

OPTIMIZING INDONESIA'S HEALTHCARE RESPONSE TO PREDIABETES: A LONGITUDINAL PERSPECTIVE

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ABSTRACT

Background: Prediabetes is an intermediate stage between normal blood glucose levels and Type 2 diabetes mellitus (T2DM), characterized by elevated blood glucose that does not yet meet the criteria for diabetes. It significantly increases the risk of progressing to T2DM, highlighting the importance of early intervention. In Indonesia, addressing modifiable risk factors is crucial to reducing the prevalence of prediabetes.

Methods: Longitudinal data from 3548 respondents who met the study criteria were taken from the Bogor Cohort Study on NCD Risk Factors. In six observations, Generalized Estimating Equations (GEE) were used to analyze the factors influencing the transition from normoglycemia to prediabetes.

Results: The analysis identified several factors significantly associated with prediabetes risk. Protective factors included maintaining a BMI <25, waist circumference <80 cm (women) or 90 cm (men), regular physical activity (≥10 minutes daily walking/cycling), optimal lipid levels (total cholesterol ≤200 mg/dL; triglycerides ≤150 mg/dL; HDL ≥40 mg/dL [men] or >50 mg/dL [women]), non-sedentary behaviour, and systolic blood pressure <140 mmHg. Conversely, factors like a family history of diabetes and age >40 years significantly increased prediabetes risk.

Conclusion: While non-modifiable factors like age and family history of diabetes increase susceptibility, the study highlights the importance of modifiable lifestyle factors like maintaining BMI and waist circumferences, maintaining optimal lipid levels, controlling blood pressure, and participating in regular physical activity and an active lifestyle in lowering the risk of prediabetes.

Keywords: Prediabetes Risk Factors; Lifestyle; Central obesity; Generalized Estimating Equations

INTRODUCTION

Prediabetes, a transitional phase between normal glucose metabolism and type 2 diabetes mellitus (T2DM), has become a serious public health threat in Indonesia. The data of Riset Kesehatan Dasar (Balitbangkes, 2018) shows that 15.3% of adults in Indonesia are classified as prediabetes, with the highest percentage recorded in urban areas such as Jakarta and Bogor. This condition not only increases the risk of developing type 2 diabetes by 5-10% each year (American Diabetes Association, 2020); but is also associated with cardiovascular complications, kidney disorders, and a decline in economic productivity due to high healthcare costs. In Indonesia, the increase in the

prevalence of prediabetes by 10.6% in the adult population is caused by urbanization. Urban lifestyles, such as high-sugar, low-fibre diets, and lack of movement (sedentary lifestyle), along with obesity incidents supported by specific genetic and sociodemographic factors, are causing the high prevalence of prediabetes. (Balitbangkes, 2018).

Prediabetes is characterized by impaired fasting blood glucose and is a critical phase where, if detected early and lifestyle modifications are made, it can halt the progression of the disease from prediabetes to T2DM. (Balitbangkes, 2018; IDF, 2021; Widiyastuti et al., 2021). The government must prioritize the prevention of prediabetes and T2DM. Primary prevention is aimed at groups

with risk factors and potential to suffer from prediabetes and T2DM. Knowledge about the risk factors for the occurrence of prediabetes is essential for effective prevention and control because the longer it is known, the greater the risk of developing prediabetes. The existing prevention and control efforts are considered less effective.(Indrahadi et al., 2021; Perkeni, 2021).

Most studies on the risk factors for prediabetes and T2DM use cross-sectional data, and there are still few studies that use longitudinal data. This study utilizes longitudinal data from the Bogor Cohort Study on Non-Communicable Disease (NCD) Risk Factor, conducted over 10 years with six measurement points. Using Generalized Estimating Equations (GEE), this longitudinal technique tracks changes in fasting blood glucose (FBG) levels and analyzes risk factors from normal FBG (normoglycemia) to prediabetes. Generalized Estimating Equations (GEE) is an analysis of multivariate, classified, and sequential data, allowing for the measurement of all variables involved in the study. Generalized Estimating Equations (GEE) have become a methodological innovation that addresses the weaknesses of conventional regression models. (Hosseinzadeh et al., 2020).

This research aims to use longitudinal analysis to identify risk factors that are modifiable and non-modifiable in order to stop prediabetes from developing in Indonesia. The development of evidence-based strategies can lead to a more optimal response from the health system when the risk factors have been identified. The results of this study's clinical and sociodemographic variable analysis are intended to inform the development of effective prediabetes preventive measures in line with Indonesia's epidemiological transition, thereby reducing the national burden due to diabetes.

METHODS

This study uses a quantitative design with an observational approach and analyzes longitudinal data, which is data from the same subjects collected at several points in time, allowing for the observation of changes occurring in individuals or groups over a specific period. This study's data comes from the Bogor Cohort Study on Non-Communicable Disease (NCD) Risk Factor, which was conducted over 10 years with 6 measurement points.

The original study included 5,330 participants, with 4,036 (75.74%) completing ≥ 3 measurements. Participants in this study had normal FBG levels at baseline, but increased in subsequent measurements, indicating prediabetes. There were 3548 respondents (88%) who matched the requirements of this study.

The dependent variable of this study is FBG levels, and the independent variables are Body Mass Index (BMI), waist circumference, diabetes family history, physical activity, smoking status & alcohol consumption, blood pressure, lipid levels, stress, and socio-economic factors. The analysis was conducted using the Generalized Estimating Equations (GEE) approach with the SPSS application to identify significant factors affecting the change in FBG level from normoglycemia to prediabetes.

RESULTS AND DISCUSSION

The objective of this study is to examine the risk factors for prediabetes based on FBG levels using longitudinal data from the Bogor Cohort Study on NCD Risk Factor, which was done over 10 years. The longitudinal approach was used to investigate differences in FBG levels at six time periods in individuals at risk of prediabetes, thereby providing new insights or predictions concerning the way changes in

risk factors over time affect FBG levels.(De Gaetano et al., 2024).

One of the novelties in this study is the use of GEE to investigate the influence of risk factors in a complicated and simultaneous manner while considering the interrelationship between risk factors. Generalized Estimating Equations (GEE) is a statistical method for analyzing correlated data where individuals may have different numbers of measurements at different points in time.(Low et al., 2023) The results of the GEE analysis in this study are shown in Table 1.

3.1 Individual Characteristics

3.1.1 Risk factor

The study found that age, education, DM family history, and insurance ownership are risk factors for prediabetes ($p < 0.05$). After controlling for confounding factors, based on previous research, age significantly affects the increased risk of prediabetes, and this is consistent with the study's findings. Previous research revealed that those under 40 easier to lose weight, so they have better glucose metabolism compared to those over 40. (M. Chen et al., 2024) According to another study, the elderly (60-80 years) have a significantly higher risk of prediabetes than the middle-aged (40-59 years) ($p < 0.001$). (Yan et al., 2023)

Individuals with higher education levels mostly have a better understanding of prediabetes and can control their blood glucose levels themselves. Previous research results have found that higher education levels in middle-aged (40-59 years) and elderly (60-80 years) increase the risk of prediabetes and diabetes.(Yan et al., 2023)

Family history is a significant predictor of FBG levels. Previous studies have shown that the average FBG level in the group with a family history of DM is 99.30 mg/dL, significantly higher ($p=0.03$) than the group without a family history (97.55 mg/dL). (Denton & Cedillo, 2023) In line with the results of this study, the FBG levels of individuals without a family history are significantly lower than those with a family history ($p < 0.001$).

The study found a significant relationship between insurance ownership and FBG levels as well as prediabetes status. This is in line with previous studies, which found that insurance holders who have access to blood sugar testing facilities and prescription reimbursements (either partially or totally) are significantly associated ($p=0.04$) with FBG levels. Individuals with insurance have more frequent blood sugar tests, leading to better control (Marvin & Powe, 2023).

Tabel 1. Results of GEE Analysis of Fasting Blood Glucose with Risk Factors

No	Parameter	B	Std. Error	95% Wald Confidence Interval		Wald Chi-Square	Sig.
				Lower	Upper		
1	Male	-0.003	0.0069	-0.017	0.011	0.195	0.659
2	Age < 40*	-0.101	0.0057	-0.112	-0.090	311.571	0.000
3	Marital Status	-0.089	0.0692	-0.224	0.047	1.638	0.201
4	Higher Education*	-0.020	0.0063	-0.033	-0.008	10.078	0.002
5	Has no family history of DM*	-0.039	0.0084	-0.056	-0.023	21.646	0.000
6	Alcohol Free	-0.068	0.0676	-0.201	0.064	1.028	0.311
7	Insurance ownership*	-1.188	0.0716	-1.329	-1.048	275.193	0.000
8	Skor SRQ < 6	-0.003	0.0623	-0.125	0.119	0.002	0.963
9	0 cigarettes	-0.010	0.0185	-0.046	0.026	0.293	0.588
10	Smoking < 200 cigarettes	-0.005	0.0195	-0.043	0.034	0.055	0.815
11	Smoking 200-600 cigarettes	-0.006	0.0189	-0.043	0.031	0.099	0.753
12	Never Smoking	-0.008	0.0063	-0.20	0.005	1.515	0.218
13	BMI $\leq 27^*$	-0.075	0.0068	-0.088	-0.061	119.736	0.000
14	BMI $\leq 25^*$	-0.067	0.0060	-0.078	-0.055	124.502	0.000

No	Parameter	B	Std. Error	95% Wald Confidence Interval		Wald Chi-Square	Sig.
				Lower	Upper		
15	Waist Circumferences < 80 cm/90 cm*	-0.084	0.0058	-0.095	-0.073	208.044	0.000
16	Cholesterol Total ≤ 200 mg/dL*	-0.057	0.0068	-0.071	-0.044	70.096	0.000
17	Triglyceride ≤ 150 mg/dL*	-0.069	0.0091	-0.087	-0.051	56.881	0.000
18	LDL ≤ 100 mg/dL*	-0.019	0.0079	-0.003	0.034	5.613	0.018
19	HDL ≥ 40 mg/dL / 50 mg/dL*	-0.018	0.0062	-0.030	-0.006	8.211	0.004
20	Systolic Blood Pressure < 140 mmHg*	-0.054	0.0100	-0.074	-0.035	29.706	0.000
21	Diastolic Blood Pressure < 90 mmHg*	-0.033	0.0100	-0.053	-0.014	11.209	0.001
22	High-Intensity activity*	-.059	.0104	-.079	-.039	32.146	.000
23	High-Intensity activity > 75 min/ week*	-.043	.0062	-.055	-.031	47.913	.000
24	High-Intensity Exercise	-.034	.0209	-.075	-.007	2.662	0.103
25	High-Intensity Exercise > 75 min/ week	-0.032	0.0269	-0.084	0.021	1.387	0.239
26	Moderate activity*	-0.692	0.1150	-0.918	-0.467	36.236	0.000
27	Moderate activity > 150 min/ week*	-0.475	0.0843	-0.640	-0.309	31.681	0.000
28	Moderate-Intensity Exercise *	-0.115	0.0502	-0.213	-0.017	5.246	0.022
29	Moderate-Intensity Exercise >150 min/week	-0.108	0.0839	-0.272	0.057	1.642	0.200
30	Walking/cycling at least 10 min/day*	-0.049	0.0071	-0.063	-0.035	46.921	0.000
31	Walking/cycling > 150 min/week*	-0.016	0.0069	-0.030	-0.003	5.471	0.019
32	Sedentary < 8 hour/day*	-0.027	0.0059	-0.039	-0.015	20.911	0.000

3.1.2 Not a Risk Factor

The study found that gender, marital status, stress or emotional mental disorders, smoking behaviors, and alcohol consumption are not risk factors for prediabetes ($p>0.05$). In this study, gender was not found to be a risk factor for prediabetes. This contradicts previous studies that state the risk of T2DM increases in women with impaired fasting glucose, but not in males.(Sasaki et al., 2021) Another study explains that males with prediabetes have a testosterone hormone that affects glucose metabolism, but not women.(Leutner et al., 2022) This finding could explain why gender has no effect on prediabetes status in this study.

In this study, marital status was not associated with prediabetes status. This contradicts previous research, which revealed marriage to be an independent risk factor for prediabetes among people aged 20 – 37, mediated by triglyceride (TG) levels. Based on prior studies, young adult couples' eating patterns are at risk of increasing TG levels, which affect blood sugar levels and the risk of prediabetes.(Y.-H. Chen et al., 2024) In this study, other variables have a bigger influence

on FBG levels than marital status, hence, the two are not statistically associated.

This study found no significant association between stress or mental emotional disorder and FBG levels ($p>0.05$). The theory states that stress raises cortisol levels, a glucocorticoid hormone generated by the adrenal glands during the stress response. Cortisol might stimulate gluconeogenesis, inhibit glucose uptake by muscles and adipocytes, and cause insulin resistance, all of which are considered risk factors for prediabetes. Although stress contributes to increased cortisol levels, more evidence is needed to recognize cortisol as the primary cause of prediabetes. The relationship between elevated cortisol levels and glucose metabolism disorder indicates that stress plays an essential role in the development of prediabetes, as well as the possibility of developing T2DM.(Abdulraheem Jabbar & Jalal Majeed, 2020)

This research contradicts previous studies, which showed that low alcohol consumption is associated with a lower risk of T2DM in women, whereas high-risk drinkers have a greater possibility of developing T2DM compared to non-drinkers. (Wu et al., 2021)

Another study found a significant association between alcohol intake and FBG levels, but not with other prediabetes parameters. The relationship between consumption of alcohol and blood sugar levels, as measured by FBG, HbA1c, and other indicators, is inconsistent. (Reed et al., 2025) In this study, respondents' alcohol consumption habits were not associated with the risk of developing prediabetes ($p>0.05$). According to previous research, this could be due to bias and the presence of other more dominant factors. The data on alcohol consumption habits in this study was obtained through respondents' reports, which introduced a high level of bias and resulted in a less accurate analysis. (Wu et al., 2021) Furthermore, FBG levels of respondents can be influenced by the existence or absence of a diabetes family history, as well as their BMI. (Reed et al., 2025).

The smoking habit in this study is not significantly associated with FBG levels ($p>0.05$), which is consistent with previous research that found no meaningful and significant causal relationship between smoking habits and FBG levels, even though smokers' average FBG is 0.003 higher. Many other factors, such as diabetes family history and BMI, influence FBG levels, as well as alcohol consumption. (Reed et al., 2025).

3.2 Obesity status

3.2.1 Body Mass Index (BMI)

According to the study's findings, having a BMI greater than 25 or 27 is strongly connected with an elevated risk of prediabetes ($p=0.000$). Previous research has shown that higher BMI increases the risk of prediabetes and T2DM. (Par et al., 2025; Yan et al., 2023) The increased risk of prediabetes is higher in the group with BMI >30 (OR=2.38, 95% CI=1.96-2.87) compared to the group with BMI > 25 (OR=1.63, 95% CI=1.38-1.93), however, there is a negative correlation for those with underweight (OR=0.19, 95% CI=0.07-0.51). (Par et al., 2025)

3.2.2 Waist Circumferences

In this study, central obesity as measured by waist circumference has a significant association with a higher risk of prediabetes ($p=0.000$). Previous studies have found a strong correlation ($p<0.05$) between increased waist circumference and the risk of prediabetes. A waist circumference increase of $>5\%$ raises the risk of prediabetes in all genders. (Zhen et al., 2022)

3.3 Cholesterol and Blood Pressure

3.3.1 Total Cholesterol, Triglycerides, Low Density Lipoprotein (LDL), High Density Lipoprotein (HDL)

The study found that higher levels of cholesterol, triglycerides, and LDL, as well as lower levels of HDL, increase the risk of prediabetes ($p<0.05$). This is consistent with previous studies showing that high HDL levels are associated with a reduced risk of prediabetes. Another study shows that a high triglyceride-to-HDL ratio (TG/HDL) is associated with an increased risk of prediabetes. As a result, lower HDL levels have triggered the development of prediabetes. (Shimodaira et al., 2024; Tohidi et al., 2023)

The study's LDL level analysis results are consistent with previous research, which found that individuals with higher LDL levels have greater correlations with prediabetes than those with lower LDL levels. According to the study's findings, LDL can be a risk factor in prediabetes. (Ruan et al., 2024)

3.3.2 Blood Pressure

The study revealed that having high systolic and diastolic blood pressure increases the risk of GDP rise ($p<0.001$). Previous research has shown that high systolic blood pressure increases the risk of prediabetes by 45% (OR = 1.45; 95% CI=1.11-1.90; $p<0.05$) compared to normal blood pressure. High diastolic blood pressure increases the risk of prediabetes by 53% (OR=1.53; 95% CI=1.21-1.94; $P<0.05$) compared to those with normal blood pressure. (Zhang et al., 2022)

3.4 Physical Activity & Sedentary Lifestyle

3.4.1 Physical Activity

The study found that moderate to high physical activity significantly reduces the risk of prediabetes ($p < 0.05$). This is consistent with earlier research. Physical activity has a diverse influence on insulin resistance, affecting various pathways implicated in metabolic dysfunction. In addition to anti-inflammatory effects, physical activity improves pancreatic beta cell function and insulin secretion. (Małkowska, 2024)

Another study found that increasing the number of daily steps has a significant impact on lowering fasting plasma glucose levels. (Kalampoki et al., 2025) The previous study result is consistent with the study results, where the habit of walking or cycling for at least 10 minutes per day considerably affects the occurrence of prediabetes ($p = 0.000$).

3.4.2 Exercise

The study's findings indicate that moderate-intensity exercise ($p < 0.05$) has a significant impact on lowering the risk of prediabetes. Previous research has shown that regular exercise improves cellular lipid metabolism, insulin sensitivity, β cell function, and glucose homeostasis. A variety of exercises, including aerobic, weight training, and high-intensity interval training, have been shown to improve beta cell activity and insulin sensitivity. (Małkowska, 2024)

3.4.3 Sedentary Life Style

Sedentary lifestyles or physical inactivity lasting more than 8 hours per day are linked to higher blood sugar levels ($p = 0.000$). Previous research has shown that a sedentary lifestyle causes mitochondrial dysfunction, leading to tissue damage, an increased burden on the pancreatic islets, and insulin resistance. A sedentary lifestyle also impairs glucose metabolism and alters glucose homeostasis. Oxidative stress and inflammation that cause a decrease in antioxidant enzyme activity also occur when individual has a sedentary lifestyle. (Małkowska, 2024).

CONCLUSION

According to the research findings, not all risk factors for prediabetes are modifiable. Modifiable prediabetes risk variables can be utilized to develop policies that improve the effectiveness of Indonesian healthcare services in preventing prediabetes. The prediabetes prevention program should focus on activities that encourage the community to engage in more physical activity and exercise, leading to BMI, waist circumference, lipid profile, and blood pressure that are within reference ranges. Improving facilities for routine health monitoring, such as prediabetes screening, is just as vital as providing public-use sports facilities. Health initiatives promoting a healthy lifestyle are projected to minimize the prevalence of prediabetes and reduce Indonesia's T2DM burden in the future.

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CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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