ORIGINAL ARTICLE

Identifying predictors of worsening glycaemic outcomes in prediabetes: a two-year cohort study in Terengganu, Malaysia

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ABSTRACT

Introduction: Prediabetes is a critical stage preceding diabetes mellitus (DM) which is also associated with an elevated risk of developing DM and related complications. Addressing predictors that influence the progression or regression of glycaemic outcomes in prediabetic individuals can enhance intervention strategies. This study aims to identify key predictors of glycaemic progression among adults with prediabetes in Terengganu, Malaysia.

Materials and Methods: A retrospective cohort study was conducted involving 592 prediabetic adults from 28 health clinics in Terengganu between January 2019 and June 2023. Participants were selected based on oral glucose tolerance test (OGTT) results indicating prediabetes. Sociodemographic, medical background, and clinical data, including body mass index (BMI), blood pressure, fasting blood sugar (FBS), and lipid profiles, were extracted from medical records. Glycaemic outcomes were classified into three categories: reversion to normoglyacemia, persistent prediabetes, or progression to DM, based on glycated haemoglobin (HbA1c) levels taken within two years of follow-up. Ordinal logistic regression analysis was used to identify the significant predictors influencing these outcomes.

Results: Analysis showed age, BMI, underlying dyslipidaemia, FBS, and triglyceride levels as significant predictors of glycaemic progression. Specifically, each additional year of age and each one-unit increase in BMI raised the likelihood of progression to DM by 3% and 6%, respectively. Participants with dyslipidaemia were noted to have a 67% higher risk of worsening glycaemic status, while increases in FBS and triglyceride levels were associated with 65% and 34% greater odds of diabetic progression, respectively.

Conclusion: This study identifies critical predictors of glycaemic outcomes in prediabetic adults, emphasizing the role of age, BMI, dyslipidaemia, FBS, and triglycerides in the disease progression. These findings support the development of targeted interventions that address these risk factors to curb diabetes progression in high-risk individuals, contributing valuable insights into diabetes prevention strategies tailored for Malaysian populations.

KEYWORDS:
Blood glucose, hyperglycaemia, prediabetic state, Diabetes Mellitus, cohort studies, risk factors, logistic models

INTRODUCTION

Diabetes mellitus (DM) ranks among the top ten global causes of mortality, accounting for over 80% of premature deaths associated with other noncommunicable diseases.[1] The incidence of diabetes has risen to epidemic proportions worldwide, especially in low- and middle-income countries.[2] Prediabetes is a state of intermediate hyperglycaemia which has been one of the major contributors to this trend.[3] Diagnosis of prediabetes is either impaired fasting glucose (IFG), and/or impaired glucose tolerance (IGT), or glycated haemoglobin (HbA1c) levels between 5.7% and 6.4%.[4] 25% prediabetes patients progressed to diabetes within three to five years, with lifetime progression rates reaching up to 70%.[5] Prediabetes carries a 10% to 40% higher risk of cardiovascular complications than normal glucose levels.[6,7] Analysis of the Framingham Heart Study found that women with IFG had a 2.5-fold higher risk of coronary heart disease, almost equal to that of women with diabetes.[6] This suggests that the early stages of glucose dysregulation, even before the onset of diabetes, can lead to substantial cardiovascular risk, although the direct causality is remained debatable.[8] Beside, prediabetes significantly increases the risk of early-stage neuropathy and nephropathy, with evidence showing early nerve dysfunction, such as autonomic and sensory neuropathy, as well as kidney damage, including microalbuminuria, even before the onset of diabetes.[5] Therefore, preventing the progression of prediabetes is critical, as it involves multiple organ complications, emphasizing the importance of early intervention to reduce the overall burden of chronic diseases.[5]

The International Diabetes Federation (IDF) reported that the global prevalence of prediabetes increased from 4.4% in 2010 to 15.5% in 2019, with projection to 8.6% of the adult by

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2045.[9] In United State (US), Rooney et al. reported that 9.1% of adults worldwide met the criteria for IGT, with significant regional variations.[3] This growing prevalence highlights the importance of public health interventions, as nearly 40% to 70% of individuals with IFG progress to diabetes without effective prevention strategies. According to the National Health and Morbidity Survey (NHMS), diabetes prevalence among adults increased from 13.4% in 2015 to 15.6% in 2023.[10] In Terengganu, overall diabetes rates surpass the national average, climbing from 18.6% in 2015 to 20.5% in 2019.[11] A local research conducted in Penang further highlights the issue, with 10.1% of adults diagnosed with prediabetes and 19.6% with diabetes.[12] Although conversion rates from prediabetes to diabetes vary across studies and populations, annual progression rates typically ranges between 5% and 10%. Major studies in US and Japan have reported similar trends.[13-15] Meta-analyses indicate that Asians are nearly twice as likely to develop diabetes within five years compared to individuals of European descent.[16] Long-term cohort studies suggest that between 40% and 50% of individuals with prediabetes may remain in a persistent prediabetic state.[17,18]

Several factors are known to influence the transition from prediabetes to diabetes. Age, obesity, and elevated triglyceride levels are associated with increased progression risk, while weight loss and lower systolic blood pressure (BP) promote reversion to normoglycaemia.[18] Additionally, individuals with higher baseline fasting blood sugar (FBS) or HbA1c levels more or equal to 6.0% are more likely to progress to diabetes.[16,17,19] Existing evidence supports the effectiveness of lifestyle interventions and also the use of metformin in prediabetes to reduce the risk of progression to DM.[8,20,21] A study done in the United States concluded that prediabetes contributes significantly to healthcare costs due to the impact of macrovascular comorbid condition and complications as well as productivity loss, requiring substantial resources for long-term management. These findings underscore the financial strain on healthcare systems and emphasize the importance of early screening and interventions to prevent the progression of prediabetes to DM.[22]

Despite the extensive body of international research, there is a significant gap in understanding prediabetes outcomes and predictors within the Malaysian context. Regional studies are limited, especially in semirural states like Terengganu, which have distinct sociodemographic and healthcare characteristics. This lack of localized data makes it challenging to develop targeted interventions that are culturally relevant and context-specific. This study aims to address this knowledge gap by identifying various key predictors of three glycaemic outcomes; reversion to normoglycaemia, persistent prediabetes and progression to DM, focusing on sociodemographic factors, medical background, and clinical indicators within two years follow-up. The two-year window offers a crucial opportunity to detect early trends in progression and reversion, which may shape intervention programs before irreversible metabolic changes occur. The findings from this study will help the development of more effective prevention strategies tailored to the local population to curb the rising burden of diabetes in Malaysia.

MATERIALS AND METHODS

This study is a retrospective cohort study conducted among 705 adults with prediabetes attending 28 health clinics comprising of 15 health clinics in urban and 13 health clinics in rural areas of Terengganu state from January 2019 to June 2023. While this distribution allows for the inclusion of participants from both urban and rural communities, the generalizability of the findings may be limited. Terengganu is a predominantly east-coast state in Malaysia with a unique sociodemographic profile characterized by a higher proportion of rural communities, distinct cultural practices, and healthcare access challenges that differ from more urbanized regions such as Kuala Lumpur.

The largest required sample size was based on smoking predictor using two-proportion formula, with a proportion of progression among former smokers (P0) at 19.4% and among current smokers (P1) at 26.4%.[18] With a significance level of 0.05 and study power of 80%, the required sample size was 586, which increased to 733 to accommodate a potential 20% dropout rate. The inclusion criteria include adults aged 18 and above diagnosed with prediabetes based on abnormal oral glucose tolerance test (OGTT) as per local guideline.[4] The exclusion criteria were a prior diabetes diagnosis, missing HbA1c results during follow up, and defaulted follow-up within two years after diagnosis of prediabetes. No probability sampling was applied due to limited number of eligible patients and high potential of loss to follow up.

Measurement tools

Data were retrieved from the medical records of adult prediabetes patients in the selected health clinics, in which they were tracked over a two-year follow-up period, started from the day of diagnosis made for each participants (Figure 1). The data retrieval was conducted by two trained healthcare professionals who cross-referenced each patient's medical records to ensure consistency in the information gathered and resolve any discrepancies through consensus, ensuring that all data entries were accurate. Data were recorded using a structured proforma to minimize errors and ensure uniformity in documentation.

The dependent variable was identified as the glycemic status during follow-up, and categorised as such; normoglycaemia, persistent prediabetes, or diabetes mellitus. The glycaemic status was determined by latest available HbA1c levels taken at least six months after diagnosis, up to two years of follow-up. Due to varying follow-up schedules during the COVID-19 pandemic, patients did not return for assessments at consistent time intervals, resulting in differences in the timing of HbA1c measurements taken during the follow-up period. Independent variables include sociodemographic information (e.g., age, gender, marital status, employment, smoking status), medical background (e.g., underlying hypertension, underlying dyslipidaemia, and family history of diabetes), and clinical parameters (e.g., weight, body mass index (BMI), OGTT results, cholesterol levels during visit 1, and systolic and diastolic BP at diagnosis (visit 1) as well as during follow-up (visit 2).

Variable definitions

1. Normoglycaemia: Prediabetes patients who reverted to normoglycaemia within two years follow-up based on one repeated HbA1c (equal or less than 5.6%).[4]
2. Persistent prediabetes: Prediabetes who remained at prediabetes state within two years follow up based on repeated HbA1c range from 5.7% to 6.2%.[4]
3. Diabetes mellitus (DM): Those who progressed from prediabetes to DM based on repeated HbA1c of 6.3% or more within two years of follow-up.[4]
4. Family history of DM: Those who have first-degree family history of DM.
5. Smoking status: Those who were recorded as a smoker in the prediabetes record.
6. Underlying hypertension: Those with pre-existing hypertension, with or without anti-hypertensive medication.
7. Underlying dyslipidaemia: Those with pre-existing dyslipidaemia, with or without lipid-lowering agent.
8. Weight: participants' body weight in Kg recorded at diagnosis of prediabetes (visit 1).
9. Body mass index (BMI): BMI kg/m2 recorded at diagnosis of prediabetes (visit 1).
10. Fasting blood sugar (FBS): level of venous blood glucose in fasting state taken at diagnosis (visit 1).
11. 2-hour postprandial (2-HPP): level of venous blood glucose after two hours of taking a standard 75-gram of glucose solution (visit 1).
12. Level of systolic blood pressure (SBP): SBP level in mmHg recorded at diagnosis of prediabetes (visit 1).
13. Level of diastolic blood pressure (DBP): DBP level in mmHg recorded at diagnosis of prediabetes (visit 1).
14. Cholesterol level: total cholesterol, triglycerides, low-density lipoprotein (LDL) cholesterol and High-density lipoprotein (HDL) cholesterol taken at diagnosis (visit 1).

Statistical analysis

Statistical analyses were performed using STATA, focusing on the ordinal logistic regression model. Descriptive statistics were initially applied to provide an overview of the dataset, with further analysis conducted to assess the relationships between prediabetes outcomes and the predictors. The variables used in the analysis were chosen based on univariable analysis with a p-value threshold of <0.25. The significant variables identified were included in the multivariable analysis. The continuous variables were treated as linear after testing for linearity using the multivariable fractional polynomial method. The assumptions for ordinal logistic regression were then assessed, including multicollinearity, interactions, similarity between the proportional model and the unconstrained baseline logit model, and proportional odds assumption. The overall fit of the model was evaluated using the Hosmer-Lemeshow test, Pearson chi-square test, correctly classified percentage, and the area under the receiver operating characteristic (ROC) curve (AUC).

Ethical approval

The present study protocol was reviewed and approved by the Universiti Sultan Zainal Abidin (UniSZA) Research Ethics Committee (approval No. UniSZA/UHREC/2023/523) and Medical Research and Ethics Committee, Ministry of Health Malaysia (NMRR ID-23-00389-BM8)

RESULTS

A total of 592 participants had complete data available for inclusion and were included in the analysis. The reduced sample size was due to missing or incomplete records, which still exceeded the original required sample size of 586, ensuring sufficient power for the analysis. Out of total 592 participants, 25.0% (n=148) reverted to normoglycemia, 59.1% (n=350) remained stable with prediabetes, and 15.9% (n=94) progressed to DM within the two-year follow-up. Majority of participants were female (68.75%), unemployed (69.43%), non-smoker (88.85%), with underlying history of hypertension (83.78%) and dyslipidaemia (81.93%). Median age was 61 years old (IQR=51.5-69.0) as in Table I.

Univariable and multivariate analysis

From the univariable analysis, several variables met the inclusion criteria for the multivariable model (p<0.25), including age, sex, occupation, underlying hypertension, underlying dyslipidemia, FBS, triglyceride level, BMI, systolic blood pressure at visit 2, and DBP at visit 2. These factors were subjected to further multivariable ordinal logistic regression analysis. The results demonstrated that age, BMI, underlying dyslipidemia, FBS level, and triglyceride level were significant independent predictors of diabetes progression (Table II). Controlling for other factors, for each additional year of age, the odds of having a worse glycaemic status (progressed from normoglycaemia to prediabetes or from prediabetes to DM) increase by 3% (OR=1.03, 95% CI=1.01 to 1.05, p=0.003). Individuals with underlying dyslipidemia have 67% higher odds of having a worse glycaemic status (progressed from normoglycaemia to prediabetes or from prediabetes to DM) compared to those without dyslipidemia (OR=1.67, 95% CI=1.05 to 2.63, p=0.03). For each one-unit increase in BMI, the odds of having a worse glycaemic status increase by 6% (OR=1.06, 95% CI=1.03 to 1.10, p< 0.001). For each unit increase in FBS, the odds of having a worse glycaemic status (progressed from normoglycaemia to pre-diabetes or from pre-diabetes to DM) increase by 65% (OR=1.65, 95% CI=1.23 to 2.21, p=0.001). For each one-unit increase in triglyceride levels, the odds of having a worse glycaemic status progressed from normoglycaemia to pre-diabetes or from pre-diabetes to DM) increase by 34% (OR=1.34, 95% CI=1.05 to 1.72, p=0.023).

Model diagnostics and assumptions

The model's assumptions were thoroughly checked. Multicollinearity was assessed using the Variance Inflation Factor (VIF). All variables included in the regression model had VIF values below 5, indicating no significant multicollinearity. The top three highest VIF values were for Age (1.93), sex (1.81), and total cholesterol (1.89), with other variables ranging between 1.05 and 1.92. No clinically significant interaction terms were identified. The proportional odds assumption was satisfied (p=0.501) based on the Brant test of parallel regression assumption, confirming that the relationship between the independent variables and the log odds of progressing to higher levels of the outcome (normoglycaemia to prediabetes, prediabetes to DM) was constant across the levels. The Bayesian Information Criterion (BIC) difference of 62.135 indicated strong support for the saved model, with a p-value of 0.272, confirming no significant difference between the proportional and unconstrained baseline models. The first

Table I: Sociodemographic, medical background and clinical parameters of participants by glycaemic outcomes (n=592)

Characteristics	Normoglycaemia, n=161 n (%)	Prediabetes, n=337 n (%)	Diabetes Mellitus, n=94 n (%)
Age (years)[a]	59 (45-68)	62 (53-69)	62 (54-69)
Sex			
Male	42 (26.09)	110 (32.64)	33 (35.11)
Female	119 (73.91)	227 (67.36)	61 (64.89)
Occupation			
Unemployed	119 (73.91)	228 (67.66)	64 (68.09)
Employed	42 (26.09)	109 (32.34)	30 (31.91)
Smoking status			
Non-smoker	144 (89.44)	301 (89.32)	81 (86.17)
Smoker	17 (10.56)	36 (10.68)	13 (13.83)
Hypertension			
No	33 (20.50)	54 (16.02)	9 (9.57)
Yes	128 (79.50)	283 (83.98)	85 (90.43)
Dyslipidaemia			
No	46 (28.57)	50 (14.84)	11 (11.70)
Yes	115 (71.43)	287 (85.16)	83 (88.30)
Family history of diabetes			
No	100 (62.11)	218 (64.69)	55 (58.51%)
Yes	61 (37.89)	119 (35.31)	39 (41.49%)
BMI[a]	26.5 (23.5-29.4)	27.9 (24.4-31.1)	28.3 (25.7-32.4)
FBS[a]	5.8 (5.3-6.2)	6 (5.6-6.3)	6.2 (5.8-6.4)
2-HPP[a]	8.8 (8.0-9.8)	8.9 (8.0-9.8)	8.6 (7.8-9.8)
Total cholesterol[a]	5.6 (4.7-6.3)	5.3 (4.7-6.3)	5.7 (4.7-6.5)
Triglycerides[a]	1 (0.8-1.4)	1.2 (0.86-1.52)	1.3 (0.91-1.80)
HDL cholesterol[a]	1.49 (1.26-1.75)	1.4 (1.2-1.66)	1.37 (1.2-1.64)
LDL cholesterol[a]	3.46 (2.6-4.2)	3.3 (2.69-4.2)	3.55 (2.8-4.5)
SBP (Visit 1)[a]	137 (126-148)	136 (127-145)	137 (129-146)
DBP (Visit 1)[a]	80 (72-87)	80 (73-86)	81 (73-85)
SBP (Visit 2)[a]	134 (126-142)	134 (126-142)	136 (126-149)
DBP (Visit 2)[a]	78 (73-85)	80 (74-86)	80 (73-85)
HbA1c level (Visit 2)[a]	6.0 (5.7-6.3)	6.1 (5.7-6.3)	6.2 (5.9-6.5)

[a] Data presented in median (interquartile range, IQR)
SBP, systolic blood pressure in mmHg; DBP, diastolic blood pressure in mmHg
BMI, body mass index in Kg/m^2; FBS, fasting blood sugar in mmol/L; 2-HPP, 2-hour postprandial in mmol/L; Total cholesterol, triglycerides, LDL, low density lipoprotein; HDL, high density lipoprotein in mmol/L; HbA1c in mmol/L

model, with outcomes regression to normoglycaemia and persistent prediabetes, showed a Hosmer-Lemeshow p-value of 0.0518 and Pearson chi-square p-value of 0.3687. For the second model, which included outcomes regression to normoglycaemia and progressed DM, the Hosmer-Lemeshow p-value was 0.5059 and, the Pearson chi-square p-value of 0.1042.

Area under the receiver-operating characteristic curve (ROC) curve
The discriminatory power of the model was assessed using the area under the ROC curve. For the first model comparing normoglycaemia to persistent prediabetes, the Area Under the curve (AUC) was 0.6861, indicating acceptable discrimination. The second model, comparing normoglycaemia to DM, showed an AUC of 0.7810, suggesting good discrimination. These results implied that the model performed reasonably well in distinguishing between different stages of diabetes progression (Figure 2).

Final model
The final model included the significant factors of age, BMI, FBS levels, underlying dyslipidaemia, and triglyceride levels. These variables, along with adjusted odds ratios and 95% confidence intervals, are presented in Table II. The model was able to correctly classify 68.3% of the cases for normoglycaemia and persistent prediabetes, and 71.0% for normoglycaemia and progression to DM, confirming its reliability.

DISCUSSION

This study revealed that more than half (59.1%) remained in the prediabetic state, 15.9% progressed to DM, while only 25.0% reverted to normoglycaemia within the two-year follow-up. Similar results were found in previous studies conducted by Shang et al., Bennasar et al. and Wuttisathapornchai et al.[17,18,28] While these prevalence findings provide valuable context, the primary focus of this study is to identify predictors of glycaemic progression among prediabetic adults. Our findings are consistent with previous research, particularly highlighting the significant roles of age, BMI, FBS levels, dyslipidaemia, and triglyceride levels in predicting the progression from prediabetes to DM. The final multivariate model developed in this study further supports these predictors, providing a reliable framework for identifying high-risk individuals who may benefit from early intervention.

Table II: Predictors of prediabetes outcomes (regression to normoglycemia, persistent prediabetes and progression to DM) within a two- year follow-up by ordinal logistic regression

Variables	Crude OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
Sex				
Female	0.75 (0.53, 1.05)	0.097	0.88 (0.57, 1.38)	0.585
Male (Ref)	Ref	-	Ref	-
Age (years)	1.02 (1.01, 1.04)	0.001	1.03 (1.01, 1.04)	0.003
Occupation				
Employed	1.23 (0.88, 1.73)	0.226	1.16 (0.74, 1.82)	0.511
Unemployed (Ref)	Ref	-	Ref	-
Smoking				
Yes	1.19 (0.72, 1.97)	0.499	-	-
No (Ref)	Ref	-	-	-
Underlying Hypertension				
Yes	1.62 (1.06, 2.46)	0.026	0.74 (0.44, 1.22)	0.243
No (Ref)	Ref	-	Ref	-
Underlying dyslipidaemia				
Yes	2.28 (1.51, 3.44)	<0.001	1.67 (1.05, 2.63)	0.028
No (Ref)	Ref	-	Ref	-
Family history DM				
Yes	1.05 (0.75, 1.46)	0.756	-	-
No (Ref)	Ref	-	-	-
BMI	1.06 (1.03, 1.09)	<0.001	1.06 (1.02, 1.11)	<0.001
FBS	1.89 (1.44, 2.49)	<0.001	1.65 (1.22, 2.21)	0.001
2 -HPP	0.96 (0.85-1.07)	0.451		
Total cholesterol	0.99(0.90-1.09)	0.782		
Triglycerides	1.48 (1.17, 1.89)	0.001	1.34 (1.04, 1.72)	0.023
LDL	1.07 (0.94-1.23)	0.310		
HDL	0.94 (0.71-1.23)	0.648		
SBP (Visit 1)a	0.99 (0.98, 1.01)	0.538	-	-
DBP (Visit 1)a	1.00 (0.98, 1.01)	0.618	-	-
SBP (Visit 2)a	1.01 (0.99, 1.03)	0.209	0.99 (0.98, 1.01)	0.387
DBP (Visit 2)a	1.01 (0.99, 1.03)	0.185	1.02 (1.00, 1.04)	0.094

SBP, systolic blood pressure in mmHg; DBP, diastolic blood pressure in mmHg
BMI, body mass index in Kg/m^2; FBS, fasting blood sugar in mmol/L; 2-HPP, 2-hour postprandial in mmol/L; Total cholesterol in mmol/L, triglycerides in mmol/L, LDL, low density lipoprotein in mmol/L; HDL, high density lipoprotein in mmol/L

Our study's findings on the role of age in the progression of prediabetes to DM aligned with previously reported data. DeJesus et al. identified age as an independent predictor of diabetes progression, while Liu et al.[16, 23] further reinforced this by demonstrating a significant difference in age between those who progressed to DM and those who did not in a two-year cohort of 14,231 Chinese participant. These studies emphasized the role of age as a key determinant in the transition from prediabetes to DM in certain populations. However, some studies did not find age as a significant predictor.[18,24,25] For instance, Rooney et al. reported progression to DM among prediabetic adults was uncommon (8%) over a five-year follow-up, with the majority either reverted to normoglycaemia (44%) or passed away (16%).[24] Similarly, Ligthart et al. reported that the lifetime risk of diabetes progression reduced with advancing age.[25] This variation in findings may be explained by the differences in study populations, definitions of prediabetes, follow-up durations, and lifestyle factors, which influence the reported risks of diabetes progression in older adults.

A population-based study conducted over a 12-year follow-up period in older adults in Sweden concluded the importance of BMI and weight changes as key factors influencing the progression of prediabetes.[17] In this study, obesity significantly increased the risk of progressing to DM, while weight loss was associated with a greater likelihood of reverting to normoglycemia. Similarly, in our study, higher BMI is a significant predictor in which for each one-unit increase in BMI, the odds of having worse glycaemic status increase by 6%. This finding is also in line with a few other studies.[8,16,18,19] The strong association between increased body weight and the development of DM can be explained by several physiological mechanisms. Greater adiposity, particularly central obesity, plays a significant role in promoting insulin resistance. The adipocytes release free fatty acids and inflammatory cytokines, which disrupt the insulin signalling pathways leading to worsening hyperglycaemia and accelerating the progression from prediabetes to DM.[26] These consistent findings highlight the critical role of addressing obesity in diabetes prevention strategies, thus reinforces the need for targeted interventions aimed at weight management.

Our study did not find elevated BP or underlying hypertension to be significant predictors of progression to diabetes. This is consistent with the findings of Yeboah et al.[14] who also reported that BP was not significant predictors of diabetes progression. However, a longitudinal study done in China demonstrated that individuals with concurrent prediabetes and hypertension exhibiting a 6.37-fold higher risk of developing DM compared to those without these conditions.[28] On the other hand, Shang et al. identified that lower SBP and the absence of heart disease were associated with reversion to normoglycaemia.[17] This suggests that effective blood pressure control may offer an additional

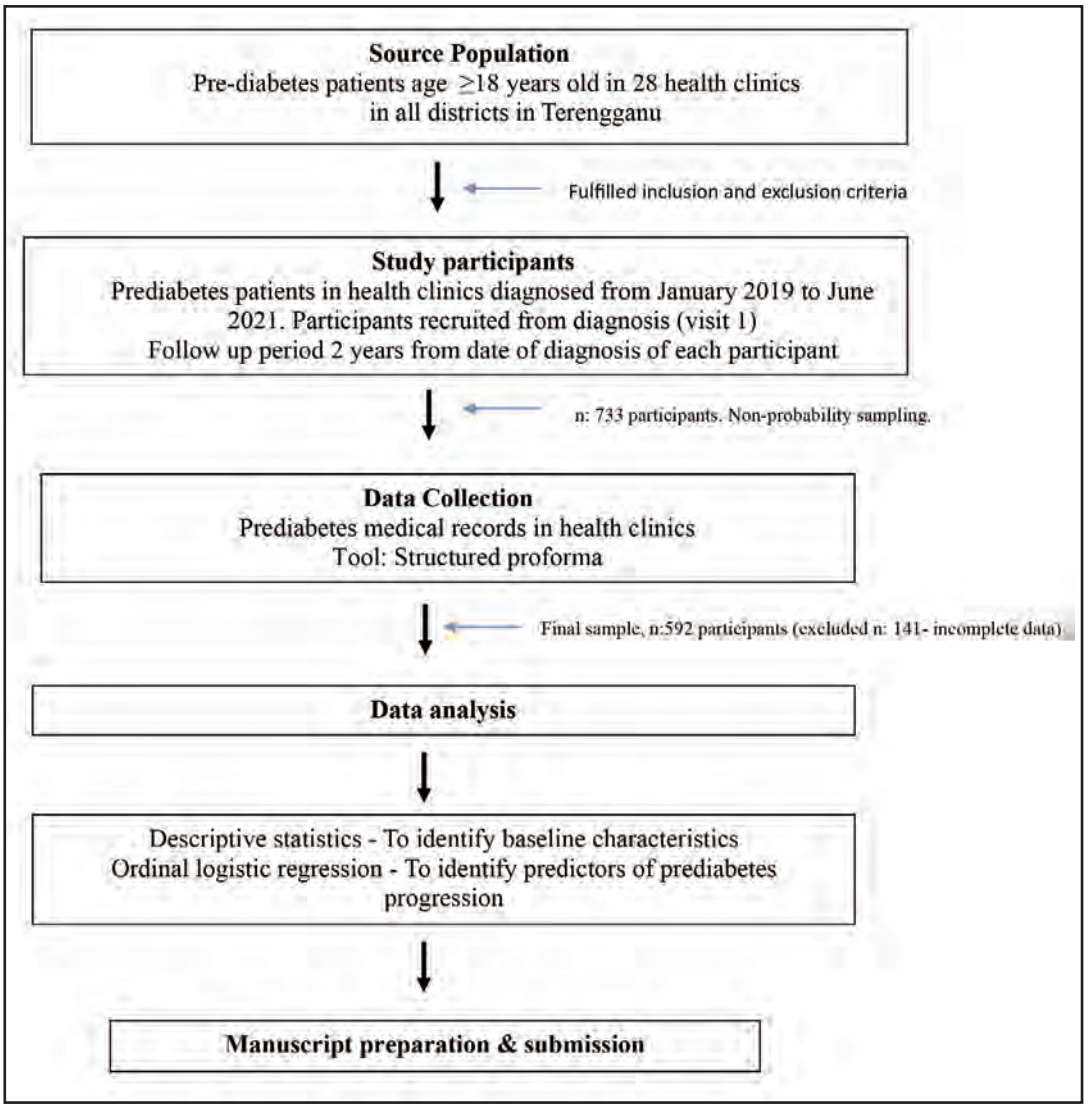

Fig. 1: Study flowchart

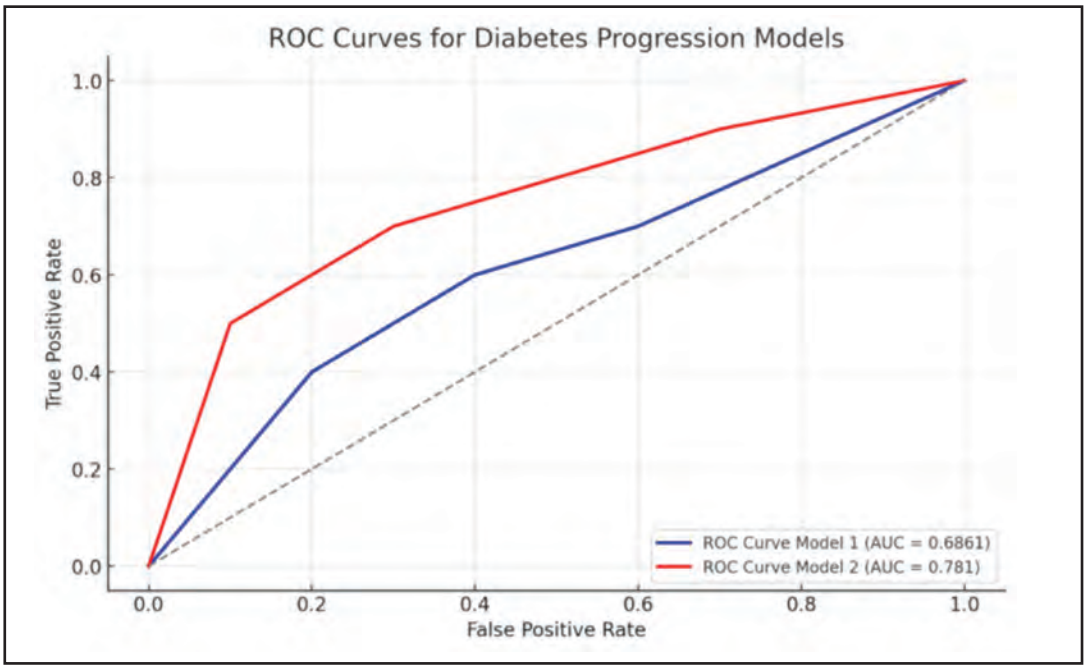

Fig. 2: Area under the curve (ROC)

approach to reducing insulin resistance and supporting glycaemic stability, further highlighting the importance of addressing cardiovascular factors in prediabetes management. In contrast, our findings suggest that hypertension alone might not strongly influence diabetes risk in this cohort. This difference could be due to variations in population characteristics, such as differences in lifestyle, healthcare access, or genetic predispositions. Additionally, the shorter follow-up period in our study may have limited the observation of the long-term effects of hypertension on glycaemic progression.

Our study's findings on the significant role of FBS level in the progression of prediabetes to DM aligned with those of DeJesus et al., Janghorbani et al., and Wutthisathapornchai et al. who also identified baseline FBS levels as a significant independent predictor of diabetes progression.[16,19,28] In a retrospective cohort study, DeJesus et al. found that each unit increase in baseline fasting glucose was associated with a 12% increase in the risk of diabetes progression, a trend that parallels the progression patterns observed in our cohort.[16] Individuals with FBS level in the prediabetic range (more or equal to 5.6 mmol/L) face a significantly higher risk of progressing to DM due to hepatic insulin resistance, a key factor in worsening glucose regulation.[5] Furthermore, numerous diabetic risk prediction models include FBS as a core component, owing to its strong association with diabetes progression. Although various models, ranging from simple clinical tools to complex machine learning algorithms, have been proposed, none have gained universal acceptance.[5] Meanwhile, in our study, abnormal 2-HPP glucose level or IGT alone was not a significant predictor of diabetes progression. This aligns with previous research, which found that individuals with IFG alone or combined IFG and IGT were more prone to develop DM than those with isolated IGT.[5,19,29] A study conducted by Loiuse and Clude highlighted the different contributions of fasting plasma glucose (FPG) and postprandial plasma glucose (PPG) to HbA1c levels.[30] It found that PPG had a lesser influence in predicting diabetes in individuals with higher HbA1c levels (more than 7.3%). That is why FBS level, which primarily reflects hepatic insulin resistance, serves as a more reliable and stronger predictor of diabetes risk.[5] The consistent identification of FBS as a key predictor in various studies underscores its crucial role in recognizing high-risk individuals who may benefit from early intervention and regular monitoring of blood sugar to reduce their risk of progressing to DM.

Based on our analysis, underlying dyslipidaemia emerged as a significant predictor of diabetes progression, increasing the risk by 67%. This aligns with existing evidence that lipid abnormalities, particularly elevated cholesterol levels, play a role in diabetes progression.[18,19,23] For instance, Liu et al. found significant differences in lipid profiles across three prediabetes outcome groups (progression to DM, persistent prediabetes, and normoglycaemia), suggesting that dyslipidaemia contributes to glycaemic deterioration.[23] However, a few other studies did not find lipid profiles, including total cholesterol and triglyceride levels, to be significant predictors of diabetes progression, reflecting variability in the influence of lipid factors across different populations and study designs.[14,17]

Elevated triglyceride levels was identified as one of the significant predictors of progression from prediabetes to DM in our study, which further supports the role of lipid abnormalities in the deterioration of glycaemic control in prediabetes. This finding is consistent with a few other studies which highlighted that high triglyceride levels contribute to insulin resistance and are often associated with other metabolic abnormalities that accelerate the progression to diabetes.[18,29] However, in contrast to these findings, Yeboah et al.[14] reported that triglyceride levels and other lipid profiles were not significantly different between IFG patients who progressed to diabetes and those who did not during follow-up. This suggests that the impact of triglycerides on diabetes progression may vary across different populations, potentially influenced by other factors like genetic predisposition or insulin resistance, which might play a more prominent role in certain groups.

This study has several limitations. As a retrospective study, it relies on existing medical records, potentially leading to incomplete or inconsistent data. Unmeasured confounding variables such as dietary habits, physical activity, and socioeconomic status may influence diabetes progression but were not included in the dataset due to the retrospective cohort design, which relied on existing secondary data in medical records where such information was unavailable. Besides, the specific population of adults attending health clinics in Terengganu may limit the generalizability of findings to other regions. The inclusion of participants from 15 urban and 13 rural health clinics within the state ensures a balanced representation of community settings; however, the reliance on government health clinics may introduce selection bias. Individuals who receive care from private healthcare providers or those who do not actively engage with the healthcare system may have different predictors of glycaemic progression. Additionally, rural populations often face barriers related to healthcare access, health literacy, and socioeconomic disparities, which may not be present in more urbanized populations. These social determinants of health could influence lifestyle behaviours, treatment adherence, and follow-up consistency, potentially affecting glycaemic outcomes.

Moreover, although the prediabetes population in Terengganu may share some similarities with other Malaysian states, differences in ethnic composition, dietary patterns, and access to health education could contribute to variations in prediabetes prevalence and its key predictors.

As such, while the findings provide crucial insights into predictors of glycaemic progression, they may not be fully generalizable to Malaysia's broader population. Hence, future research should aim to include multiple states with a more diverse sociodemographic profile to improve the generalizability and external validity of the results. Finally, variations in follow-up intervals due to the COVID-19 pandemic could affect the consistency of glycaemic tracking.

CONCLUSION

This study highlights key predictors; age, BMI, dyslipidaemia, FBS, and triglycerides that significantly influence the progression from prediabetes to DM among Malaysian adults. By establishing a local understanding of these

predictors, our study contributes valuable insights to the ongoing efforts on diabetes prevention, emphasizing the importance of early intervention in high-risk individuals as well as developing more proactive diabetes prevention strategies tailored to specific population needs. Such efforts are essential for reducing the clinical and economic burden of diabetes in Malaysia. Future studies could employ a prospective design with extended follow-up periods to capture long-term outcomes and provide a clearer view of glycaemic progression. Additionally, intervention-based research focusing on targeted lifestyle modifications or medication efficacy would help identify effective strategies for high-risk groups.

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CONFLICT OF INTEREST

The authors declare they have no conflicts of interest.

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