci S, Tanacan A, et al. Combination of Doppler measurements with amniotic fluid volume for the prediction of perinatal outcomes in fetal growth restriction. *Int J Gynaecol Obstet.* 2023;161(1): 190-7.
 11. Mascherpa M, Pegoire C, Meroni A, Minopoli M, Thilaganathan B, Frick A, et al. Prenatal prediction of adverse outcome using different charts and definitions of fetal growth restriction. *Ultrasound Obstet Gynecol.* 2023.
 12. Shmueli A, Mor L, Blickstein O, Sela R, Weiner E, Gonen N, et al. Placental pathology in pregnancies with late fetal growth restriction and abnormal cerebroplacental ratio. *Placenta.* 2023; 138:83-7.
 13. Sapoval J, Singh V, Carter RE. *Ultrasound Biophysical Profile.* StatPearls. Treasure Island (FL)2023.
 14. Umana OD, Siccaldi MA. *Prenatal Nonstress Test.* StatPearls. Treasure Island (FL)2023.
 15. Arnold JJ, Gawrys BL. Intrapartum Fetal Monitoring. *Am Fam Physician.* 2020;102(3):158-67.
 16. Lin XS, Peng XY, Yang MM, Ning LL, Shao YW, Jiang Y, et al. The single pregnancy predicting model of 1 minute Apgar score less than 7 after preterm birth: A retrospective study. *PLoS One.* 2022;17(12):e027938
 17. Sirivunnabood T, Wanitpongpan P, Yapan P. Incidence and risk factors of neonatal sepsis in preterm premature rupture of membranes before 34 weeks of gestation. *Siriraj Med J.* 2022; 74:169-77.
 18. Qureshey EJ, Mendez-Figueroa H, Wiley RL, Bhalwal AB, Chauhan SP. Cesarean delivery at term for non-reassuring fetal heart rate tracing: risk factors and predictability. *J Matern Fetal Neonatal Med.* 2022;35(25):6714-20.
 19. Dall'Asta A, Ghi T, Rizzo G, Cancemi A, Aloisio F, Arduini D, et al. Cerebroplacental ratio assessment in early labor in uncomplicated term pregnancy and prediction of adverse perinatal outcome: prospective multicenter study. *Ultrasound Obstet Gynecol.* 2019;53(4):481-7
 20. Gunay T, Bilir RA, Hocaoglu M, Bor ED, Ozdamar O, Turgut A. The role of abnormal cerebroplacental ratio in predicting adverse fetal outcome in pregnancies with scheduled induction of labor. *Int J Gynaecol Obstet.* 2021;153(2):287-93.
 21. Mecke L, Ignatov A, Redlich A. The importance of the cerebroplacental ratio for the prognosis of neonatal outcome in AGA fetuses. *Arch Gynecol Obstet.* 2023;307(1):311-7.
 22. Chainarong N, Petpichetchian C. The relationship between intrapartum cerebroplacental ratio and adverse perinatal outcomes in term fetuses. *Eur J Obstet Gynecol Reprod Biol.* 2018;228: 82-6.
 23. Bendall A, Schreiber V, Crawford K, Kumar S. Predictive utility of the fetal cerebroplacental ratio for hypoxic ischaemic encephalopathy, severe neonatal morbidity and perinatal mortality in late-preterm and term infants. *Aust N Z J Obstet Gynaecol.* 2023; 63(4):491-8.
 24. Mathewlynn S, Beriwal S, Ioannou C, Cavallaro A, Impey L. Abnormal umbilical artery pulsatility index in appropriately grown fetuses in the early third trimester: an observational cohort study. *J Matern Fetal Neonatal Med.* 2023;36(1):2152670.
 25. Winchester ML, McCarther N, Cancino D, Fitzgerald S, Parrish M. Second trimester cerebroplacental ratio versus umbilicocerebral ratio for the prediction of adverse perinatal outcomes. *J Matern Fetal Neonatal Med.* 2022;35(25):7929-35.
 26. Irvine KM, Bligh LN, Kumar S. Association between the fetal cerebroplacental ratio and biomarkers of hypoxia and angiogenesis in the maternal circulation at term. *Eur J Obstet Gynecol Reprod Biol.* 2020;245:198-204.