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Serum Estradiol/Testosterone ratio as a cost-effective biomarker for early prediction of pre-eclampsia in LMIC settings: A prospective cohort study

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Abstract

Background

Pre-eclampsia is a multifactorial pregnancy disorder marked by hypertension and proteinuria after the first trimester, contributing to maternal and fetal morbidity and mortality. Early identification of at-risk women is critical in obstetric care. Disruptions in steroid hormone homeostasis, particularly estradiol and testosterone, may play a role in its pathogenesis. Investigating the estradiol-to-testosterone (E2/T) ratio in early pregnancy may offer a promising biomarker for prediction.

Methods

A prospective cohort study was conducted over one year following ethical approval at the Departments of Obstetrics and Gynaecology and Fetomaternal Medicine, BMU, Dhaka and Islami Bank Hospital, Dhaka. Pregnant women in their first trimester who met inclusion and exclusion criteria were consecutively enrolled. A total of 224 participants were recruited. Data were collected using a semi-structured, pre-tested questionnaire covering sociodemographic details, clinical history, and laboratory investigations. Serum estradiol and testosterone levels were measured in the first trimester using chemiluminescent immunoassays. Participants were followed until delivery for development of pre-eclampsia (PE). Based on outcomes, Group A included women who developed PE, while Group B consisted of those who did not. Statistical analysis was performed using SPSS version 25.0. Continuous variables were summarized using means, medians, and standard deviations, while categorical variables were expressed as frequencies and percentages. Group comparisons used Pearson's chi-square test, Student's t-test, or Mann–Whitney U test. Predictive value of the E2/T ratio was evaluated using ROC curve analysis. A p-value < 0.05 was considered significant.

Results

Of 224 women, 14.7% developed preeclampsia. They had significantly lower estradiol levels (1411.6 ± 823.2 pg/mL) and E2/T ratios (3.6 ± 2.8) compared to non-preeclamptic participants (2043.7 ± 1132.7 pg/mL; 6.0 ± 4.3), with $p = 0.002$ and $p < 0.001$ respectively. ROC analysis showed fair predictive accuracy (AUC = 0.733, 95% CI: 0.640–0.825, $p < 0.001$). A cut-off ≤ 3.92 yielded 78.8% sensitivity, 65.4% specificity, and 94.7% negative predictive value. Women with ratios ≤ 3.92 had a 5.33-fold higher risk (95% CI: 2.42–11.75, $p < 0.001$). Logistic regression confirmed E2/T as an independent predictor (Adjusted OR = 0.73; 95% CI: 0.60–0.89; $p = 0.002$).

Conclusion

The first-trimester E2/T ratio demonstrated significant potential as a predictive biomarker for preeclampsia. An E2/T ratio ≤3.92 was associated with a more than five-fold increased risk, highlighting its value for early risk stratification. This cost-effective hormonal marker could support early prediction and timely intervention.

BACKGROUND

Preeclampsia (PE) is a leading cause of maternal and fetal morbidity and mortality worldwide, affecting 2–10% of pregnancies and contributing to an estimated 70,000 maternal and 500,000 infant deaths annually (1–3). It is defined by the American College of Obstetrics and Gynecology as a multisystem hypertensive disorder of pregnancy, characterized by new-onset hypertension after 20 weeks of gestation with proteinuria or, in its absence, evidence of maternal end-organ dysfunction (4). Severe PE is distinguished by marked hypertension (≥ 160/110 mmHg) or organ damage, while milder forms present without such severity (5). Persistent hypertension in PE can result in renal, hepatic, and pulmonary complications (6).

The underlying pathophysiology involves placental hypoxia, inflammation, and oxidative stress, leading to endothelial dysfunction and reduced uteroplacental perfusion (7). Global incidence varies, with higher prevalence in developing countries (up to 16.7%) compared to developed nations (~ 0.4%) (8). In Bangladesh, cross-sectional studies report a prevalence of 14.4%, with 10% of cases occurring in normotensive women and 5.4% superimposed on chronic hypertension (8). Such regional disparities highlight the urgent need for cost-effective predictive tools.

Traditional predictors—such as maternal age, BMI, blood pressure, and uterine artery Doppler indices—have shown inconsistent predictive accuracy (9). Biomarkers including VEGF, PlGF, PAPP-A, and sFlt-1 have been explored, but their high cost and limited availability restrict widespread use in low-resource settings (10). Recent evidence suggests sex steroid hormones, particularly estradiol (E2) and testosterone (T), may play a role in PE pathogenesis. Estradiol promotes uterine vascular remodeling and angiogenesis, whereas testosterone exerts opposing vascular effects (11, 12). Studies using sensitive assays (LC-MS, GC-MS) consistently report reduced E2 levels in preeclamptic women, while elevated maternal T levels have been linked to impaired placental function and increased PE risk (13–15).

Emerging data indicate that the estradiol-to-testosterone (E2/T) ratio may serve as a reliable early biomarker. Lower E2/T ratios in the first trimester have been associated with higher PE incidence, with significant predictive value demonstrated in recent studies (16). This ratio is simple to calculate from routine hormone assays, making it a cost-effective and accessible tool for early screening in resource-limited settings such as Bangladesh. By identifying high-risk pregnancies early, targeted interventions and closer monitoring could improve maternal and fetal outcomes.

Therefore, this study aims to evaluate the predictive potential of the first-trimester serum E2/T ratio among Bangladeshi women. Establishing this ratio as a reliable biomarker could enhance early detection protocols, reduce the burden of PE, and inform future policy and clinical practice tailored to low-resource healthcare systems.

METHODS

This investigation was designed as a prospective cohort study. The study was conducted in two hospitals - the Department of General Obstetrics and Gynaecology and the Department of Fetomaternal Medicine at Bangladesh Medical University (BMU), Dhaka and Islami Bank Hospital, Dhaka. Data collection spanned a one-year period, from January 2025 to December 2025, following approval from the Institutional Review Board (IRB).

The study population comprised pregnant women attending antenatal care during their first trimester, specifically between 11 and 13 + 6 weeks of gestation. Participants were enrolled only if they met the inclusion criteria and did not fall under the exclusion criteria. A purposive sampling technique was employed to recruit eligible participants. A total of 224 pregnant women were included.

Independent variables included demographic and physical characteristics (age, BMI, educational level, occupation, monthly income), obstetric factors (gestational age at onset of preeclampsia, parity, gravida, complications in previous pregnancy, complications in current pregnancy), and laboratory measures (serum estradiol [E2], serum testosterone [T], and the estradiol-to-testosterone ratio). The dependent variable was the occurrence of preeclampsia.

Women were excluded if they had gestational diabetes, hyperandrogenism, thyroid disorders (hypo- or hyperthyroidism), autoimmune disease, chronic hypertension, connective tissue disease, renal disease, or a history of preeclampsia in a previous pregnancy. Multiple gestations, such as twin pregnancies, were also excluded to ensure homogeneity of the study population.

Serum estradiol and testosterone levels were measured using chemiluminescent immunoassays. The serum E2/T ratio was subsequently calculated, and an optimal cut-off value was determined through receiver operating characteristic (ROC) curve analysis, balancing sensitivity and specificity.

Data was collected using a semi-structured, pre-tested questionnaire developed de novo for this study, covering sociodemographic details, clinical history, and laboratory investigations. The questionnaire was not adapted from any previously published instrument. It was pre-tested on a small sample prior to the main data collection to assess clarity and consistency.

RESULTS

The study aimed to evaluate the role of serum estradiol and testosterone ratio during 11 to 13 weeks of gestation as a predictor of PE. A total of 224 pregnant women were included. Data collected encompassed demographic details, physical and laboratory parameters. The findings obtained from data analysis are documented below.

Table 1 shows the distribution of the study participants according to key sociodemographic characteristics. More than half of the participants belonged to the 26–34 years age group (52.7%), followed by 18–25 years (35.3%), while only 12.1% were aged 35–40 years. Regarding educational status, the largest proportion had completed secondary education (SSC: 31.3%), followed by participants

with education ≥ HSC (22.8%), whereas illiteracy was relatively low (1.3%). In terms of occupation, housewives constituted the majority (50.9%), with a substantial proportion engaged in service-related jobs (31.7%). Most participants reported a monthly household income above 25,000 Tk (59.8%), while only a small fraction earned less than 10,000 Tk (3.1%).

Table 2 summarizes the distribution of physical parameters among the study participants (n = 224). The mean body mass index (BMI) was 24.8 kg/m² (SD 3.9), with a median value of 24.0 kg/m² and an interquartile range (IQR) of 21.8–27.2 kg/m². The mean systolic blood pressure (SBP) was 120 mmHg (SD 14.6), with a median of 120 mmHg and an IQR of 110–130 mmHg. The mean diastolic blood pressure (DBP) was 74.0 mmHg (SD 8.1), with a median of 70 mmHg and an IQR of 70–80 mmHg. Blood pressure measurements were obtained at the time of pre-eclampsia diagnosis.

Table 3 summarizes first-trimester hormonal parameters among participants (n = 224). Mean serum estradiol concentration was 1950.6 pg/mL (SD 1113.9), with a median of 1758.4 pg/mL (IQR 1085.8–2694.1) and a range of 478.0–6175.2 pg/mL. Mean serum testosterone concentration was 404.5 ng/dL (SD 193.1), with a median of 347.6 ng/dL (IQR 280.5–527.0) and a range of 106.0–1148.0 ng/dL. The estradiol:testosterone ratio showed a mean of 5.6 (SD 4.2), median of 4.6 (IQR 3.0–6.9), and ranged from 1.30 to 31.26.

Table 4 illustrates the parity status of the participants in relation to the development of preeclampsia. Among the 33 women who developed preeclampsia, 57.6% were primigravida, while 42.4% were multigravida. In the non-preeclamptic group, 67.0% were primigravida and 33.0% were multigravida. The overall distribution showed that 65.6% of all participants were in their first pregnancy. However, the association between parity and the occurrence of preeclampsia was not statistically significant ($p = 0.292$).

Table 5 shows the comparison of biochemical and hormonal profiles among study participants. Haemoglobin levels did not differ significantly between groups ($p = 0.460$). However, estradiol (E2) levels were notably lower in the PE group, with a mean of 1411.6 ± 823.2 pg/mL and median of 1106.0 pg/mL, compared to 2043.7 ± 1132.7 pg/mL and median 1834.0 pg/mL in the non-PE group ($p = 0.002$). Testosterone (T) levels showed a higher mean in the PE group (442.7 ± 218.3 ng/dL) compared to the non-PE group (397.8 ± 188.2 ng/dL), but this difference was not statistically significant ($p = 0.369$). Importantly, the estradiol-to-testosterone (E2/T) ratio was significantly lower in the PE group (mean 3.6 ± 2.8, median 3.10) than in the non-PE group (mean 6.0 ± 4.3, median 4.85), with a highly significant difference ($p < 0.001$).

Table 6 presents the results of the ROC analysis evaluating the performance of the estradiol to testosterone (E2/T) ratio as a predictive marker for preeclampsia. The area under the curve (AUC) was found to be 0.733, with a 95% confidence interval ranging from 0.640 to 0.825, indicating a fair level of diagnostic accuracy. The result was statistically significant ($p < 0.001$). The optimal cut-off value of the E2/T ratio was determined to be 3.92. At this threshold, the sensitivity was 78.8% and specificity was 65.4%. The positive predictive value (PPV) was 28.3%, whereas the negative predictive value (NPV) was

high at 94.7%. The overall diagnostic accuracy of the E2/T ratio was 67.4%, supporting its potential utility as an early screening tool for preeclampsia in the first trimester.

Table 7 demonstrates a statistically significant association between a lower E2/T ratio (≤ 3.92) and the development of preeclampsia. Among those who developed preeclampsia, 78.8% had an E2/T ratio ≤ 3.92, whereas only 21.2% had a ratio above this threshold. Conversely, the majority of women without preeclampsia (65.4%) had an E2/T ratio > 3.92. The calculated relative risk (RR) for developing preeclampsia in participants with an E2/T ratio ≤ 3.92 was 5.33 (95% CI: 2.42–11.75), indicating they were over five times more likely to develop the condition. This association was statistically significant ($p < 0.001$).

Table 8 presents the results of the logistic regression analysis evaluating factors associated with preeclampsia. The E2/T ratio showed a significant independent association with preeclampsia, with higher values decreasing the odds of developing the condition (Adjusted OR = 0.73; 95% CI: 0.60–0.89; $p = 0.002$). BMI was not significantly related to preeclampsia (Adjusted OR = 0.93; 95% CI: 0.84–1.04; $p = 0.22$). Age demonstrated a borderline association, indicating a slight increase in risk with advancing age, although this did not reach statistical significance (Adjusted OR = 1.08; 95% CI: 1.00–1.17; $p = 0.058$).

This ROC curve illustrates the diagnostic performance of the Estradiol-to-Testosterone (E2/T) ratio in predicting preeclampsia during early pregnancy.The ROC analysis demonstrated fair predictive accuracy with an AUC = 0.733 (95% CI: 0.640–0.825, $p < 0.001$).An optimal cut-off value ≤ 3.92 provided:Sensitivity: 78.8%,Specificity: 65.4%,Negative Predictive Value: 94.7%. Women with E2/T ratios ≤ 3.92 had a 5.33-fold higher risk of developing preeclampsia (95% CI: 2.42–11.75, $p < 0.001$).Logistic regression confirmed the E2/T ratio as an independent predictor, with higher values reducing the odds of preeclampsia (Adjusted OR = 0.73; 95% CI: 0.60–0.89; $p = 0.002$).

DISCUSSION

This prospective cohort study was conducted over 12 months at Bangladesh Medical University, Dhaka and Islami Bank Hospital, Dhaka, to evaluate the predictive value of the serum estradiol-to-testosterone (E2/T) ratio measured in the first trimester for preeclampsia. Pregnant women between 11–13 + 6 weeks were enrolled and followed until delivery. The E2/T ratio was chosen for its role in placental development and vascular remodeling, aiming to establish a cost-effective marker for early screening.

The incidence of preeclampsia (PE) was 14.7%, consistent with South Asian data and higher than the global average of 2–8% (17). A similar prevalence was reported by Sultana et al. (2010) at 16% (18). The tertiary referral nature of the study site likely contributed to higher frequency, as high-risk pregnancies were overrepresented. Early recruitment and structured follow-up ensured accurate case detection, reinforcing the importance of systematic antenatal screening (5).

Parity was not significantly associated with PE ($p = 0.292$), though primigravida women accounted for 57.6% of cases. This aligns with literature identifying nulliparity as a risk factor (19, 20), but the lack of

statistical significance here may reflect sample distribution or confounding factors. Other studies (21) highlight immunological maladaptation in first pregnancies, but our findings suggest parity alone is insufficient as a predictor without biochemical markers.

Hormonal analysis revealed significantly lower estradiol (E2) levels in women who developed PE (1411.6 ± 823.2 pg/mL vs. 2043.7 ± 1132.7 pg/mL; p = 0.002). This supports prior evidence linking suboptimal estrogen to impaired placental vascular development (22, 23). Testosterone (T) levels were higher in the PE group (442.7 ± 218.3 ng/dL vs. 397.8 ± 188.2 ng/dL), but not statistically significant (p = 0.369), echoing findings that androgens alone are not predictive (19).

The most striking result was the E2/T ratio. Women with PE had a significantly lower mean ratio (3.6 ± 2.8) compared to non-PE women (6.0 ± 4.3; p < 0.001). This highlights the ratio as a more sensitive marker of endocrine imbalance than absolute hormone levels, supporting the hypothesis that relative estrogen deficiency disrupts endothelial function and placental perfusion (24, 25).

ROC curve analysis confirmed predictive utility, with an AUC of 0.733 (95% CI: 0.640–0.825; p < 0.001). The optimal cutoff of 3.92 yielded sensitivity of 78.8%, specificity of 65.4%, and a high negative predictive value (94.7%). Although the positive predictive value was modest (28.3%), this reflects the relatively low incidence of PE. Overall accuracy was 67.4%, consistent with other studies (26).

Relative risk analysis showed women with E2/T ≤ 3.92 had a 5.33-fold higher risk of PE (95% CI: 2.42–11.75; p < 0.001). After adjusting for BMI and age, a higher E2/T ratio remained independently protective (adjusted OR = 0.73 per unit increase; 95% CI: 0.60–0.89; p = 0.002). These findings underscore the clinical utility of the E2/T ratio as a feasible early screening biomarker for preeclampsia in Bangladesh.

In summary, the study supports the idea that the estradiol-to-testosterone ratio is a practical and reliable marker for early detection of preeclampsia. It strengthens the link between hormonal imbalance and vascular dysfunction in pregnancy and shows how this knowledge can be applied to improve antenatal care.

Novelty in Bangladesh Context

This is the first prospective cohort study in Bangladesh to validate the estradiol-to-testosterone ratio as a cost-effective biomarker for early prediction of preeclampsia. By integrating hormonal screening into routine antenatal care, it offers a locally relevant, accessible tool to improve maternal outcomes in resource-limited settings.

CONCLUSIONS

This study found a clear link between a lower estradiol-to-testosterone (E2/T) ratio in early pregnancy and the later development of preeclampsia. At a cut-off value of 3.92, the ratio showed good predictive ability, with high sensitivity and strong negative predictive value. Because it can be measured with

standard, affordable assays, the E2/T ratio offers a practical tool for early screening in low- and middle-income countries, helping improve outcomes for mothers and babies.

ABBREVIATIONS

AUC
Area Under the Curve
BMI
Body Mass Index
BMU
Bangladesh Medical University
CI
Confidence Interval
DBP
Diastolic Blood Pressure
E2
Estradiol
E2/T
Estradiol-to-Testosterone ratio
IQR
Interquartile Range
IRB
Institutional Review Board
LMIC
Low- and Middle-Income Country
NPV
Negative Predictive Value
OR
Odds Ratio
PE
Pre-eclampsia
PlGF
Placental Growth Factor
PAPP-A
Pregnancy-Associated Plasma Protein-A
PPV
Positive Predictive Value
ROC
Receiver Operating Characteristic
RR

Relative Risk
SBP
Systolic Blood Pressure
SD
Standard Deviation
sFlt-1
Soluble FMS-like Tyrosine Kinase-1
SPSS
Statistical Package for the Social Sciences
T
Testosterone
VEGF
Vascular Endothelial Growth Factor

DECLARATIONS

Human Ethics and Consent to Participate

This study was approved by the Institutional Review Board (IRB) of Bangladesh Medical University, Dhaka and the authority of the Islami Bank Hospital, Dhaka. Written informed consent to participate was obtained from all study participants prior to enrolment. All procedures were conducted in accordance with the Declaration of Helsinki and applicable institutional guidelines.

For the three illiterate participants, the consent form was read aloud in Bangla by a research team member, and consent was documented by thumbprint in the presence of an impartial witness, in accordance with ICH-GCP E6 guidelines.

Clinical trial number

Not applicable

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

FH, LJH, RR: study conception, design, data interpretation FH & LJH: data collection, laboratory analysis AC & RR: data analysis and manuscript writing All authors read and approved the final manuscript.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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TABLES

Table 1 to 8 available in the Supplementary Files section.

Figures

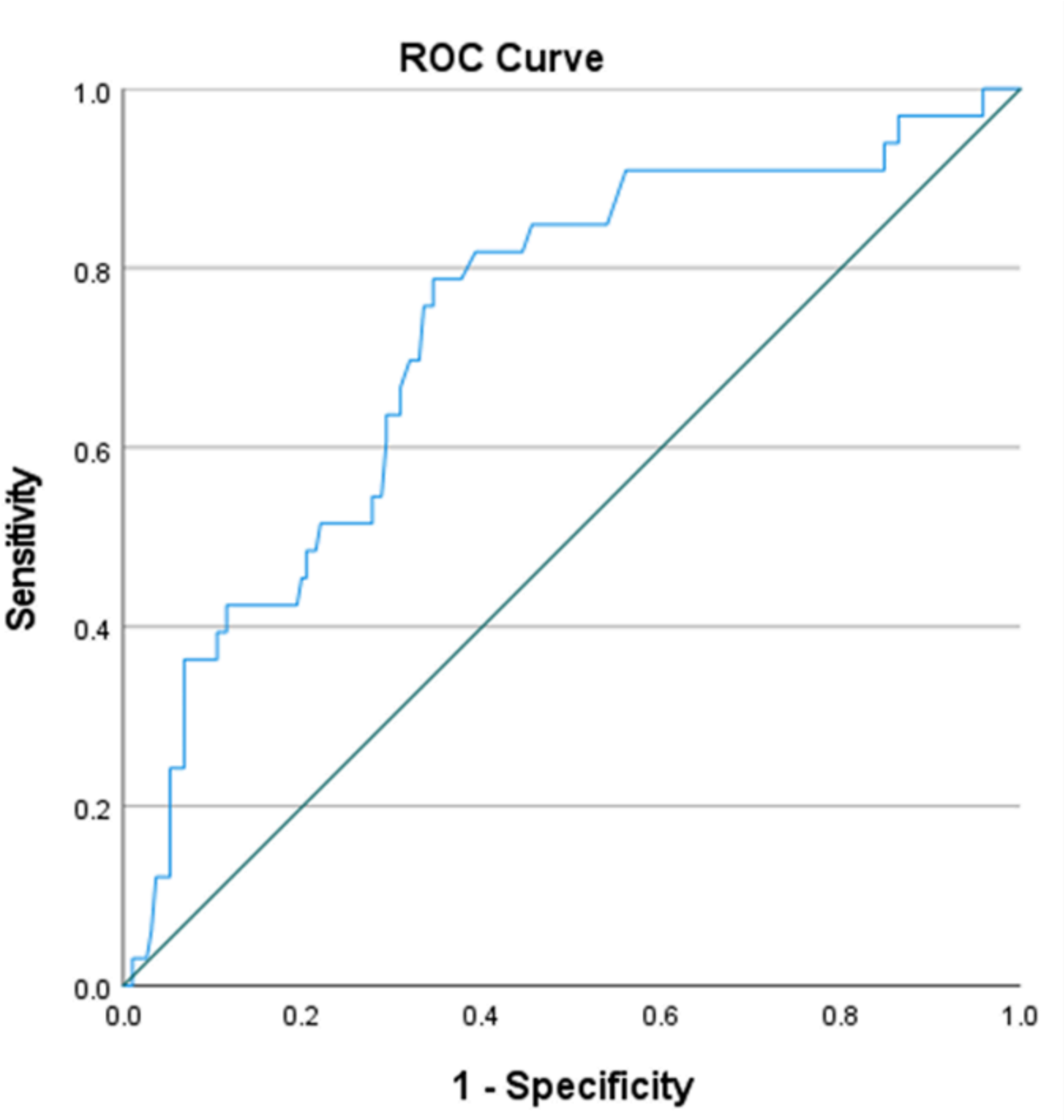


Figure 1

Receiver Operating Characteristic (ROC) Curve of E2/T Ratio for Early Prediction of Preeclampsia

Supplementary Files

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- Screenshot132.png
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