Thieme

Value of Cerebroplacental Ratio in Predicting Adverse Perinatal Outcome in Term Pregnancies Complicated by Obesity

Vorhersagekraft der zerebroplazentaren Ratio zur Prädiktion des perinatalen Outcomes bei adipösen Schwangeren am Termin

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ABSTRACT

Objectives
To evaluate the performance of cerebroplacental ratio (CPR) in predicting composite adverse perinatal outcome (CAPO) in women with obesity compared to non-obese women at term.

Methods
This is a retrospective cohort study in a single tertiary referral centre over a 3-year period. All singleton pregnancies with CPR measurements ≥ 37 + 0 weeks and estimated fetal weight ≥ 10th centile and attempted vaginal delivery were included and divided into two groups defined by pre-pregnancy body mass index (BMI) </≥ 30 kg/m^2. The presence of at least one of the following outcome parameters was defined as CAPO: operative delivery (OD) due to intrapartum fetal compromise (IFC), admission to the neonatal intensive care unit, umbilical cord arterial pH ≤ 7.15, 5 min Apgar < 7. The prognostic performance of CPR MoM was evaluated using receiver operating characteristic (ROC) analysis.

Results
The study cohort included 1207 pregnancies, of which 112 were women with a BMI ≥ 30 kg/m^2. In obese women, CAPO occurred in 21 cases (18.8%) compared to 247 (22.6%) cases in women with BMI < 30 kg/m^2 (p = 0.404). In the entire study cohort, CPR MoM was significantly lower in the CAPO and OD for IFC group. ROC analyses revealed a significant predictive value of low CPR MoM for CAPO in obese women (AUC = 0.64, p = 0.024). Furthermore, CPR was predictive for OD for IFC not only in obese (AUC = 0.72, p = 0.023) but also in non-obese (AUC = 0.61, p = 0.003) women.

Conclusions
Low CPR MoM was predictive for CAPO and OD for IFC in obese women without additional risk factors. However, the overall predictive performance of CPR for CAPO in obese women was poor.

ZUSAMMENFASSUNG

Zielsetzung
Ziel der Studie war es, die Vorhersagekraft der zerebroplazentaren Ratio (CPR) in Bezug auf schlechtes perinatales Outcome (CAPO) bei adipösen Schwangeren in Terminnähe zu beurteilen.

Methoden
Es handelt sich um eine retrospektive monozentrische Kohortenstudie über einen Zeitraum von 3 Jahren in einem Referenzzentrum der Maximalversorgung. Alle Einlingsschwangerschaften mit CPR-Messungen ab 37 + 0 Schwangerschaftswochen, einem fetalen Schätzgewicht ≥ 10. Perzentile und vaginalem Entbindungsversuch wurden gemäß dem mütterlichen Body-Mass-Index (BMI) vor der Schwangerschaft </≥ 30 kg/m^2 in 2 Gruppen aufgeteilt. Das Vorliegen von mindestens einem der nachfolgenden Outcome-Parameter wurde als ein CAPO definiert: operative Entbindung aufgrund intrapartalem fetalen Distress (OD for IFC); Verlegung auf die neonatale Intensivstation; Nabelschnurarterien-pH ≤ 7,15; 5-Minuten-Apgar-Wert < 7. Die prognostische Aussagekraft des CPR-MoM-Wertes wurde mithilfe einer Receiver-Operating-Characteristic-(ROC-)Analyse untersucht.

Ergebnisse
Die Studienpopulation bestand aus 1207 Schwangerschaften; davon hatten 112 Frauen einen BMI ≥ 30 kg/m^2. In der Gruppe der übergewichtigen Frauen trat ein CAPO in 21 Fällen auf (18,8 %), verglichen mit 247 (22,6 %) Fällen in der Gruppe der Frauen mit einem BMI < 30 kg/m^2 (p = 0,404). In der gesamten Studienpopulation war der CPR-MoM-Wert signifikant niedriger in der CAPO- und OD-for-IFC-Gruppe. Die ROC-Analysen ergaben einen signifikanten Zusammenhang zwischen CPR MoM und CAPO bei adipösen Schwangeren (AUC = 0,64, p = 0,024). Außerdem ließ sich mittels CPR MoM auch ein OD for IFC nicht nur bei adipösen (AUC = 0,72, p = 0,023), sondern auch bei nicht adipösen Schwangeren (AUC = 0,061, p = 0,003) vorhersagen.

Schlussfolgerungen
Ein niedriges CPR MoM sagt CAPO und OD for IFC bei adipösen Schwangeren ohne weitere Risikofaktoren vorher. Jedoch war die Vorhersagekraft der CPR für CAPO bei adipösen Schwangeren niedrig.

Introduction

Identification of pregnancies at risk for adverse perinatal outcome (APO) remains a major clinical challenge. Although fetuses that are small for gestational age (SGA) are at higher risk for neonatal morbidity, most cases affect appropriate for gestational age (AGA) fetuses [1]. The cerebroplacental ratio (CPR) takes into account changes in the pulsatility index (PI) of the fetal middle cerebral artery (MCA) and the umbilical artery (UA). It reflects placental dysfunction (PD) leading to a cerebral redistribution in fetal circulation ("brain-sparing") [2]. Large prospective studies have shown that low CPR not only predicts APO in SGA but also in AGA fetuses [3, 4]. This makes it a promising candidate for implementation into clinical practice even in a low-risk population. Systematic meta-analyses reported an association between low CPR and APO in low-risk term pregnancies, although its predictive value was low [5, 6]. Furthermore, the optimal CPR cut-off value in defining "low" remains unclear (< 5th centile, < 10th centile, < 20th centile, < 1.1) and the optimal gestational age at CPR measurement regarding the time of delivery must be considered as well [5, 6]. Of note, low CPR has been proven to predict operative delivery for intrapartum fetal compromise (OD for IFC), but the heterogeneity of available data prevents clinical recommendations based on CPR at this stage [7]. Recently, the RATIO37-Trial has provided evidence that considering CPR in clinical decision making about planned delivery at term can reduce neonatal morbidity, especially neonatal neurological morbidity, compared to fetal growth assessment alone [8].

Obesity is a global increasing health problem. Within the European Union, the percentage of obese women varies between countries, with an overall rate of 16.3 % in 2019 [9]. When pregnant, obese women are at higher risk of pregnancy complications like gestational diabetes or preeclampsia (PE) [10, 11]. Importantly, neonatal outcomes worsen with increasing maternal BMI, leading to increased risk for stillbirth, prematurity and neonatal death [12]. Notably, maternal obesity also increases the risk for fetal growth restriction (FGR) [13]. Considering the rates of PE and FGR, this points towards a PD in obesity, possibly mediated by changes in the metabolic profile [14, 15]. Doppler studies demonstrated changes in fetal and uterine artery Doppler parameters depending on maternal BMI [15, 16, 17], which emphasizes the impact of maternal obesity on fetomaternal hemodynamics. Given the significance of maternal BMI as a risk factor for APO and PD, we sought to examine the performance of CPR for APO prediction in obese women at term.

Methods

Study protocol

This is a retrospective, single-centre cohort study. Singleton pregnancies with cephalic presentation in the period of 01/2021–12/2023 were screened and included if maternal BMI was known and UA PI and MCA PI were recorded ≥ 37 + 0 weeks of gestation. In our centre, UA PI and MCA PI are routinely measured during every ultrasound examination unless it is impossible due to maternal

contractions or low position of the fetal head. Obesity was defined as a BMI ≥ 30 kg/m^2 according to the WHO classification and routine clinical use [12, 18]. Only cases with a primary vaginal delivery attempt were included. We excluded cases with elective cesarean delivery (CD) since a significant influence on the perinatal outcome can be assumed in cases with inapparent PD and attempted vaginal birth, knowing that uterine contractions during labour and the subsequent compression of the uterine arteries physiologically reduce uteroplacental perfusion by up to 60 % [19].

In addition, we excluded pregnancies with evidence of chromosomal or morphological fetal anomalies, maternal age > 40 years, smoking, and other fetomaternal conditions with possible effects on fetomaternal hemodynamics such as hypertensive disorders of pregnancy (blood pressure > 140/90 in two independent measurements [20]), intrahepatic cholestasis of pregnancy (fasting serum bile acids > 10µmol/l) [21], SGA (estimated fetal weight (EFW) < 10th centile [22, 23]) or endocrine disorders (e.g. diabetes mellitus type 1). All term pregnancies including those with suspected large for gestational age (LGA) fetuses (EFW > 90th centile [22]) were monitored and treated following the recommendations of national guidelines [24]. Induction of labour was discussed with obese women from 39 weeks of gestation according to national guidelines [25].

Fetal Doppler examinations were performed using a Voluson E10 and E8 (GE Medical Systems, Solingen, NRW, Germany) with a 2–8 MHz convex probe, including UA PI and MCA PI. Doppler measurements were performed by trained operators of our division of prenatal diagnostics and obstetrics following the recommendations of the International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) and national guidelines [26, 27]. CPR was calculated as MCA-PI/UA-PI and defined as pathological when it was < 5th centile [28]. In case of more than one Doppler examination, the closest examination to delivery was included.

The presence of at least one of the following APO parameters was defined as composite APO (CAPO):

- Emergency operative delivery (OD) due to intrapartum fetal compromise (IFC).
- Admission to the neonatal intensive care unit (NICU).
- Umbilical cord arterial pH ≤ 7.15.
- 5 min Apgar < 7.

The diagnosis of IFC was made based on abnormal fetal heart rate (FHR) patterns and/or pH value ≤ 7.20 of fetal blood sampling (scalp). Abnormal FHR was defined as pathological cardiotocography (CTG) according to the International Federation of Gynecology and Obstetrics (FIGO) criteria [29]. OD was defined as cesarean section or operative vaginal delivery.

Analyzed data

Recorded variables included maternal age, BMI, parity, ethnicity, gestational diabetes, GA at ultrasound, EFW, EFW centile, UA PI, MCA PI, CPR, induction of labour, use of oxytocin, gestational age (GA) at delivery, mode of delivery, birth weight (BW), BW centile, Apgar score at 5 minutes, UA pH, NICU admission.

Statistical analysis

IBM SPSS Statistics (Version 29.0) was used for statistical analysis. Data are presented as median (interquartile range) or absolute and relative frequencies. Differences in the distributions of quantitative variables between groups were tested using the Mann–Whitney U test. Categorical data were compared between groups using Pearson's chi-square test or Fisher's exact test. All statistical tests were conducted two-sided, and a p value < 0.05 was considered statistically significant. The study cohort was divided into two groups according to maternal BMI (< 30 kg/m^2 and ≥ 30 kg/m^2). CPR values were converted into multiples of the median (MoM), correcting for gestational age using reference ranges [28]. Correlation between CPR MoM and CAPO or OD for IFC was quantified by Spearman's correlation. Multivariable logistic regression analyses were performed using CPR MoM and parity as independent variables with CAPO or OD for IFC as binary outcome. Receiver operating characteristic curves (ROC) analyses were performed to assess the predictive value of CPR MoM with respect to the occurrence of adverse perinatal outcome (APO). Subgroups that excluded cases with BW < 10th centile alone or BW < 10th centile and > 90th centile were subsequently analysed.

Ethical approval

The study was approved by our local Institutional Ethic Board (Ethikkommission der Fakultät für Medizin der Technischen Universität München, protocol number 2024–139-S-SB). The study was not registered in a public trial registry.

Results

Study participants and characteristics

This study included 1207 pregnant women with CPR evaluation ≥ 37 + 0 weeks of gestation, of which 112 (9.3 %) were obese. The median BMI was 31.94 kg/m^2 in the obese group and 22.47 kg/m^2 in the non-obese group. In our cohort, obese women were more often multiparous. Expectedly, the obese group showed a higher rate of gestational diabetes. Moreover, induction of labour was more frequent among obese than non-obese women. Baseline characteristics and APO frequencies of the study population are displayed in ▶ **Table 1**.

Doppler parameters and pregnancy outcomes

Regarding Doppler parameters, there were no significant differences between both groups in CPR and CPR MoM values or frequencies of CPR < 5th centile. Furthermore, there were no significant differences in use of oxytocin, GA at delivery, mode of delivery, fetal sex or BW > 90th centile. Likewise, the rates of CAPO and single APO criteria did not differ between non-obese and obese pregnant women (▶ **Table 1**).

Participant characteristics according to pregnancy outcome

When stratifying for maternal BMI, we observed differences in parity and frequencies of induction of labour and gestational diabetes

▶**Table 1** Study cohort characteristics and frequencies of adverse perinatal outcomes according to maternal BMI </≥ 30 kg/m^2. Data were compared using Mann–Whitney U test, Pearson's chi-square test or Fisher's exact test and a p value < 0.05 was considered statistically significant.

		BMI < 30 kg/m^2 (n = 1095)	BMI ≥ 30 kg/m^2 (n = 112)	p value
Maternal age		32.5 (29.2–35.4)	32.0 (27.7–35.2)	0.172
Maternal BMI (kg/m²)		22.47 (20.42–24.74)	31.94 (30.58–34.67)	**< 0.001**
Nulliparous		609 (55.6%)	42 (37.5%)	**< 0.001**
Ethnicity	Caucasian	793 (72.4%)	61 (54.5%)	**< 0.001**
	Non-Caucasian	302 (27.6%)	51 (45.5%)	
Gestational diabetes	No diabetes	963 (87.9%)	78 (69.6%)	**< 0.001**
	Gestational diabetes (diet)	78 (7.1%)	12 (10.7%)	
	Gestational diabetes (insulin)	54 (4.9%)	22 (19.6%)	
GA at ultrasound (weeks)		40.0 (38.7–40.6)	39.5 (38.3–40.3)	**0.009**
CPR to delivery (days)		2 (1–5)	3 (1–8)	**0.003**
EFW (g)		3467 (3244–3741)	3531 (3326–3795)	0.148
CPR		1.75 (1.48–2.06)	1.79 (1.53–2.09)	0.288
CPR MoM		1.01 (0.86–1.19)	1.04 (0.87–1.18)	0.579
CPR < 5 th centile		42 (3.8%)	2 (1.8%)	0.424
Induction of labour		430 (39.3%)	60 (53.6%)	**0.003**
Use of oxytocin		498 (45.5%)	43 (38.4%)	0.151
Mode of delivery	Spontaneous vaginal delivery	818 (74.7%)	85 (75.9%)	0.312
	Vaginal operative delivery	83 (7.6%)	4 (3.6%)	
	Secondary cesarean section	185 (16.9%)	23 (20.5%)	
	Emergency cesarean section	9 (0.8%)	0 (0%)	
GA at delivery		40.3 (39.4–41.0)	40.1 (39.5–40.9)	0.251
Birthweight (g)		3470 (3220–3760)	3565 (3348–3855)	**0.011**
Birthweight (centile)		44 (22–67)	54 (31–75)	**0.009**
BW < 10 centile		113 (10.3%)	4 (3.6%)	**0.018**
BW > 90 centile		62 (5.7%)	10 (8.9%)	0.204
Apgar 5 min		10 (9–10)	10 (9–10)	0.706
UA pH		7.24 (7.18–7.29)	7.24 (7.19–7.30)	0.325
UA pH ≤ 7.15		171 (15.6%)	13 (11.6%)	0.261
Apgar 5 min < 7		27 (2.5%)	2 (1.8%)	1.000
OD for IFC		79 (7.2%)	7 (6.3%)	0.848
NICU admission		28 (2.6%)	3 (2.7%)	0.761
CAPO		247 (22.6%)	21 (18.8%)	0.404

Data: Median (interquartile range) or n (%)
Abbreviations: BMI = body mass index; BW = birthweight; CAPO = composite adverse perinatal outcome; CPR = cerebroplacental ratio; EFW = estimated fetal weight; GA = gestational age; MoM = multiples of the median; NICU = neonatal intensive care unit; OD for IFC = operative delivery for intrapartum fetal compromise

(▶ **Table 1**). Therefore, in a second step, we stratified the study cohort according to CAPO and OD for IFC to identify potential confounders. Expectedly, in pregnancies with CAPO, CPR MoM was significantly lower, and we observed a higher rate of nulliparity. The same applies to the group of OD for IFC (▶ **Table 2**). Notably, there was a significant inverse correlation of CPR MoM with CAPO and OD for IFC, respectively: The Spearman's correlation coefficient for CPR MoM and CAPO was − 0.065 (p = 0.024) and for CPR MoM and OD for IFC − 0.103 (p < 0.001).

▶**Table 2** Characteristics of the study population according to pregnancy outcome. Top panel: characteristics according to the occurrence of CAPO. Lower panel: characteristics according to the occurrence of OD for IFC. Data were compared using Mann–Whitney U test, Pearson's chi-square test or Fisher's exact test and a p value < 0.05 was considered statistically significant.

				p value
		Non CAPO (n = 939)	**CAPO (n = 268)**	
Maternal BMI (kg/m²)		23.03 (20.62–26.03)	22.59 (20.69–25.27)	0.174
Maternal age		32.55 (29.20–35.48)	32.10 (28.54–35.10)	0.133
Nulliparous		487 (51.9%)	164 (61.2%)	**0.007**
Gestational diabetes	No diabetes	806 (85.8%)	235 (87.7%)	0.542
	Gestational diabetes (diet)	70 (7.5%)	20 (7.5%)	
	Gestational diabetes (insulin)	63 (6.7%)	13 (4.9%)	
Induction of labour		369 (39.3%)	121 (45.1%)	0.085
CPR MoM		1.02 (0.87–1.20)	0.99 (0.84–1.16)	**0.024**
CPR < 5 th centile		32 (3.4%)	12 (4.5%)	0.410
		No OD for IFC (n = 1121)	**OD for IFC (n = 86)**	
Maternal BMI (kg/m²)		22.92 (20.58–25.89)	23.12 (21.26–25.16)	0.784
Maternal age		32.45 (29.03–35.40)	32.66 (29.16–35.39)	0.640
Nulliparous		595 (53.1%)	56 (65.1%)	**0.031**
Gestational diabetes	No diabetes	965 (86.1%)	76 (88.4%)	0.579
	Gestational diabetes (diet)	86 (7.7%)	4 (4.7%)	
	Gestational diabetes (insulin)	70 (6.2%)	6 (7.0%)	
Induction of labour		456 (40.7%)	34 (39.5%)	0.835
CPR MoM		1.02 (0.87–1.20)	0.91 (0.76–1.12)	**< 0.001**
CPR < 5 th centile		37 (3.3%)	7 (8.1%)	**0.021**

Data: Median (interquartile range) or n (%)
Abbreviations: BMI = body mass index; CAPO = composite adverse perinatal outcome; CPR = cerebroplacental ratio; MoM = multiples of the median; OD for IFC = operative delivery for intrapartum fetal compromise

Logistic regression model

Due to the observed differences in parity in the CAPO and OD for IFC groups, we decided to perform multivariable logistic regression analyses. These showed nulliparity but not CPR MoM as independent predictor of CAPO (▶ **Table 3**, upper panel). However, both, CPR MoM and nulliparity were independent predictors of OD for IFC (▶ **Table 3**, lower panel).

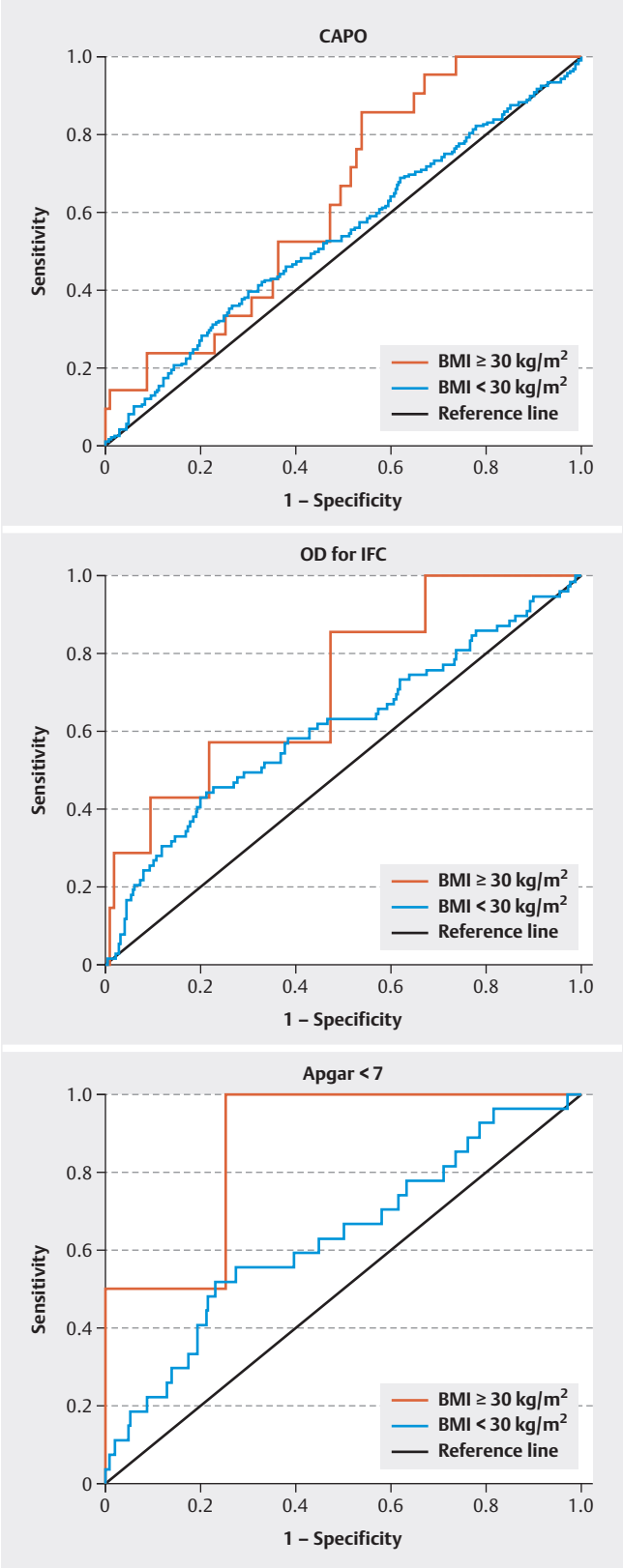
Prediction of adverse perinatal outcomes in obese women

The results of ROC analyses are depicted in ▶ **Fig. 1** and ▶ **Table 4**. They indicated a predictive performance of CPR MoM for CAPO only in the obese group (AUC = 0.635, p = 0.024). In addition, CPR MoM showed a significant association with OD for IFC in both groups (obese: AUC = 0.718, p = 0.023; non-obese: AUC = 0.607, p = 0.003). Although AUC was greater among obese than non-obese women, the AUC difference was not statistically significant (p = 0.276). Moreover, prediction of Apgar < 7 at 5 minutes was also possible in both groups (obese: AUC = 0.873, p < 0.001; non-obese: AUC = 0.631, p = 0.02), but the number of events was com-

▶**Table 3** Multivariable logistic regression analyses of nulliparity and CPR MoM for the prediction of CAPO (top panel) and OD for IFC (lower panel).

	Adjusted OR	95% CI	p value
CAPO			
Nulliparity	1.449	1.098–1.913	**0.009**
CPR MoM	0.669	0.393–1.138	0.138
OD for IFC			
Nulliparity	1.593	1.005–2.526	**0.048**
CPR MoM	0.242	0.093–0.629	**0.004**

Abbreviations: CAPO = composite adverse perinatal outcome; CI = confidence interval; CPR = cerebroplacental ratio; OD for IFC = operative delivery for intrapartum fetal compromise



▶ **Fig. 1** Graphical results of ROC-analyses for the prediction of CAPO (top panel), OD for IFC (middle panel) and Apgar < 7 (lower panel). Corresponding numbers are displayed in ▶ **Table 4**. Red line: BMI ≥ 30 kg/m^2, blue line: BMI < 30 kg/m^2, black line: reference line (AUC = 0.50).

parably small (obese: n = 2 vs. non-obese: n = 27 cases). Subsequent ROC analyses of subgroups stratified by BW revealed decreasing predictive performance of CPR MoM (**Table S1** and **Table S2**, online supplementary materials).

Discussion

This study shows a significant association of CPR MoM with CAPO and OD for IFC in obese women. AUC values were poor for CAPO and acceptable for OD for IFC. In non-obese women, CPR MoM did not predict CAPO but had a significant association with OD for IFC with poor performance, corresponding to previous findings in low-risk women at term [30].

Multiple studies have assessed the association between CPR and adverse perinatal outcomes [7, 30]. We were able to show a similar association between CPR and CAPO/OD for IFC in our study irrespective of maternal BMI.

Yet, the optimal patient population, timepoint, and cut-off values for CPR evaluation in AGA fetuses at term are still discussed [6]. Our results showed that women with a BMI ≥ 30 kg/m^2 may benefit from CPR evaluation at term due to obesity-mediated PD. The placenta of obese women is negatively affected by a variety of metabolic and inflammatory alterations and increased amounts of oxidative stress [31]. Moreover, an accumulation of pathological signs of vascular malperfusion has been shown [32]. Thus, it stands to reason that fetuses from obese mothers are more frequently affected by lower degrees of PD, which do not result in SGA or FGR, but might be identified by CPR evaluation.

In our study, AUC analysis showed higher AUC for CAPO and OD for IFC in obese women, compared to non-obese women, even if the differences were not statistically significant, possibly due to relatively small numbers in the obese group. Despite similar median values of CPR MoM and comparable rates of pathological CPR values < 5th centile in both study groups, the prediction of CAPO was better in obese women. It appears that fetuses with similar CPR MoM from obese mothers tolerate the reduction of uteroplacental perfusion during contractions less well than fetuses from non-obese mothers, which in our setting may improve APO prediction.

It could be argued that sonographic accuracy to identify fetal smallness in obese women is reduced, leading to a bias in our study results. Yet, in our cohort of "low-risk" pregnancies with EFW ≥ 10th centile, there were significantly fewer neonates with a BW < 10 th centile in the obese group.

Subgroup analyses after exclusion of cases in which fetuses were classified as SGA or LGA according to BW showed similar trends compared to the entire study cohort, although the predictive performance declined and was overall poor. It must be noted that the number of cases of CAPO and APO decrease with narrower cohorts, complicating data analysis and interpretation. However, we think excluding cases according to BW does not reflect the everyday clinical situation, in which only EFW is known when assessing CPR.

Surprisingly, in our cohort, obese women had apparently better outcomes compared to non-obese women. This might be due to the inclusion criteria of our study and the close monitoring of

▶**Table 4** Results of ROC-analyses for the entire study cohort. Predictive performance of CPR MoM for the occurrence of CAPO and individual APO parameters according to maternal BMI </≥ 30 kg/m^2. A p value < 0.05 was considered statistically significant.

Outcome and group	AUC	Δ AUC	Std. error	Asymp. Sig.	Lower asymp. 95% CI	Upper asymp. 95% CI
CAPO						
BMI ≥ 30 kg/m²	0.635		0.021	0.024	0.518	0.752
BMI < 30 kg/m²	0.538		0.060	0.072	0.497	0.580
		0.096		0.128	− 0.028	0.221
OD for IFC						
BMI ≥ 30 kg/m²	0.718		0.096	0.023	0.531	0.906
BMI < 30 kg/m²	0.607		0.036	0.003	0.536	0.678
		0.112		0.276	− 0.089	0.312
NICU admission						
BMI ≥ 30 kg/m²	0.685		0.122	0.129	0.446	0.924
BMI < 30 kg/m²	0.474		0.056	0.652	0.364	0.585
		0.211		0.117	− 0.053	0.474
UA-pH ≤ 7,15						
BMI ≥ 30 kg/m²	0.521		0.064	0.749	0.395	0.647
BMI < 30 kg/m²	0.514		0.024	0.571	0.466	0.562
		0.007		0.921	− 0.128	0.142
Apgar 5 min ≤ 7						
BMI ≥ 30 kg/m²	0.873		0.094	< 0.001	0.689	1.056
BMI < 30 kg/m²	0.631		0.057	0.020	0.520	0.742
		0.242		0.027	− 0.109	0.456

Abbreviations: AUC = area under the curve; CAPO = combined adverse perinatal outcome; CI = confidence interval; Δ AUC = difference between the AUCs listed above; NICU = neonatal intensive care unit; OD = for IFC operative delivery for intrapartum fetal compromise; ROC = receiver operating characteristics; UA-pH = umbilical artery pH

obese women in our hospital with the recommendation of labour induction > 39 weeks following national guidelines [24, 25].

There are several limitations of our study. Due to the retrospective character, we could not investigate whether clinical consequences drawn from reduced CPR in obese women would influence CAPO rates or rates of OD for IFC. Furthermore, we included all women with Doppler evaluation ≥ 37 + 0 weeks of gestation independent of the interval between examination and delivery. Although previous studies have investigated different intervals from several hours up to 4 weeks [7], homogeneity concerning the interval or choosing a shorter interval could improve the predictive performance [33]. In addition, cerebral Doppler evaluations have been reported to be observer-dependent [34]. Therefore, a second evaluation to confirm CPR measurements would be of interest, especially if clinical decisions were based on these measurements. Unfortunately, the sample size in the obese group was too small to conduct subgroup analyses based on gestational age at delivery, especially late-term pregnancies. Based on the hypothesis of impaired placental function in obese women and the fact that the rates of OD for IFC increase with gestational age [35], late-term pregnancies of obese women would be of special interest.

Although maternal BMI is routinely recorded in studies evaluating the predictive performance of CPR, to the best of our knowledge, we are the first to explicitly investigate it in a group of obese patients compared to non-obese controls. National and international guidelines state that obese women are to be monitored more carefully, especially in the third trimester [25, 36]. Counselling obese women about pregnancy risks [37] and the necessity and time point of labour induction is our daily routine and will become even more frequent in the future. A better prediction of APO and particularly OD for IFC has great potential to improve patient care and counselling for obese pregnant women. Large multicentre prospective studies are required to elucidate the predictive potential of CPR measurements in pregnancies complicated by maternal obesity.

Supplementary Material

- **Table S1.** Results of ROC-analyses of all cases with birthweight ≥ 10 th centile. Predictive performance of CPR MoM for the occurrence of CAPO and individual APO parameters according to maternal BMI </≥ 30 kg/m^2.
- **Table S2.** Results of ROC-analyses of all cases with birthweight ≥ 10 th centile and ≤ 90 th centile. Predictive performance of CPR MoM for the occurrence of CAPO and individual APO parameters according to maternal BMI </≥ 30 kg/m^2.

Conflict of Interest

The authors declare that they have no conflict of interest.

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