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RESEARCH ARTICLE

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Oxidative stress in preeclampsia: A comparative biomarker analysis across body mass index categories

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ABSTRACT

Background: Preeclampsia is a complex form of prenatal hypertension associated with endothelial dysfunction, systemic inflammation, and oxidative stress. This study aimed to determine the amounts of malondialdehyde, total oxidant status, and oxidative stress index in the blood of pregnant women with preeclampsia and controls, as well as how these parameters varied with body mass index.

Methods: The present study was a case-control study carried out in the Department of Obstetrics and Gynecology, Faculty of Medicine Çanakkale Onsekiz Mart University, Turkiye, from July 2023 to May 2025. The study included 50 pregnant women with preeclampsia and 50 with normotension (control group). They were divided into three groups: normal weight, overweight, and obese, using body mass index. Serum malondialdehyde, total oxidant capacity, total antioxidant capacity, and oxidative stress index levels were measured using validated spectrophotometric techniques. Statistical analyses were performed using SPSS version 25.0, with a significance level of $p<0.05$.

Results: Malondialdehyde, total oxidant capacity, and oxidative stress index levels were significantly higher in the preeclampsia group than in the control group. Compared with the control group, total antioxidant capacity levels were significantly lower, particularly in the obese preeclampsia subgroup ($p<0.05$).

Conclusions: According to this study, preeclamptic women's oxidative stress rose as their body mass index rose. Our study's observed values suggest that they may be applied as prognostic or diagnostic biomarkers for preeclampsia. Our research might help create tailored risk evaluations and focused antioxidant treatments for high-risk pregnancies.

Keywords: body mass index, oxidative stress, preeclampsia

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INTRODUCTION

The characteristics of preeclampsia (PE), a multifactorial hypertensive condition, include proteinuria and new-onset hypertension after 20 weeks of pregnancy. Between 5 and 8% of newborns worldwide are affected with PE, which remains a leading cause of maternal and neonatal illness and mortality [1]. The clinical spectrum includes severe multi-organ involvement, such as renal impairment, fetal growth restriction, and hepatic dysfunction, as well as moderate hypertension. Although endothelial dysfunction and placental insufficiency are acknowledged as key characteristics, the exact processes behind PE are still unknown despite continuous investigation [2].

One of the primary pathophysiological components of PE is oxidative stress (OS), a state in which an excess of reactive oxygen species (ROS) is generated and overwhelms antioxidant defence systems [3]. Mild oxidative stress promotes placental development during a typical pregnancy; in PE, placental ischemia-reperfusion damage is a result of insufficient trophoblast invasion and compromised spiral artery remodeling. Lipid peroxidation, endothelial activation, and systemic inflammation are triggered by the overproduction of ROS that results from this [4-6].

Lipid peroxidation produces malondialdehyde (MDA), which is commonly used to measure oxidative tissue damage. Experimentally, total oxidant status (TOS) and total antioxidant status (TAS) are measured together to give us information about the redox balance of the system. One useful integrative biomarker for pregnancy-related oxidative stress is the oxidative stress index (OSI), which is the TOS/TAS ratio and offers a composite assessment of oxidative burden [7].

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Maternal body mass index (BMI) has become a substantial risk factor for PE, in addition to oxidative imbalance. Obesity can worsen vascular stress during pregnancy because it is linked to persistent low-grade inflammation and increased ROS generation through adipocyte malfunction. In preeclamptic patients, metabolic dysregulation and oxidative stress are strongly correlated, as evidenced by several studies that found a significant correlation between raised BMI and higher levels of MDA and TOS, along with a decrease in TAS [8,9].

Findings about the levels of oxidative stress in preeclampsia are still contradictory, despite mounting data. While some studies have found no discernible alterations, others have shown higher oxidative markers in preeclampsia. Variations in research design, demographic heterogeneity, biomarker selection, and confounding variables like body mass index or comorbidities might all be responsible for these discrepancies [4,5,10,11]. Redox indicators in PE have clinical value, according to recent investigations. Regardless of gestational age, preeclamptic women had significantly higher MDA and TOS levels than normotensive controls, according to a 2022 prospective investigation [9,12]. These markers can identify high-risk individuals early on and offer insight into the underlying pathophysiology of the disease. They could also be connected to how severe the illness is.

Given these considerations, the aim of this study is to evaluate the oxidative and antioxidative states in preeclamptic women by measuring blood levels of MDA, TAS, TOS, and OSI. In order to get a better understanding of the interplay between metabolic state and oxidative load in preeclampsia, it also looks into the link between these indicators and maternal body mass index. Making sense of this relationship might help create predictive biomarkers and enhance obstetric care's early risk assessment methods.

METHODS

Sample characteristics

Our case-control study was conducted in the Department of Obstetrics and Gynecology, Faculty of Medicine Çanakkale Onsekiz Mart University, Turkiye, from July 2023 to May 2025. One hundred pregnant women signed a written consent form for the study; fifty of them were in the normotensive group (control group) and fifty were in the PE group. The Faculty of Medicine Çanakkale Onsekiz Mart University Ethics Committee granted ethical permission for our study (Decision Date and No: July 26, 2023; 2023/10-05), and all procedures were conducted in accordance with the ethical principles outlined in the Helsinki Declaration.

The participants were diagnosed with preeclampsia by a specialist using the PE diagnostic criteria developed by the International Society of Hypertension in Pregnancy (ISSHP) [13]. The study's inclusion criteria were expectant mothers aged 18–45, singleton pregnancies, gestational ages ≥20 weeks, and the lack of pre-existing chronic hypertension, diabetes mellitus, renal, or hepatic disease. Healthy expectant mothers with normotensive pregnancies who were matched for gestational age and number of births made up the control group. Weight in kilograms divided by height in meters squared yields a person's body mass index, or BMI. Participants were split into three groups according to their body mass index in compliance with World Health Organization (WHO) criteria [14]: Normal weight (NW) has a BMI between 18.5 and 24.9 kg/m². If a person's BMI is between 25.0 and 29.9 kg/m2, they are considered overweight (OW). If a person's BMI is 30.0 kg/m2, they are considered obese (OB).

Four milliliters of hemolysis-free venous blood were extracted from each pregnant study participant, allowed to clot, and then centrifuged for 10 minutes at 3000 rpm. The serum samples were stored at -80°C until biochemical assays were performed.

Biochemistry analyses

The MDA, TAS, and TOS measurements related to the study were performed at the laboratory of Health Service Vocational College, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye and at the private laboratory of the company that supplied the kits. MDA, TAS, and TOS levels were measured using branded commercial kits (Rel Assay Diagnostic, Turkey). A spectrophotometer was used to evaluate the MDA, TAS and TOS measurements from the samples based on their absorbance values (Mindray-BS400, Shenzhen Mindray Bio-Medical Electronics Co., Ltd., REL ASSAY-Microplate Reader, Rel Assay Diagnostic, Turkey). Each measurement was performed twice, and analysis was done using the average of the results [15-17].

The following formula was used to determine the oxidative stress index (OSI) [7]:

Trolox equivalents/L (mmol) TOS = OSI (arbitrary units) × 100 (µmol H_2O_2 equivalents/L)

Statistical analysis

Version 26 of IBM SPSS Statistics was used for all analyses. The data distribution was assessed using the Shapiro-Wilk test. The Mann-Whitney U test was utilized for two-group analyses, whereas the Kruskal-Wallis test was utilized for comparisons between BMI categories. Results are expressed as mean ± standard deviation. A *p*-value of less than 0.05 was established as the threshold for statistical significance.

RESULTS

Two groups of one hundred pregnant women who agreed to participate were created. Fifty pregnant women with a diagnosis of PE made up Group 1, and fifty pregnant women in good health (the control group) made up Group 2. Table 1 displays the clinical and demographic characteristics of both groups. Maternal age, BMI, and high-density lipoprotein cholesterol (HDL-C) values did not differ statistically significantly across the groups ($p>0.05$). Systolic and diastolic blood pressure, gestational age, triglycerides (TG), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), MDA, TAS, TOS, and OSI values all differed significantly ($p<0.05$) between the groups, as anticipated (Table 1).

The MDA, TAS, TOS, and OSI mean ± standard deviation (SD) for the PE and control groups, classified by BMI, are shown in Table 2. For all BMI classes (normal weight, overweight, and obese), MDA levels in the PE group were significantly higher than in the control groups ($p<0.05$) (Figure 1). TAS levels were significantly lower in the obese PE group than in the obese control group ($p<0.05$). In the PE group, TOS levels were significantly higher in the normal weight and obese groups than in the control group ($p<0.05$). Remarkably, the OSI values of the PE group's normal weight, overweight, and obese subgroups were significantly higher ($p<0.05$) than those of the corresponding control groups.

DISCUSSION

With further assessment based on BMI classifications, this study examined the oxidative-antioxidative balance in pregnant women with PE in comparison to healthy pregnant women. Our results demonstrated that women with PE had considerably greater levels of oxidative stress, as shown by lower TAS, higher OSI values, and raised levels of MDA and TOS. These results are in line with the increasing amount of data that links the pathophysiology of PE to oxidative stress [10,18,19].

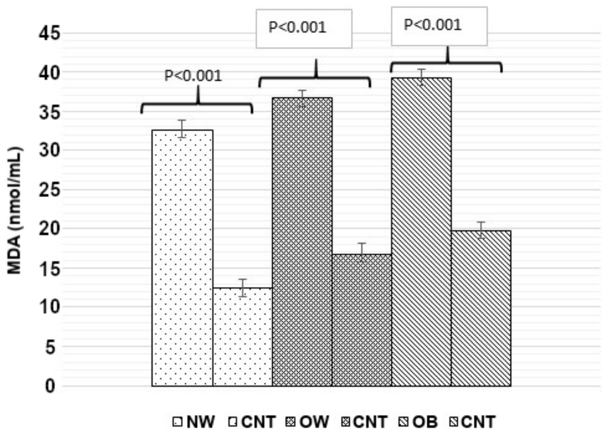

Figure 1. Comparison of malondialdehyde (MDA) levels

Abbreviations: NW – normal weight, OW – overweight, OB – obese, CNT – control.

Table 1. Clinical, metabolic, and oxidative stress parameters of patients with PE and control women

	PE (n=50)	Controls (n=50)	*p* value
Age (mean years ± SD)	31.76 ± 1.63	34.6 ± 1.38	0.07
Pre-pregnancy BMI (kg/m^2)	27.36 ± 1.49	26.80 ± 1.49	0.56
Systolic blood pressure (mmHg)	155.40 ± 8.63	115.26 ± 9.85	0.01
Diastolic blood pressure (mmHg)	98.21 ± 4.68	71.90 ± 3.24	0.01
Gestational age (weeks)	36.14 ± 1.13	39.02 ± 1.29	0.01
Triglyceride (mg/dL)	218.30 ± 1.68	117.80 ± 1.59	0.01
Total cholesterol (mg/dL)	199.84 ± 3.56	174.68 ± 3.59	0.01
HDL-cholesterol (mg/dL)	65.18 ± 1.86	63.76 ± 1.78	0.69
LDL-cholesterol (mg/dL)	124.34 ± 3.29	110.95 ± 3.27	0.04
Malondialdehyde (nmol/mL)	35.31 ± 1.85	15.30 ± 1.63	< 0.001
TAS (mmol Trolox equiv/L)	1.55 ± 0.19	1.68 ± 0.14	< 0.001
TOS (µmol H_2O_2 equiv/L)	98.05 ± 3.37	70.16 ± 3.34	0.01
Oxidative stress index	6.45 ± 0.30	4.51 ± 0.22	< 0.001

Data are presented as mean and standard deviation. Abbreviations: BMI – body mass index, PE – preeclampsia, SD – standard deviation, TAS – total antioxidant status, TOS – total oxidant status.

Table 2. Association of oxidative stress parameters with all PE patients and in groups divided by BMI

	Normal weight			Overweight			Obese		
	PE (n=24)	CNT (n=24)	*p* value	PE (n=14)	CNT (n=15)	*p* value	PE (n=12)	CNT (n=11)	*p* value
MDA (nmol/mL)	32.56 ± 1.35	12.39 ± 1.11	< 0.001	36.62 ± 1.39	16.70 ± 1.01	< 0.001	39.28 ± 1.13	19.74 ± 1.12	< 0.001
TAS (mmol Trolox equiv/L)	1.59 ± 0.10	1.69 ± 0.11	0.17	1.56 ± 0.10	1.67 ± 0.11	0.06	1.53 ± 0.10	1.66 ± 0.11	0.02
TOS (µmol H_2O_2 equiv/L)	94.22 ± 6.50	71.99 ± 6.45	0.04	98.23 ± 6.15	75.99 ± 6.21	0.13	106.61 ± 6.57	77.47 ± 6.53	0.04
OSI	6.27 ± 0.45	4.38 ± 0.47	< 0.001	6.38 ± 0.62	4.61 ± 0.64	0.05	6.90 ± 0.95	4.66 ± 0.92	0.02

Weight categories were defined according to WHO: normal BMI <25 kg/m^2, overweight BMI ≥25 kg/m^2 and <30 kg/m^2, obese BMI ≥ 30 kg/m^2) Abbreviations: BMI – body mass index, CNT – controls, MDA – malondialdehyde, OSI – oxidative stress index, PE – preeclampsia, SD – standard deviation, TAS – total antioxidant status, TOS – total oxidant status.

Abnormal placentation, systemic endothelial dysfunction, and inflammatory activation are all hallmarks of PE, a complex, multifactorial syndrome that is strongly associated with oxidative stress [20,21]. Our PE group's higher MDA levels are a sign of accelerated lipid peroxidation, which happens when the body's antioxidant defences are overpowered by ROS [22]. Numerous studies have demonstrated that preeclamptic pregnancies are associated with considerably higher levels of MDA, one of the most commonly used indicators for oxidative damage to lipids [23,24].

You can find more evidence of a pro-oxidative environment in the PE group's elevated TOS and OSI scores. No matter the BMI category, the PE group consistently showed a higher oxidative stress index, which measures the balance between oxidants and antioxidants. This points to a redox imbalance throughout the system. This finding is especially important because oxidative stress not only worsens the inflammatory and thrombotic responses linked to PE, but also leads to placental ischemia and vascular dysfunction [25].

Obese women with PE had considerably decreased TAS levels, which indicate the total amount of non-enzymatic antioxidants in the plasma. This implies that obesity, a disease already linked to chronic inflammation, elevated oxidative stress, and endothelial dysfunction, further impairs antioxidant defence systems, which are already compromised by the pathophysiology of PE [26,27]. Obesity is a major risk factor for PE, according to several studies, and it may exacerbate oxidative stress by releasing proinflammatory cytokines and adipokines [28].

Crucially, the fact that oxidative stress indicators were also markedly changed in PE patients of normal weight suggests that oxidative imbalance is a key mechanism inherent to the illness and is not only reliant on obesity. Prior studies have shown that hypoxia-reperfusion injury, which sets off excessive ROS production and oxidative damage, might result from poor trophoblast invasion and deficient spiral artery remodeling during early fetal development [29,30].

Our results also highlight the need to classify oxidative stress indicators according to BMI, as the interaction between redox homeostasis and metabolic condition may provide light on PE heterogeneity. Comprehending these interplays might potentially direct customized risk assessment and intervention tactics. Furthermore, OSI's potential use as a trustworthy composite marker for oxidative stress evaluation in obstetric practice is supported by the constant rise of OSI values across all BMI categories in PE [31].

PE is the leading cause of maternal mortality worldwide, ranking second after postpartum hemorrhage, and affects both fetal and maternal health in the short and long term. It has been reported that the likelihood of preeclampsia is significantly lower in individuals who are underweight before pregnancy, while those who are overweight or obese before pregnancy have a higher risk of both preeclampsia and severe preeclampsia [32]. Therefore, it can be concluded that optimal weight management before pregnancy is crucial in reducing the risks associated with preeclampsia. Additionally, oxidative stress levels can be controlled through a healthy diet and a regular lifestyle.

Furthermore, due to the small sample size in each BMI group and the fact that stress, employment status, socioeconomic status, and smoking status were not examined between groups, the results may not be widely applicable. Future longitudinal studies are essential to fully understand if oxidative stress biomarkers might be utilized as early indicators for PE detection and whether antioxidant therapy might be employed in its prevention or treatment.

CONCLUSIONS

This study found that pregnant women with PE had a markedly different oxidative-antioxidative balance than pregnant women with normal blood pressure. A substantial increase in oxidative stress markers, including MDA, TOS, and OSI, and a decrease in TAS levels point to a systemic oxidative burden linked to PE. Although changes were similar for all BMI categories, obese women showed the largest effects, suggesting that obesity may exacerbate redox imbalance.

Our results lend credence to the idea that, regardless of maternal obesity, oxidative stress plays a significant role in the pathophysiology of PE and might be a target for early detection and treatment. BMI stratification shed important light on the relationship between oxidative stress and metabolic state, indicating that tailored strategies might be helpful for PE risk assessment and management.

In light of these findings, oxidative stress indicators, including MDA, TOS, TAS, and OSI, may be used as additional instruments in the clinical assessment of pregnancies at risk for PE. To prove causation, assess predictive value, and investigate if antioxidant-based treatments might lessen the incidence or severity of PE, especially in high-risk groups, further longitudinal and interventional research is necessary.

ABBREVIATIONS

BMI – body mass index

HDL-C – high-density lipoprotein cholesterol

LDL-C – low-density lipoprotein cholesterol

OSI – oxidative stress index

PE – preeclampsia

TAS – total antioxidant status

TC – total cholesterol

TG – triglycerides

TOS – total oxidant status

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AUTHORS' CONTRIBUTION

SC: writing draft, data analysis, data visualization
ESP: writing draft, data analysis, data management
FB: writing draft, data analysis, data visualization

CONFLICT OF INTEREST

None to declare.

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