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ORIGINAL RESEARCH

A Cross-Sectional Analysis of Maternal Cardiac Autonomic Function in Kazakh Pregnant Women with Gestational Diabetes

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Introduction: Gestational diabetes mellitus (GDM) is a common complication during pregnancy that poses considerable risks to both maternal and fetal health. However, its effect on cardiac autonomic function, measured by heart rate variability (HRV), remains uncertain. This study aims to investigate potential alterations in cardiac autonomic function in women diagnosed with GDM.

Methods: In this cross-sectional study, 80 Kazakh pregnant women in their third trimester with GDM were enrolled from the endocrinology department of Aktobe Medical Center between January and April 2023. A control group of 30 third-trimester pregnant women without GDM was also selected from outpatient clinics in Aktobe City. HRV was measured with participants in a seated position. A nomogram was developed to predict GDM risk, integrating relevant parameters associated with the condition.

Results: Women with GDM were found to be older than those in the control group (p=0.005), though there were no significant differences in education level, employment status, or parity between the two groups. GDM was associated with larger fetal size (p=0.035) and a higher incidence of miscarriages and abortions (p<0.05) compared to the control group. Additionally, obesity was more prevalent among women with GDM (p<0.05). HRV parameters showed no significant differences between the GDM group and healthy pregnant women. The nomogram demonstrated good predictive accuracy, with an area under the curve of 0.7847 in the training cohort.

Conclusion: The nomogram developed in this study may prove useful for clinicians and patients in making informed clinical decisions and assessing outcomes. Notably, no significant differences in HRV were observed between women with uncomplicated pregnancies and those with GDM.

Keywords: diabetes, gestational, heart rate, Kazakh people, hyperglycemia

Introduction

In recent years, growing attention has been given to forecasting cardiovascular diseases in pregnant women and their unborn children by examining cardiometabolic complications that arise during pregnancy. One prevalent complication is gestational diabetes mellitus (GDM), with a global prevalence of 14%, varying from 7.1% to 26.7% worldwide, influenced by racial and ethnic factors, notably affecting women from Asian regions, including Central Asia.[1–3]

GDM raises the risk of overt maternal diabetes, hypertension, heart disease, and adverse maternal outcomes. Fetuses exposed to maternal hyperglycemia face an increased risk of macrosomia, diabetes, and organ malposition.[4–6] Conversely, chronic hyperglycemia poses a threat by increasing the risk of cardiovascular events due to autonomic diabetic neuropathy. Early detection of autonomic system changes holds promise for managing this condition. A minimally invasive and effective technique for assessing cardiac neuropathy is heart rate variability (HRV).[7] HRV

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involves monitoring changes in the intervals between heartbeats (RR or NN) and measures the fluctuations between successive heartbeats. Diminished HRV parameters are indicative of heightened cardiovascular risk.[8,9]

Nonetheless, investigating HRV in the context of GDM presents challenges due to the unique physiological state of pregnancy itself.[10] Pregnancy entails psychological and physiological alterations that affect both the central and autonomic nervous systems (ANS).[11] As a result of systemic vasodilation, the body undergoes a series of adaptations regulated by the ANS to meet the physiological demands of pregnancy. One of the early hemodynamic responses includes an increase in circulating blood volume, encompassing both plasma and red blood cells, which rises by 40–45% compared to pre-pregnancy levels.[12] This increase in blood volume, combined with a decrease in vascular resistance, leads to an elevation in heart rate and cardiac output, while maternal blood pressure remains stable These hemodynamic changes ensure adequate blood supply to support fetal growth, driven by increased sympathetic activity and reduced parasympathetic influence.[13] Importantly, pregnant women exhibit distinct HRV changes compared to non-pregnant women, including a gradual decline in HRV parameters toward the end of pregnancy, followed by gradual recovery post-labor.[14,15] Previous studies, primarily conducted during the third trimester, have revealed substantial variations in various HRV parameters between healthy pregnant women and those with GDM, especially during nighttime, postpartum, and post-exercise.[16]

However, a recent extensive review, which analyzed data from 12 studies with a total of 6,656 participants, concluded that while the autonomic nervous system is related to hypertension and fetal growth, it does not have a significant connection to GDM.[17] This study seeks to thoroughly investigate the potential effects of GDM on cardiac autonomic function, as measured by HRV, in pregnant women, with a specific focus on the unique characteristics of this condition within a predominantly Kazakh ethnic population.

Materials and Methods

Study Setting and Population

This cross-sectional study included 80 third-trimester pregnant women diagnosed with GDM at the endocrinology department of Aktobe Medical Center from January to April 2023. All participants were of Kazakh ethnicity. A control group consisting of 30 third-trimester pregnant women without GDM was recruited from outpatient clinics in Aktobe City. The participants' ages ranged from 19 to 44 years.

Sampling Size

A convenience sampling method was employed, consisting of pregnant women who attended the Endocrinology Department of the Medical Center of Aktobe during a four-month period. As a result, 80 women were included in experimental group of the study. For the control group, women were recruited from the city's public health centers, with a total of 30 participants.

Inclusion Criteria

In this study, GDM was diagnosed based on specific criteria: fasting blood glucose levels greater than 5.1 mmol/l but less than 7.0 mmol/l, or oral glucose tolerance test results exceeding 8.5 mmol/l but below 11.1 mmol/l two hours after intake. Participants were excluded if they were younger than 19 or older than 44 years, had chronic illnesses, or were carrying multiple pregnancies.

For the control group, inclusion criteria were restricted to single pregnancies in the third trimester without complications and with no previous history of gestational diabetes. Data on age, BMI, education, employment status, number of pregnancies, previous occurrence of macrosomic fetuses, miscarriages, abortions, and mode of delivery were extracted from medical records.

Blood Pressure Measurement

Blood pressure (BP) was measured using an Omron M2 Basic tonometer (Omron Healthcare Co., Ltd., Japan). Blood pressure measurements were taken in the morning, prior to the ECG recording.

Measurement of HRV Indicators

The following HRV indicators were measured, resampled, and computed using the "Varicard 2.52" equipment (Institute of Introduction of New Medical Technologies of RAMEN LLC, Ryazan, Russia). We utilized time-domain measures, such as the standard deviation of normal-to-normal intervals (SDNN) and the root mean square of successive differences between adjacent RR intervals (RMSSD). Additionally, we analyzed frequency-domain measures, including low-frequency power (LF), high-frequency power (HF), and the ratio of low-frequency to high-frequency power (LF/HF). Measurements were taken with participants in a seated position, and ECG electrodes were placed on the arms and feet. ECG recording was conducted in one of the three standard leads and transmitted in real time via the USB interface. The sampling rate was 2000 hz, and the analog-to-digital converter bit rate was 16 bits.

Blood Parameters

Hemoglobin, platelet counts, red blood cells (RBC), and glycosylated hemoglobin data were obtained from medical history records and outpatient records.

Statistical Analysis

To compare categorical variables between groups, chi-square tests were utilized, with results presented as counts and percentages. The comparison of age between the GDM group and the control group was performed using independent two-sample t-tests. All statistical analyses were conducted with SPSS for Windows version 22 (SPSS Inc., Chicago, Illinois, USA). Group means and standard errors were illustrated in both textual and graphical formats using GraphPad Prism version 9.0 for Windows (GraphPad Software Inc., San Diego, CA, USA).

Receiver Operating Characteristic (ROC) Curve Analysis

We performed Receiver Operating Characteristic (ROC) curve analyses in RStudio to evaluate the discriminatory ability of various heart rate variability (HRV) metrics in predicting gestational diabetes mellitus (GDM). The metrics included: Heart rate (HR, bpm); Mean duration of RR interval (ms); Root mean square of successive differences (RMSSD, ms); Proportion of NN50 (pNN50, %); Standard deviation of NN interval (SDNN, ms); Stress index (SI); Total Power (TP, ms^2); High frequency (HF, ms^2); Low frequency (LF, ms^2); Very low frequency (VLF, ms^2); Ultra-low frequency (ULF, ms^2); Each metric was used as a predictor variable, while GDM status (binary: 1 = GDM, 0 = non-GDM) was the outcome. Using the pROC package in RStudio, ROC curves were plotted for each metric, and the Area Under the Curve (AUC) was calculated to assess the discriminatory performance of each metric.

For each ROC analysis, the optimal cut-off value was identified using the Youden J index ($J = \text{Sensitivity} + \text{Specificity} - 1$), which provides the threshold maximizing the balance between sensitivity and specificity. Sensitivity, specificity, and the corresponding Youden J index were reported for all metrics at their optimal cut-off values.

Model Development and Validation

To develop the model, 70% of participants from both the GDM and control groups were randomly assigned to the training set. Continuous variables were reported as mean ± standard deviation (SD), while categorical variables were analyzed using the chi-square test. Univariate logistic regression analysis was used to identify variables significantly associated with gestational diabetes mellitus in the training group. Predictors with a p-value below 0.05 and those deemed clinically significant were included in multivariate logistic regression models. Stepwise backward selection was applied with an entry criterion of $p<0.1$ and a retention criterion of $p<0.05$.

A nomogram was created to represent the model visually, based on the multivariate logistic regression results, using the rms package in R version 4.0.3. The model's performance was evaluated by assessing discrimination and calibration. Discrimination was measured by the area under the receiver operating characteristic (ROC) curve (AUC), which indicates the model's capacity to differentiate between patients with elevated blood glucose and those without. Calibration was evaluated with the Hosmer-Lemeshow test, where a p-value above 0.05 suggested a good fit.

The remaining 30% of cases were utilized for internal validation. Data analysis, nomogram creation, and AUC calculations were conducted using IBM SPSS Statistics (version 25) and R (version 1.3). A significance level of less than 0.05 was used for all statistical tests.

Results

Demographics and Clinical Characteristics

Data were gathered from 80 pregnant women, divided into two groups: a healthy group (n=30) with an average age of 27.7±6.1 years and a BMI of 22.6±3.7 kg/m², and a GDM group (n=50) with an average age of 33.9±5.7 years and a BMI of 27.6±7.5 kg/m². Significant age differences were noted, with the GDM group being older than the control group (p=0.005; Figure 1a).

There were no significant differences between the groups in terms of education, employment status, or the number of pregnancies (Figure 1b–d). Women with GDM had larger fetuses (p=0.035, Figure 1e) and a higher rate of miscarriages and abortions (p<0.05, Figure 1f) compared to the healthy controls. Furthermore, the prevalence of obesity was greater in the GDM group (p<0.05, Figure 1g). However, no significant differences were found between the groups regarding the type of delivery (Figure 1h).

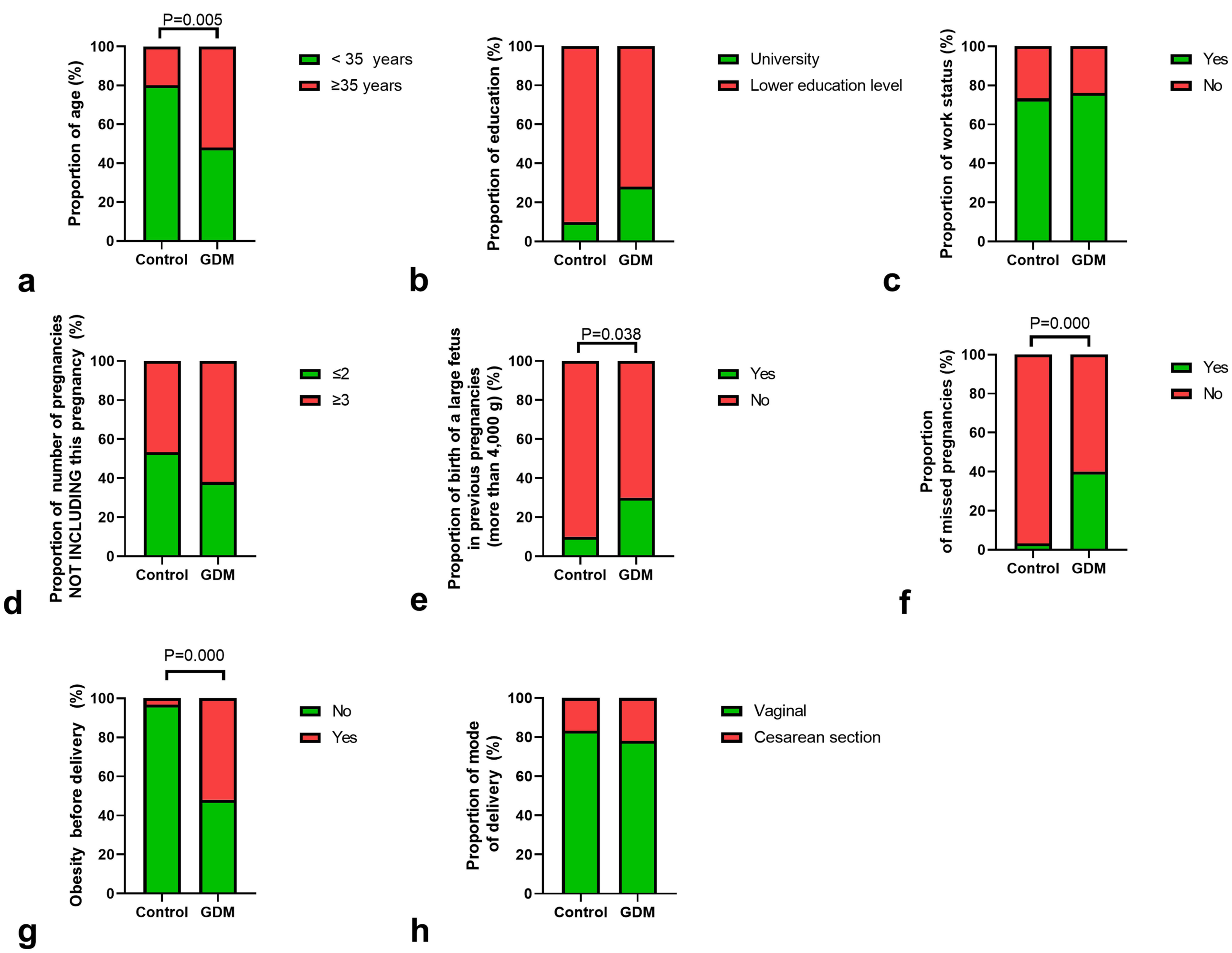

Figure 1 Comparison of demographic characteristics between healthy pregnant women and pregnant women with GDM, including age (**a**), education (**b**), work status (**c**), number of pregnancies, excluding this pregnancy (**d**), previous occurrences of macrosomic fetuses (**e**), missed pregnancies (**f**), obesity (**g**), and mode of delivery (**h**). Lines above the columns show significant differences between columns. Statistically significant differences observed in age (p=0.005), previous occurrences of macrosomic fetuses (p=0.038), missed pregnancies (p=0.000), and obesity (p=0.000).

Heart Rate Variability Parameters

No notable differences were found in heart rate variability parameters (HR, SDNN, RMSSD, pNN50, HF, LF, VLF, SI) between the group of pregnant women with gestational diabetes mellitus (GDM) and the healthy pregnant women (Figure 2a-i).

Receiver Operating Characteristic (ROC) Curve Analysis

The AUC values for the HRV metrics ranged from 0.56 to 0.92, indicating varying levels of discriminatory ability in predicting gestational diabetes mellitus (GDM). The metrics with the highest AUC values were Low Frequency (LF)

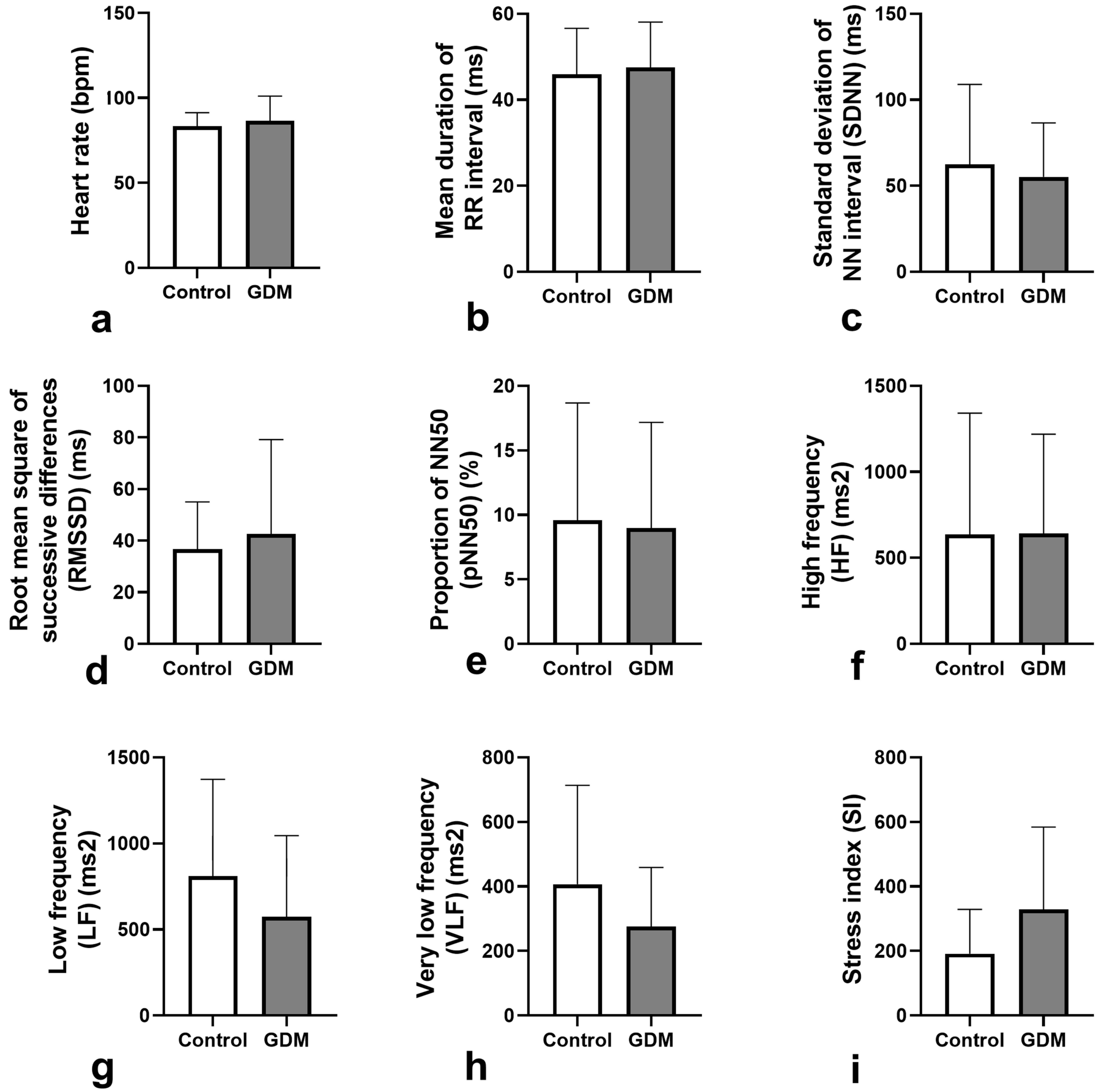

Figure 2 Comparison of average and standard deviation heart rate variability parameters between healthy pregnant women and those with gestational diabetes mellitus (GDM): heart rate (HR) (**a**), mean heart rate (**b**), standard deviation of normal-to-normal intervals (SDNN) (**c**), root mean square of successive differences (RMSSD) (**d**), proportion of NN50 intervals (pNN50) (**e**), low frequency power (LF) (**f**), high frequency power (HF) (**g**), very low frequency power (VLF) (**h**), and stress index (SI) (**i**). No significant differences in these heart rate variability metrics were detected between the two groups ($p < 0.05$).

(0.92), Heart Rate (HR) (0.76), and Stress Index (SI) (0.76), suggesting better predictive performance compared to other HRV indices. The optimal cut-off values, sensitivity, specificity, and Youden J index for each HRV metric are summarized in Table 1. Among the metrics, Low Frequency (LF) demonstrated the highest Youden J index (1.43), indicating a balanced trade-off between sensitivity and specificity. The findings suggest that Low Frequency (LF), Heart Rate (HR), and Stress Index (SI) are the most promising markers for predicting GDM among the HRV indices tested.

Laboratory Parameters

Significant differences were noted in glycosylated hemoglobin (HbA1c) levels ($p<0.05$), which were elevated in individuals with GDM (Figure 3a). However, no significant differences were observed in systolic and diastolic blood pressure between the groups (all $p>0.05$; Figure 3b and c). Similarly, blood counts including hemoglobin, red blood cells (RBC), and platelets showed no significant differences (Figure 3d–f).

Predictors of Gestational Diabetes Mellitus

Univariate logistic regression analysis identified several factors significantly associated with GDM and blood glucose levels within the training group (Table 2). After backward stepwise selection, multivariate analysis highlighted age, previous births of large infants, number of previous miscarriages, obesity, highest glycated hemoglobin level, blood glucose level, highest systolic and diastolic blood pressure during the current pregnancy, lowest RBC count, stress index (SI), low frequency (LF), and very low frequency (VLF) as significant predictors of GDM. Specifically, a high stress index (SI >134.03) was associated with a protective effect, while elevated low-frequency (LF >506.54 ms²) power was also protective. In contrast, very low-frequency (VLF >642.18 ms²) power was associated with a markedly increased risk of GDM. These findings underline the importance of HRV parameters, alongside traditional risk factors, in predicting GDM.

Building the Nomogram Predictive Model in the Training Cohort

Based on the results from the multivariate logistic regression analysis, we created a nomogram model that integrates key risk factors for gestational diabetes mellitus (GDM). These factors include the number of previous miscarriages, BMI, peak glycated hemoglobin levels, systolic and diastolic blood pressure during the current pregnancy, lowest red blood cell count, stress index (SI), low frequency (LF), and very low frequency (VLF), as shown in Figure 4. The total score is calculated by summing the individual scores for each risk factor, with the score for BMI (eg, 13 points for a BMI of 28 kg/m²) derived directly from the regression model coefficients, scaled appropriately for use in the nomogram. The probability of GDM is then estimated by aligning the total score with the corresponding blood glucose level axis.

For example, a female patient with a BMI of 28 kg/m² (13 points), a history of three miscarriages (25 points), a highest glycated hemoglobin level of 5.6% (37 points), systolic blood pressure of 120 mmHg (48 points), diastolic

Table 1 Summary of Receiver Operating Characteristic (ROC) Analysis for Heart Rate Variability (HRV) Metrics in Predicting Gestational Diabetes Mellitus (GDM)

HRV Metric	Optimal Cut-off Value	Sensitivity (%)	Specificity (%)	Youden J Index
Heart Rate (HR, bpm)	89.78	46	83	1.29
Mean RR Interval (ms)	668.27	46	83	1.29
RMSSD (ms)	32.27	60	53	1.13
pNN50 (%)	3.25	52	53	1.05
SDNN (ms)	51.35	62	57	1.19
Stress Index (SI)	134.03	76	53	1.29
Total Power (TP, ms²)	1874.95	64	57	1.21
High Frequency (HF, ms²)	431.82	60	57	1.17
Low Frequency (LF, ms²)	506.54	70	73	1.43
Very Low Frequency (VLF, ms²)	642.18	96	27	1.23
Ultra-Low Frequency (ULF, ms²)	460.57	86	37	1.23

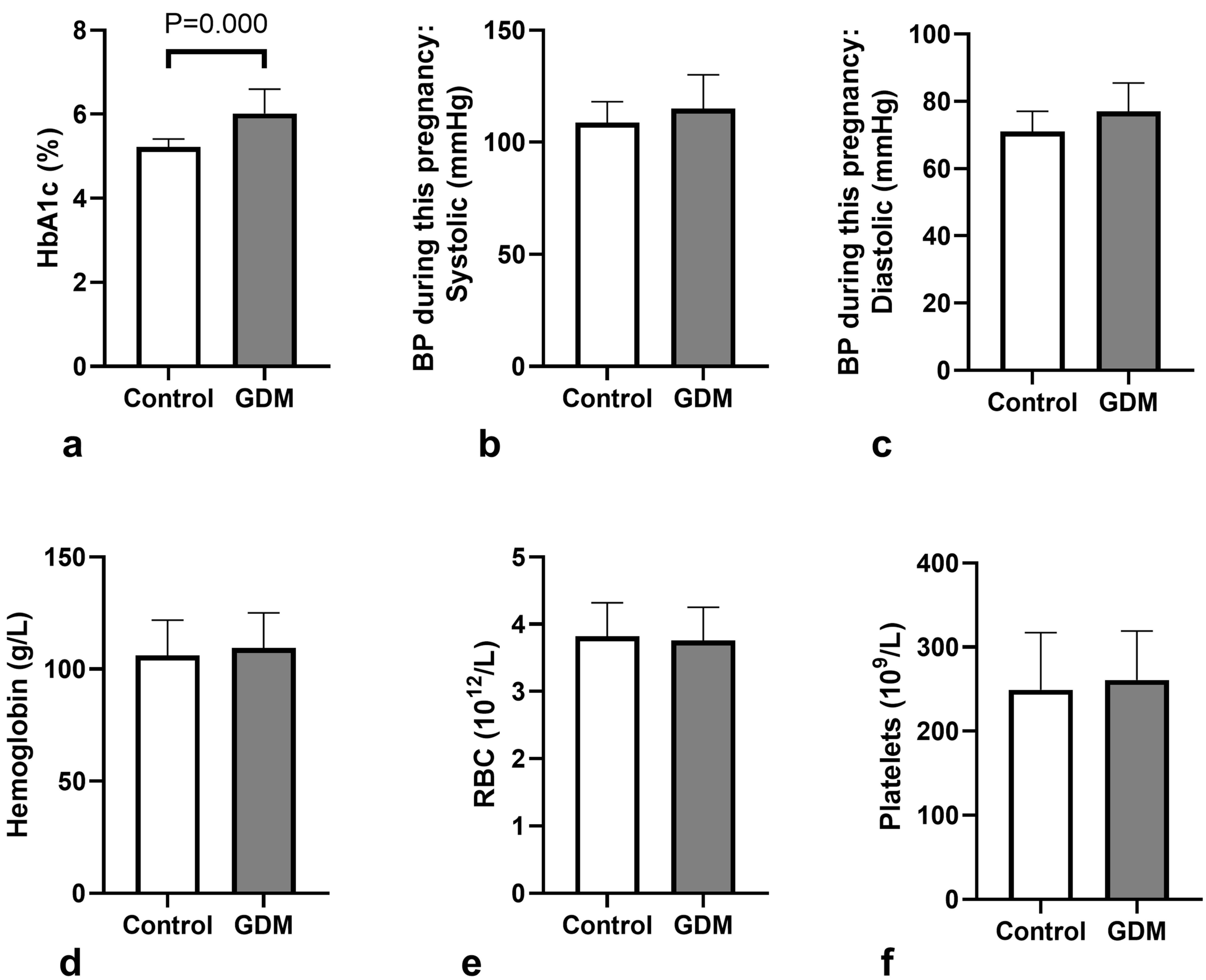

Figure 3 Comparison of mean and standard deviation laboratory parameters between healthy pregnant women and those with gestational diabetes mellitus (GDM), including HbA1c (**a**), systolic (**b**), diastolic blood pressure (**c**), hemoglobin (**d**), RBC (**e**), and platelets (**f**). Line above the columns shows significant differences between columns. HbA1c levels were significantly higher in patients with GDM (p=0.000).

blood pressure of 70 mmHg (28 points), an RBC count of 3.6 × 10^{12}/L (8 points), a stress index (SI) of 600 (12 points), a low frequency (LF) of 1200 ms^2 (12 points), and a very low frequency (VLF) of 200 ms^2 (20 points) would have a total score of 203. This score correlates with an estimated blood glucose level of about 5.25 mmol/L. Such calculated scores can aid in making informed treatment decisions and counseling patients.

Validation of the Predictive Model in the Validation Cohort

To evaluate the performance of the model, we assessed both its discrimination and calibration. Figure 5 illustrates the receiver operating characteristic (ROC) curves, with the model achieving an area under the curve (AUC) of 0.7847 for the training cohorts, indicating its discrimination capability. Calibration was assessed using the Hosmer-Lemeshow test, which resulted in a Hosmer-Lemeshow chi-square statistic of −0.18642 (P = 1).

Discussion

Our study, which examined heart rate variability (HRV) in Kazakh patients with and without gestational diabetes mellitus (GDM), revealed significant differences in specific HRV parameters. Notably, a higher stress index (SI >134.03) and low-frequency (LF >506.54 ms^2) power were associated with a protective effect against GDM, while very low-frequency

Table 2 Odds Ratios for Variables Examined in Univariate Logistic and Linear Regression Models Related to Gestational Diabetes Mellitus (GDM)

Variables	**Odds Ratio (95% Confidence Interval)**	**P-value**
Age		
Before 34 years	Reference	
After 35 years	4.333 (1.512–12.416)	0.006
Education		
Primary; secondary; technical (college)	Reference	
Higher	3.500 (0.914–13.400)	0.680
Birth of a large fetus in previous pregnancies (more than 4000 g)		
No	Reference	-
Yes	3.857 (1.013–14.650)	0.048
Employment		
Does not work	Reference	-
Works	1.152 (0.408–3.249)	0.790
Total number of pregnancies, not including this pregnancy		
≪2	Reference	-
≫3	1.865 (0.745–4.664)	0.183
Number of missed pregnancies		
≪2	Reference	-
≫3	19.333 (2.434–153.552)	0.005
Mode of delivery		
Vaginal	Reference	-
Cesarean section	1.410 (0.438–4.545)	0.565
Obesity		
No	Reference	-
Yes	31.417 (3.967–248.781)	0.001
The highest glycated hemoglobin (%)	2590.579 (83.134–75,291.864)	0.000
Highest blood glucose level (mmol/L)	589.381 (14.248,24,380.522)	0.001
Highest systolic blood pressure during this pregnancy (mmHg)	1.056 (1.012,1.101)	0.012
Highest diastolic blood pressure during this pregnancy (mmHg)	1.116 (1.039,1.199)	0.003
The lowest level of platelets (× 10^9/L)	1.003 (0.996,1.011)	0.422
The lowest level of hemoglobin (g/L)	1.014 (0.985,1.045)	0.346
Lowest red blood cell (RBC) count (× 10^{12}/L)	2590.579 (83.134–75,291.864)	0.000
Heart rate (bpm)		
<89.78	Reference	
>89.78	4.259 (1.404–12.919)	0.010
Mean duration of RR interval (ms)		
<668.27	Reference	
>668.27	4.259 (1.404–12.919)	0.010
Root mean square of successive differences (RMSSD) (ms)		
<32.27	Reference	
>32.27	1.714 (0.688–4.274)	0.248
Proportion of NN50 (pNN50) (%)		
<3.25	Reference	
>3.25	1.238 (0.500–3.066)	0.644
Standard deviation of NN interval (SDNN) (ms)		
<51.35	Reference	
>51.35	0.469 (0.187–1.177)	0.107
Stress index (SI)		
<134.03	Reference	
>134.03	0.276 (0.105–0.727)	0.009

(*Continued*)

Table 2 (Continued).

Variables	Odds Ratio (95% Confidence Interval)	P-value
Total Power (TP) (ms^2)		
<1874.95	Reference	
>1874.95	0.430 (0.171–1.084)	0.074
High frequency (HF) (ms^2)		
<431.82	Reference	
>431.82	0.510 (0.204–1.276))	0.150
Low frequency (LF) (ms^2)		
<506.54	Reference	
>506.54	0.156 (0.057-0.428)	<0.001
Very low frequency (VLF) (ms^2)		
<642.18	Reference	
>642.18	8.727 (1.711–44.525)	0.009
Ultra-low frequency (ULF) (ms^2)		
<460.57	Reference	
>460.57	1.427 (0.398–5.112)	0.585

(VLF >642.18 ms^2) power was linked to an increased risk of GDM. These findings suggest that alterations in autonomic nervous system regulation, reflected in HRV metrics, may contribute to the pathophysiology of GDM.

Previous research into HRV in pregnant women has yielded mixed results, as pregnancy induces substantial autonomic changes to accommodate physiological demands. Some studies report an initial decrease in HRV parameters during the first and second trimesters, followed by an increase in the third trimester.[14] Fehlert observed increased heart rates in mothers with GDM during the third trimester but did not identify significant HRV differences between women with and without GDM.[18] Aguilera similarly found subclinical cardiac changes in both mothers and fetuses during pregnancies complicated by GDM, yet no significant differences were observed in fetal cardiac parameters.[18]

Our findings diverge from earlier studies that reported no significant HRV differences, highlighting the potential utility of HRV metrics such as VLF and LF power in understanding autonomic dysfunction in GDM. While some studies suggest that the autonomic nervous system may adapt differently in GDM compared to uncomplicated pregnancies,[19] others, like recent research in Indian women with GDM at 36 weeks gestation, observed reduced cardio-vagal modulation.[20] These discrepancies may be attributable to differences in study design, patient populations, and timing of assessments. Future research should explore how HRV changes throughout pregnancy and its potential role in early GDM detection and management.

In our cohort of patients with GDM, we observed a significantly higher prevalence of large fetuses, miscarriages, and abortions in their medical history, which is consistent with findings from international studies.[21,22] Additionally, obesity was more common among the pregnant women with GDM compared to the control group, reinforcing the established link between obesity and the incidence of gestational diabetes. Obesity is widely recognized as a major risk factor for developing gestational diabetes.[23,24]

Our study also found higher levels of glycated hemoglobin in blood samples from GDM patients compared to healthy controls. It is important to highlight that the use of glycated hemoglobin as a diagnostic marker for GDM remains debated, largely due to the variability in study outcomes influenced by racial and ethnic differences.[25] Despite this, we considered it valuable to analyze glycated hemoglobin for further investigation. Notably, systolic and diastolic blood pressure levels showed no significant differences between the GDM group and the controls, aligning with findings from similar studies.[26,27] However, a recent meta-analysis emphasized that blood pressure exceeding 135/85 mmHg during early pregnancy was strongly linked to the development of GDM.[28] Furthermore, no significant differences were found between the groups in terms of blood parameters such as hemoglobin, erythrocyte count, and platelet count. However, a study investigating the prognostic value of thrombocrit in GDM patients reported a notable increase in thrombocrit compared to the control group, despite no corresponding rise in platelet count.[29]

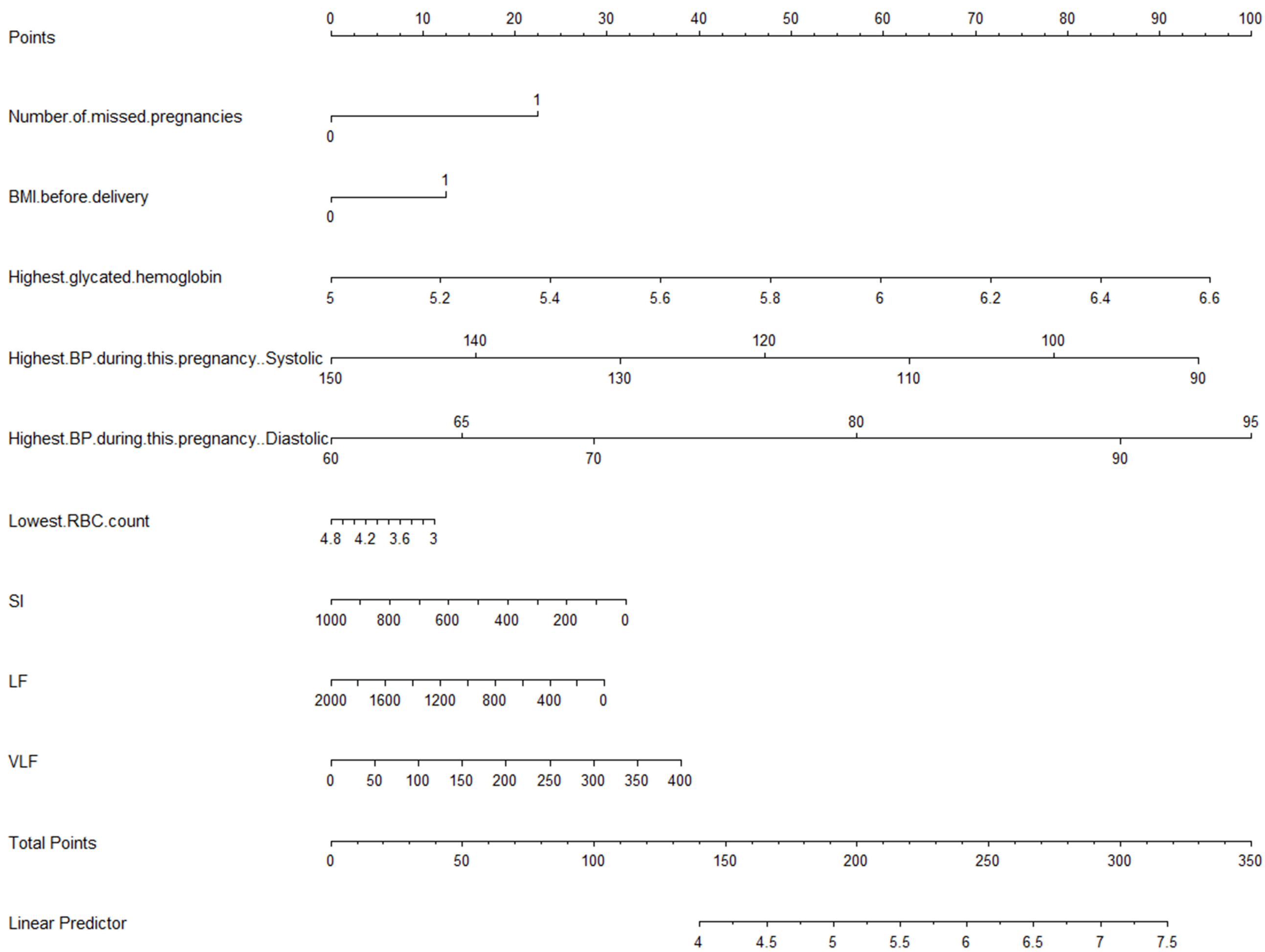

Figure 4 Nomogram for assessing the risk of gestational diabetes mellitus (GDM). This tool uses nine parameters: number of missed pregnancies, BMI before delivery, peak glycated hemoglobin, highest systolic and diastolic blood pressure, lowest red blood cell (RBC) count, stress index (SI), low frequency (LF), and very low frequency (VLF) to predict GDM risk. The differences in patient distribution among subgroups are illustrated by the size of the rectangles.

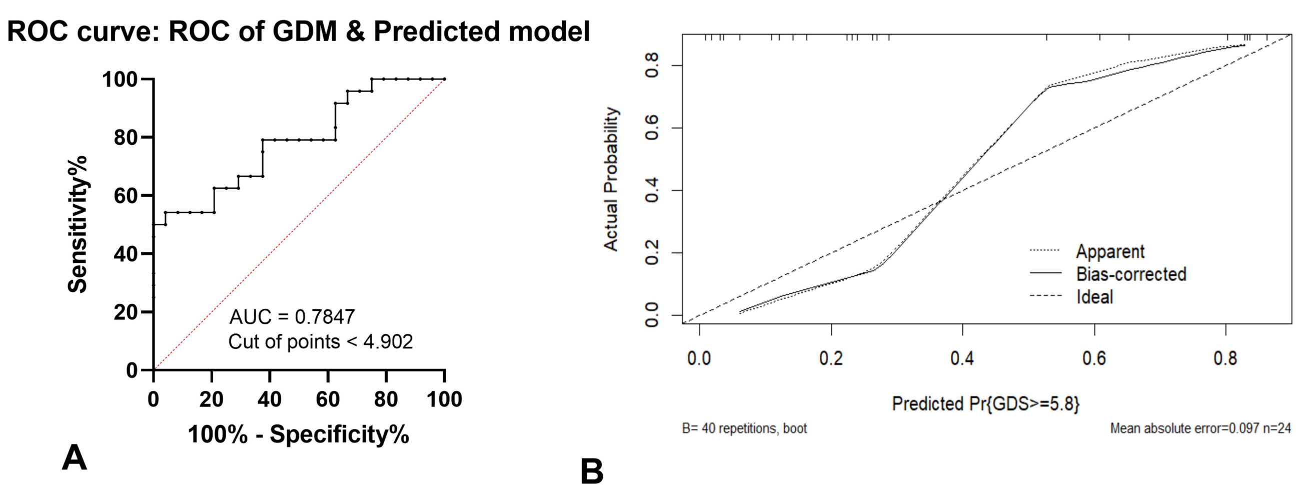

Figure 5 (**A**) Receiver Operating Characteristic (ROC) Curves for GDM Prediction. The ROC curve, along with the AUC value, was used to evaluate the model's ability to discriminate between patients with and without GDM. The AUC of 0.7847 reflects the model's performance. (**B**) Calibration Plots illustrate the alignment between the predicted probabilities of GDM from the nomogram and the actual observed outcomes in the cohort. The y-axis represents the observed cumulative incidence of GDM, while the x-axis shows the predicted probability based on the model. A line close to the ideal line indicates better predictive accuracy. Calibration was further evaluated using the Hosmer-Lemeshow chi-square statistic, which produced a value of −0.18642 (P = 1).

A significant finding was that the group with gestational diabetes had a higher proportion of participants over the age of 35 compared to their healthy counterparts. This finding aligns with a meta-analysis of over 120 million individuals, which showed a strong positive association between the risk of gestational diabetes and advancing maternal age, with the risk increasing linearly. Previous studies have also highlighted that Asian women, starting from age 25, have a significantly higher risk of developing gestational diabetes compared to their Caucasian counterparts.[30,31]

Interestingly, no variations in social factors like education and employment status were found between the two groups. This result is in line with findings from some previous studies.[32,33] However, some research indicates that lower education levels and socioeconomic status may have a modest impact on the likelihood of developing GDM.[34] The limited sample size in our study might have influenced these results.

Interestingly, there were no significant differences between the groups concerning the mode of delivery, as the rates for both vaginal deliveries and cesarean sections were comparable. Existing literature often reports a higher prevalence of cesarean deliveries among women with GDM.[35,36]

In contrast to existing models, our predictive nomogram offers a valuable enhancement to GDM screening strategies. Nevertheless, this study has several limitations. Firstly, the sample size and number of GDM patients were relatively small. Secondly, the data were collected from a single Center, which may not fully represent the broader pregnant population, and there was an unavoidable risk of selection bias. Lastly, the nomogram has not been validated using an external dataset.

Limitation of the Study

The study employed a convenience sampling method, which may introduce selection bias and limit the generalizability of the findings to a broader population of pregnant women with gestational diabetes in Kazakhstan. However, this approach enabled the rapid collection of data from several medical institutions, a crucial factor given the limited time and resources available for the study.

The relatively small sample size, particularly in the control group, may limit the statistical power of the study and the ability to detect significant differences or trends in the data. Despite this, the smaller sample size allowed for a more detailed investigation and better-quality control of the data, which contributed to the accuracy of the analysis and helped minimize potential errors.

The study was conducted at a single medical Center in Aktobe, which may not fully reflect the diversity of medical institutions or populations in other regions of Kazakhstan, potentially affecting the external validity of the results. Nevertheless, the single-Center design enabled a more focused examination of a specific group, ensuring a higher level of quality in data collection and analysis within a unified clinical environment.

Conclusions

Our study offers important insights into heart rate variability, glycated hemoglobin levels, and other key parameters in Kazakh pregnant women with and without gestational diabetes mellitus (GDM). These results enhance the understanding of gestational diabetes and its cardiovascular effects within this particular demographic, highlighting potential directions for future research and clinical applications.

Data Sharing Statement

Data available on request due to ethical restrictions.

Compliance with Ethical Standards

The study was conducted in accordance with Declaration of Helsinki and was approved by the local ethical committee of the Non-Profit Joint-Stock Company "Kazakh National Medical University approved the study. S.D. Asfendiyarov" (Almaty, Kazakhstan), application No. 1121 dated April 28, 2021.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare no conflicts of interest in this work.

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