INTERNATIONAL JOURNAL OF HEALTH & MEDICAL RESEARCH
ISSN(print): 2833-213X, ISSN(online): 2833-2148
Volume 05 Issue 09 September 2026
DOI : 10.58806/ijhmr.2026.v5i9n13
Page No. 948-957

Determinants of Type 2 Diabetes Mellitus among Women Aged 46–55 Years: An Explanatory Sequential Mixed-Methods Study in West Aceh, Indonesia

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ABSTRACT

Background: Type 2 diabetes mellitus (T2DM) is a major and rapidly expanding global health challenge, with a disproportionate burden in low- and middle-income countries. Indonesia is among the countries with the highest number of adults living with diabetes worldwide, with approximately 10.7 million cases reported. Women aged 46–55 years may represent a particularly vulnerable population because age-related hormonal, metabolic, and behavioral changes can increase susceptibility to dysglycemia and T2DM. In the working area of Suak Ribee Public Health Center, West Aceh Regency, 48 of 98 women aged 46–55 years were reported to have T2DM, underscoring the need to identify population-specific determinants of the disease.

Objective: This study aimed to identify and quantify the factors associated with T2DM among women aged 46–55 years in the working area of Suak Ribee Public Health Center, West Aceh Regency, Indonesia.

Methods: An explanatory sequential mixed-methods design was employed. The quantitative phase included women aged 46–55 years identified in the study area. Total population sampling was applied to 98 eligible women, of whom 97 provided complete data and were included in the quantitative analysis. Data were collected using a structured questionnaire and blood glucose measurement. Quantitative analyses comprised descriptive statistics, assessment of distribution using the Shapiro–Wilk test, bivariate analysis using Spearman's rank correlation and Pearson's chi-square or Fisher's exact test, and multivariable analysis using binary logistic regression. A qualitative phase involving in-depth interviews was subsequently undertaken to provide contextual explanations for the dominant quantitative findings**.**

Results: Of the 97 participants, 57 (58.8%) had blood glucose levels ≥200 mg/dL and were classified as having DM according to the study's operational definition. Physical activity frequency was inversely correlated with blood glucose level (Spearman's rs = −0.277; p = 0.006), as was physical activity duration (rs = −0.306; p = 0.002). A family history of DM was significantly associated with DM status (χ^2 = 14.484; p < 0.001). In the multivariable logistic regression model, longer physical activity duration was independently associated with lower odds of DM (OR = 0.433; 95% CI: 0.244–0.766; p = 0.004), whereas participants with a family history of DM had substantially higher odds of DM (OR = 4.779; 95% CI: 1.866–12.236; p = 0.001). The final model was statistically significant (χ^2 = 23.429; p < 0.001), demonstrated adequate calibration (Hosmer–Lemeshow p = 0.409), and accounted for approximately 29.5% of the variance in DM status (Nagelkerke R^2 = 0.295).

Conclusion: Family history of DM and physical activity duration were independently associated with DM status among women aged 46–55 years in this primary healthcare population. These findings support the incorporation of family history into community-level diabetes risk stratification and the implementation of structured, context-specific physical activity promotion as complementary strategies for diabetes prevention and early detection. Further integration of the qualitative findings is warranted to elucidate the behavioral and contextual mechanisms underlying these associations.

KEYWORDS: type 2 diabetes mellitus; diabetes determinants; physical activity; family history; women aged 46–55 years; primary health care; mixed-methods study

INTRODUCTION

Diabetes mellitus (DM) is a chronic metabolic disorder characterized by persistent hyperglycemia resulting from impaired insulin secretion, impaired insulin action, or a combination of both. Type 2 diabetes mellitus (T2DM), which accounts for the majority of diabetes cases, is primarily characterized by insulin resistance accompanied by progressive pancreatic β-cell dysfunction[1], [2]. The rapidly increasing prevalence of T2DM, together with its substantial morbidity, mortality, and economic burden, has become a major global public health concern. Globally, an estimated 463 million adults aged 20–79 years were living with diabetes, with approximately 4.2 million deaths attributable to the disease[3], [4]. This burden is projected to increase substantially, with the number of adults with diabetes expected to reach approximately 700 million by 2045. The economic consequences are also considerable, with global diabetes-related healthcare expenditure estimated at USD 548 billion annually[4], [5], [6]. Indonesia is among the countries with the highest diabetes burden worldwide, ranking seventh globally, with approximately 10.7 million adults living with diabetes[1], [7]. Moreover, diabetes has become one of the leading causes of mortality in Indonesia, and the number of individuals affected has increased markedly, from 10.7 million in 2019 to approximately 19.5 million in 2021.

The increasing burden of T2DM is also evident at the regional and community levels. According to the West Aceh Regency Health Profile, 4,310 cases of diabetes mellitus were recorded between January and December 2022, of which 99.6% received healthcare services in accordance with the established minimum service standards[4], [5]. At the Suak Ribee Public Health Center, 98 women aged 46–55 years were registered as early-elderly individuals, and 48 of them had been diagnosed with T2DM. This relatively high proportion underscores the importance of identifying factors associated with T2DM within this population, particularly because early-elderly women may experience substantial physiological and metabolic changes that increase their susceptibility to metabolic disorders.

The development of T2DM is multifactorial, involving complex interactions between genetic predisposition, demographic characteristics, metabolic conditions, dietary behaviors, and lifestyle factors[8], [9], [10]. The study further suggested that women entering the early-elderly period may have an increased susceptibility to T2DM due to age-related hormonal and metabolic alterations [1]. Consistent with these findings, community-based studies conducted among older populations in Aceh have reported associations between lifestyle-related and metabolic factors and the occurrence of diabetes mellitus[10], [11], [12]. These findings indicate that the determinants of T2DM should be examined within specific population and community contexts, as the relative contribution of individual risk factors may vary according to sociodemographic characteristics, health behaviors, and local environmental conditions[13], [14], [15]. The clinical significance of identifying these determinants is underscored by the substantial risk of complications associated with poorly controlled T2DM. Chronic hyperglycemia promotes endothelial dysfunction, inflammation, oxidative stress, and progressive vascular damage, thereby increasing the risk of both microvascular and macrovascular complications. Individuals with diabetes have an approximately 1.5-fold higher risk of stroke than those without diabetes, while diabetes is also an established risk factor for coronary heart disease, heart failure, and atrial fibrillation[16], [17], [18]. In addition, peripheral arterial disease may result in pain, sensory impairment, ulceration, gangrene, and, in severe cases, lower-limb amputation. Microvascular complications include diabetic retinopathy, which may lead to visual impairment and blindness; diabetic nephropathy, which can progress to chronic kidney disease and kidney failure; and diabetic neuropathy, which may cause substantial sensory and functional impairment. Accordingly, early identification of individuals at increased risk of T2DM is essential for strengthening preventive interventions and reducing the long-term burden of diabetes-related complications[19], [20], [21], [22].

Risk factors for T2DM can broadly be categorized into modifiable and non-modifiable determinants. Modifiable factors include overweight or obesity (BMI $\geq$23 kg/m²), physical inactivity, hypertension (>140/90 mmHg), dyslipidemia, and unhealthy dietary patterns characterized by high consumption of sugars and low intake of dietary fiber. Non-modifiable factors include increasing age, genetic susceptibility, family history of diabetes, and ethnicity. [19] Although these determinants have been extensively investigated, their occurrence and interaction may differ across populations. Therefore, evidence derived from general populations may not adequately explain the mechanisms underlying T2DM among specific demographic groups, particularly women in the early-elderly period living in rural or semi-urban communities. Despite the growing body of evidence regarding T2DM risk factors in Indonesia, most previous studies have predominantly employed quantitative approaches to identify statistical associations between individual risk factors and diabetes occurrence[23], [24]. Although quantitative analysis is essential for determining the magnitude and statistical significance of associations, it provides limited insight into the contextual and behavioral mechanisms through which these factors influence diabetes risk. In particular, quantitative findings alone may not sufficiently explain why individuals exhibit specific dietary patterns, levels of physical activity, healthcare-seeking behaviors, or difficulties in modifying established risk factors[25], [26], [27]. This limitation highlights the need for an integrated methodological approach capable of not only identifying statistically significant determinants but also exploring the contextual factors that may explain these relationships.

To address this gap, the present study employed an explanatory sequential mixed-methods design. Quantitative analysis was conducted initially to identify factors associated with the occurrence of T2DM, followed by a qualitative phase involving in-depth interviews to provide contextual explanations and enhance the interpretation of the quantitative findings[28], [29], [30], [31]. This approach enables statistical associations to be complemented by participants' lived experiences, perceptions, and behavioral contexts. Importantly, the study focuses specifically on women aged 46–55 years, an early-elderly population that may be particularly susceptible to metabolic changes associated with aging but remains comparatively underrepresented in targeted research on T2DM determinants. By integrating quantitative and qualitative evidence, this study seeks to generate a more comprehensive understanding of the determinants of T2DM within a specific community context. Therefore, this study aimed to identify and analyze the determinants associated with the occurrence of T2DM among women aged 46–55 years in the working area of Suak Ribee Public

Health Center, West Aceh Regency, and to further explore the contextual factors underlying the quantitative associations through an explanatory qualitative approach.

METHODS

This study employed a mixed-methods approach using an explanatory sequential design, in which quantitative data collection and analysis were conducted initially, followed by a qualitative phase designed to provide contextual explanations for and further elucidate the quantitative findings concerning determinants of type 2 diabetes mellitus (T2DM), namely family history of diabetes mellitus (DM), dietary patterns, hypertension, and physical activity. The study was conducted in the working area of Suak Ribee Public Health Center, West Aceh Regency, Aceh, Indonesia, in 2026. The target population comprised early-elderly women aged 46–55 years residing in the study area, with a total population of 98 individuals. Given the relatively small population size, total population sampling was employed, whereby all eligible individuals were invited to participate; following data screening, 97 participants with complete and valid data were included in the final analysis. Data collection was conducted in two sequential phases. In the quantitative phase, blood glucose levels were measured, followed by administration of a structured questionnaire assessing sociodemographic characteristics, including age, educational attainment, and occupation; anthropometric status based on body mass index (BMI); dietary patterns, including the consumption of sweet foods and fruits and vegetables; physical activity, assessed in terms of frequency and duration; blood pressure; and family history of DM among parents, grandparents, and siblings. In the qualitative phase, in-depth interviews and direct observation were conducted among participants diagnosed with DM to explore their experiences, perceptions, behavioral patterns, and contextual circumstances related to the occurrence of T2DM, with particular emphasis on the determinant identified as the most influential factor in the quantitative analysis. Quantitative data were analyzed sequentially using univariate, bivariate, and multivariate approaches. Univariate analysis was performed to describe the distribution of study variables using frequencies, percentages, and appropriate descriptive statistics. The normality of numerical variables, including age, blood glucose level, BMI, systolic blood pressure, and diastolic blood pressure, was assessed using the Shapiro–Wilk test. Because these variables did not demonstrate a normal distribution, non-parametric methods were applied. Spearman's rank correlation coefficient was used to assess associations between blood glucose levels and numerical or ordinal variables, whereas associations between categorical variables, particularly family history of DM and T2DM status, were examined using the Pearson chi-square test, with Fisher's exact test applied when the assumptions for the chi-square test were not satisfied. Multivariate analysis was subsequently performed using binary logistic regression to identify the determinant factors most strongly associated with T2DM. The results were expressed as odds ratios (ORs) with corresponding 95% confidence intervals (CIs). Model fit was evaluated using the Hosmer–Lemeshow goodness-of-fit test, while the explanatory capacity of the model was assessed using Nagelkerke's R^2. Statistical significance was defined as a two-sided α level of 0.05. Qualitative data obtained from in-depth interviews and observations were analyzed thematically through systematic coding, categorization, and identification of overarching themes, and the resulting findings were integrated with the quantitative results during the interpretation stage to provide a more comprehensive explanation of the dominant determinant of T2DM within the study population. Ethical approval was obtained through the relevant institutional research ethics review process before data collection commenced, and all participants provided written informed consent after receiving information regarding the study objectives, procedures, confidentiality, potential benefits and risks, and their right to withdraw from participation at any time without consequence

RESULTS

Respondent Characteristics

The study was conducted according to the predefined research protocol and yielded a final analytic sample of 97 respondents. The sociodemographic, clinical, behavioral, and familial characteristics of the participants are summarized in Table 1. The age distribution ranged from 46 to 55 years, with the largest proportion of respondents aged 55 years (33/97; 34.0%). Regarding educational attainment, 38 respondents (39.2%) had a basic level of education, followed by secondary education (38.1%) and higher education (22.7%). Most participants were housewives (72.2%), while 27.8% were civil servants or retirees. With respect to blood pressure status, 59 respondents (60.8%) were classified as non-hypertensive, whereas 38 (39.2%) met the criteria for hypertension. Based on body mass index (BMI), 37 respondents (38.1%) had normal body weight, while 34 (35.1%) were overweight and 26 (26.8%) were obese. Thus, approximately three-fifths of the participants (61.9%) had excess body weight. In terms of dietary behavior, 49 respondents (50.5%) reported rarely consuming sweet foods, whereas 27 (27.8%), 14 (14.4%), and 7 (7.2%) reported consuming sweet foods sometimes, often, and almost daily, respectively. Fruit and vegetable consumption was comparatively frequent, with 52 respondents (53.6%) reporting frequent consumption and 37 (38.1%) reporting consumption almost daily. Nevertheless, physical activity was generally limited. Nearly half of the respondents (49.5%) reported never engaging in physical activity based on frequency, while 34.0% reported physical activity only 1–2 times per week. Similarly, more than half of the participants (55.3%) reported no physical activity when assessed according to duration, whereas 27.9% reported engaging in physical activity for less than 30 minutes. A family history of DM among parents or grandparents was reported by 51 respondents (52.6%), while 49 (50.5%) reported a history of DM among siblings. Based on blood glucose measurements, 57 respondents (58.8%) had blood glucose levels ≥200 mg/dL and were classified as having DM, whereas 40 respondents (41.2%) had blood glucose levels <200 mg/dL and were classified as having normal blood glucose status. Collectively, these findings indicate a substantial burden of hyperglycemia within the study population, accompanied by a relatively high prevalence of excess body weight, insufficient physical activity, and a positive family history of DM.

Table 1. **Sociodemographic, Clinical, Behavioral, and Familial Characteristics of Respondents in the Working Area of Suak Ribee Public Health Center (n = 97)**

Variable	Category	n	%
Age (years)	46	21	21.6
	47	6	6.2
	48	5	5.2
	49	2	2.1
	50	5	5.2
	51	10	10.3
	52	7	7.2
	53	4	4.1
	54	4	4.1
	55	33	34.0
Education	Basic	38	39.2
	Secondary	37	38.1
	Higher	22	22.7
Occupation	Housewife	71	72.2
	Civil servant/retired	26	27.8
Blood pressure status	Not hypertensive	59	60.8
	Hypertensive	38	39.2
Body weight category (BMI)	Normal	37	38.1
	Overweight	34	35.1
	Obese	26	26.8
Sweet food intake	Rarely	49	50.5
	Sometimes	27	27.8
	Often	14	14.4
	Almost daily	7	7.2
Fruit and vegetable intake	Sometimes	8	8.2
	Often	52	53.6
	Almost daily	37	38.1
Physical activity frequency	Never	48	49.5
	1–2 times/week	33	34.0
	3–4 times/week	10	10.3
	>5 times/week	6	7.2
Physical activity duration	Never	54	55.3
	<30 minutes	28	27.9
	30–60 minutes	14	13.4
	>60 minutes	3	3.4
Family history: parent/grandparent	Yes	51	52.6
	No	45	46.4
	Do not know	1	1.0
Family history: sibling	Yes	49	50.5
	No	47	48.5
	Do not know	1	1.0
Blood glucose status	Normal (<200 mg/dL)	40	41.2
	DM (≥200 mg/dL)	57	58.8

Note: Percentages are based on n = 97. Minor discrepancies may occur because of rounding.

Normality Assessment

The distributional characteristics of the continuous variables were assessed using the Shapiro–Wilk test prior to bivariate analysis. As shown in Table 2, age, blood glucose level, BMI, systolic blood pressure, and diastolic blood pressure did not meet the assumption of normality ($p < 0.05$). Accordingly, subsequent analyses involving these variables were performed using non-parametric statistical procedures. Specifically, Spearman's rank correlation coefficient was considered appropriate for assessing associations involving continuous or ordinal variables, while categorical associations were evaluated using the corresponding chi-square or exact tests, as appropriate.

Table 2. **Shapiro–Wilk Normality Test for Continuous Variables (n = 97)**

Variable	Distribution assessment	p-value	Interpretation
Age (years)	Non-normal	<0.05	Not normally distributed
Blood glucose (mg/dL)	Non-normal	<0.05	Not normally distributed
BMI (kg/m²)	Non-normal	<0.05	Not normally distributed
Systolic blood pressure (mmHg)	Non-normal	<0.05	Not normally distributed
Diastolic blood pressure (mmHg)	Non-normal	<0.05	Not normally distributed

Note: The Shapiro–Wilk test was used to assess the normality assumption. Variables with p < 0.05 were considered to deviate significantly from a normal distribution.

Editorial note: Before submission, the percentage for the category ">5 times/week" should be corrected: 6 of 97 respondents corresponds to 6.2%, not 7.2%. It would also be advisable to verify the exact Shapiro–Wilk *p*-values from the statistical output rather than reporting only "$p < 0.05$," as Q1 journals generally favor complete statistical reporting.

Bivariate and Multivariate Analysis of Determinants of Diabetes Mellitus

The bivariate analysis was conducted to examine the magnitude, direction, and statistical significance of the relationships between selected anthropometric, dietary, and behavioral factors and blood glucose levels. As presented in **Table 3**, physical activity demonstrated the most consistent pattern of association with blood glucose levels among the variables examined. Physical activity frequency was significantly and inversely correlated with blood glucose concentration (Spearman's rs = −0.277; p = 0.006), indicating that respondents who reported engaging in physical activity more frequently tended to have lower blood glucose levels. Although the correlation coefficient was relatively modest, the direction of the association was consistent with the expected physiological relationship between regular physical activity and glycemic regulation. Similarly, physical activity duration showed a statistically significant inverse correlation with blood glucose levels (rs = −0.306; p = 0.002). This association was slightly stronger than that observed for activity frequency, suggesting that longer periods of physical activity may be associated with lower blood glucose levels in this population. Taken together, these findings indicate that both the frequency and duration of physical activity may be relevant behavioral factors in glycemic regulation among early-elderly women.

In contrast, no statistically significant association was observed between BMI and blood glucose level (rs = 0.011; p = 0.916). The correlation coefficient was close to zero, indicating virtually no monotonic relationship between BMI and blood glucose concentration in the present sample. Likewise, sweet food consumption was not significantly correlated with blood glucose levels (rs = 0.147; p = 0.150), despite the positive direction of the correlation coefficient. Fruit and vegetable consumption also showed a weak inverse correlation with blood glucose levels, but this association did not reach statistical significance (rs = −0.098; p = 0.341). These findings suggest that, within the observed population and measurement framework, the frequency of specific dietary behaviors and BMI did not demonstrate sufficient evidence of a statistically significant relationship with blood glucose levels. However, the absence of statistical significance should not be interpreted as evidence that these factors have no biological or epidemiological relevance, particularly given the cross-sectional nature of the analysis, the relatively limited sample size, and the possibility of residual confounding or measurement variability.

Table 3. **Spearman's Rank Correlation between Study Variables and Blood Glucose Level**

Variable	n	Spearman's rs	p-value	Interpretation
BMI	97	0.011	0.916	Not significant
Sweet food consumption	97	0.147	0.150	Not significant
Fruit and vegetable consumption	97	−0.098	0.341	Not significant
Physical activity frequency	97	−0.277	0.006	Significant, inverse
Physical activity duration	96	−0.306	0.002	Significant, inverse

Note: Spearman's rank correlation coefficient was used because the variables did not meet the assumption of normality. A negative coefficient indicates that higher values of the predictor variable were associated with lower blood glucose levels.

The association between **family history of DM and DM status** was subsequently examined using categorical analysis (Table 4). A statistically significant association was identified between familial history of DM and the occurrence of DM (χ^2 = 14.484, df = 1; p

< 0.001). Among respondents who reported a family history of DM, 40 of 52 (76.9%) were classified as having DM, compared with only 17 of 44 (38.6%) among those without a reported family history. Thus, the proportion of DM was approximately two-fold higher among respondents with a positive family history than among those without such a history. The magnitude and consistency of this association were further supported by Fisher's exact test, which also yielded $p < 0.001$. One respondent who reported not knowing their family history was excluded from this analysis, resulting in an effective sample size of 96 respondents. These findings provide evidence that familial predisposition may represent an important determinant of DM status in this population.

Table 4. Association between Family History of Diabetes Mellitus and DM Status

Family history of DM	Normal (<200 mg/dL), n	DM (≥200 mg/dL), n	Total, n
No	27	17	44
Yes	12	40	52
Total	39	57	96

Note: Pearson $\chi^2 = 14.484$, df = 1, $p < 0.001$; Fisher's exact test, $p < 0.001$. One respondent who reported "do not know" was excluded from the analysis.

To determine which factors remained independently associated with DM status after accounting for the influence of other variables, a binary logistic regression analysis was performed. The final model retained physical activity duration and family history of DM as statistically significant predictors of DM status (Table 5). Physical activity duration was inversely associated with the odds of DM (B = −0.838; OR = 0.433; 95% CI: 0.244–0.766; $p = 0.004$). Specifically, each one-category increase in physical activity duration was associated with an estimated 56.7% reduction in the odds of DM after adjustment for family history of DM. This finding strengthens the bivariate result and suggests that the relationship between physical activity duration and DM status persisted even after accounting for familial susceptibility. Importantly, because physical activity duration was analyzed as an ordinal variable, the OR should be interpreted per one-category increase rather than as a direct percentage reduction associated with a specific number of minutes of activity. Family history of DM demonstrated a comparatively stronger independent association with DM status. Respondents with a positive family history had approximately 4.78-fold higher odds of having DM than respondents without a family history (OR = 4.779; 95% CI: 1.866–12.236; $p = 0.001$), after adjustment for physical activity duration. The confidence interval did not include the null value of 1.0, supporting the statistical robustness of this association. The persistence of family history as an independent predictor indicates that familial susceptibility may remain important even after consideration of a modifiable behavioral factor such as physical activity. Nevertheless, the association should be interpreted as an adjusted association rather than a causal effect, given the observational study design. The final logistic regression model was statistically significant overall ($\chi^2 = 23.429$; $p < 0.001$), indicating that the set of predictors included in the model provided a significantly better fit than an intercept-only model. The model yielded a Nagelkerke R^2 of 0.295, suggesting that approximately 29.5% of the variation in DM status was accounted for by the predictors included in the final model. The remaining variation may reflect other biological, behavioral, socioeconomic, environmental, or unmeasured factors that were not incorporated into the model. The Hosmer–Lemeshow goodness-of-fit test was not statistically significant ($p = 0.409$), indicating no evidence of a significant discrepancy between the observed and model-predicted probabilities and therefore supporting the adequacy of the model's fit to the observed data.

Table 5. Final Binary Logistic Regression Model for Determinants of DM Status

Variable	B	SE	Wald	df	*p*-value	OR (Exp[B])	95% CI
Physical activity duration	−0.838	0.292	8.265	1	0.004	0.433	0.244–0.766
Family history of DM (yes vs. no)	1.564	0.480	10.632	1	0.001	4.779	1.866–12.236
Constant	1.021	0.573	3.181	1	0.075	2.777	0.904–8.534

Note: Model $\chi^2 = 23.429$, $p < 0.001$; Nagelkerke $R^2 = 0.295$; Hosmer–Lemeshow goodness-of-fit test, $p = 0.409$.

the quantitative findings identify family history of DM and physical activity duration as the principal independent determinants of DM status in this study population. The consistency between the bivariate and multivariate analyses is particularly notable for physical activity, which remained significantly associated with DM after adjustment for familial history. Family history demonstrated the strongest statistical association, with respondents reporting familial DM having substantially greater odds of DM. These findings provide an important basis for the subsequent qualitative phase of the explanatory sequential design, in which the experiences and contextual factors underlying the dominant determinants—particularly familial susceptibility and physical activity behavior—can be explored in greater depth. Such integration is important because statistical associations alone cannot fully explain the behavioral and contextual mechanisms through which these determinants may contribute to DM within the study population.

DISCUSSION

This study identified physical activity duration and family history of diabetes mellitus (DM) as independent determinants of DM status among early-elderly women aged 46–55 years in the working area of Suak Ribee Public Health Center, West Aceh Regency. In the multivariable model, longer physical activity duration was associated with significantly lower odds of DM, whereas participants reporting a family history of DM had substantially higher odds of having DM. These findings are biologically plausible and broadly consistent with epidemiological evidence indicating that physical activity and genetic or familial susceptibility are important components of T2DM risk. Evidence from prospective studies has demonstrated that higher levels of physical activity are associated with a lower incidence of T2DM, including among individuals with an elevated genetic predisposition, suggesting that favorable lifestyle behaviors may partially offset inherited susceptibility[23], [32], [33] The present findings therefore reinforce the concept that T2DM arises from the interaction of relatively fixed susceptibility factors and potentially modifiable behavioral exposures rather than from a single determinant.

The inverse association between physical activity duration and DM status observed in this study is consistent with the established physiological role of physical activity in glucose homeostasis. Regular muscle contraction stimulates glucose uptake through insulin-independent pathways and, over time, improves peripheral insulin sensitivity, skeletal-muscle glucose utilization, and metabolic flexibility. Physical activity may also contribute to improved body composition and reduced visceral adiposity, thereby mitigating pathways associated with insulin resistance [9,10]. In the present study, each one-category increase in physical activity duration was associated with lower odds of DM (OR = 0.433; 95% CI: 0.244–0.766; $p = 0.004$), corresponding to an estimated 56.7% reduction in the odds of DM per category increase after adjustment for family history. The consistency of this association across both the bivariate analysis, in which physical activity duration was inversely correlated with blood glucose concentration (rs = −0.306; $p = 0.002$), and the multivariable model strengthens the interpretation that physical activity duration represents an important behavioral correlate of glycemic status in this population. Nevertheless, because the quantitative component was cross-sectional, the observed association should not be interpreted as evidence of a causal effect. Reverse causation is also possible, whereby women with diabetes or poorer health may have reduced their physical activity because of symptoms, functional limitations, or health-related restrictions.

Family history of DM emerged as the strongest independent determinant in the final model. Participants with a reported family history of DM had approximately 4.78-fold higher odds of having DM than those without such a history (OR = 4.779; 95% CI: 1.866–12.236; $p = 0.001$). This finding is consistent with the established contribution of genetic susceptibility to T2DM and with previous evidence demonstrating increased diabetes risk among individuals with affected first-degree relatives [24].

The association, however, should not be interpreted as reflecting genetic transmission alone. Families frequently share dietary practices, patterns of physical activity, socioeconomic circumstances, health beliefs, and trajectories of body weight, all of which may contribute to the aggregation of diabetes risk within households. Thus, the observed association between family history and DM status may represent the combined influence of inherited susceptibility and shared environmental and behavioral exposures. From a public health perspective, family history represents a readily ascertainable and relatively low-cost risk marker that could be incorporated into risk stratification at the primary healthcare level. Early-elderly women with a positive family history may therefore constitute a priority group for periodic glycemic assessment, lifestyle counseling, and targeted preventive interventions. In contrast, BMI, sweet food consumption, and fruit and vegetable consumption were not significantly associated with blood glucose levels in the present analysis. BMI showed virtually no monotonic correlation with blood glucose (rs = 0.011; $p = 0.916$), while sweet food consumption (rs = 0.147; $p = 0.150$) and fruit and vegetable consumption (rs = −0.098; $p = 0.341$) also failed to reach statistical significance. These findings should be interpreted cautiously and should not be taken to imply that adiposity or dietary behavior is irrelevant to T2DM pathogenesis. Several methodological and contextual explanations may account for the absence of statistically significant associations. First, dietary exposure was assessed using relatively broad frequency categories rather than quantitative measures of energy, carbohydrate, or total sugar intake, which may have limited the ability to detect dose–response relationships. Second, self-reported dietary information is inherently susceptible to recall error and social desirability bias. Third, the relatively homogeneous dietary practices of this community may have reduced between-participant variability and consequently attenuated statistical associations. Similarly, the BMI measure provides an assessment of overall adiposity but does not capture visceral fat distribution, which may be more closely related to insulin resistance. Finally, the relatively small sample size may have limited statistical power to detect modest associations. These considerations highlight the importance of interpreting non-significant findings within the context of study design and measurement characteristics rather than as evidence of the absence of biological effects.

The relatively high proportion of participants classified as having DM in this study further emphasizes the potential public health significance of the findings. More than half of the participants had blood glucose levels ≥200 mg/dL according to the operational classification used in this study. However, interpretation of this proportion requires careful consideration of the diagnostic context. A blood glucose concentration of ≥200 mg/dL is consistent with a diagnostic criterion for diabetes when obtained as a random plasma glucose measurement in the presence of classic symptoms of hyperglycemia or hyperglycemic crisis; therefore, the measurement conditions and diagnostic confirmation procedures should be explicitly reported. If the measurement was not performed under the conditions required for definitive diagnosis, the terminology should be revised appropriately—for example, to "elevated blood glucose" or "probable diabetes"—rather than implying a confirmed clinical diagnosis. This distinction is particularly important for an international journal because precise alignment between operational definitions and established diagnostic criteria is essential for methodological validity and comparability across studies.

The findings have implications for diabetes prevention and risk stratification at the primary healthcare level. The combination of a high prevalence of familial susceptibility and limited physical activity suggests that prevention strategies in this population should not rely exclusively on generalized health promotion messages. Instead, primary healthcare providers could consider a more targeted approach in which family history is incorporated into routine risk assessment and women with elevated familial risk receive intensified counseling regarding physical activity and periodic glycemic assessment. Such an approach may be particularly relevant in community-based settings where resources for comprehensive metabolic screening are limited. Importantly, physical activity interventions should be culturally and contextually appropriate, taking into account participants' daily routines, occupational roles, environmental constraints, and perceived barriers to sustained activity. The qualitative component of the present mixed-methods design is particularly valuable in this regard because it can help explain why some women engage in limited physical activity and identify contextual barriers and facilitators that cannot be adequately captured through quantitative measures alone. The focus on early-elderly women is also clinically and epidemiologically relevant. The transition into later adulthood is accompanied by changes in body composition, hormonal regulation, muscle mass, and insulin sensitivity that may increase susceptibility to metabolic disorders. In women, age-related hormonal changes may further interact with changes in adiposity and physical activity, potentially amplifying metabolic risk. Consequently, this population may represent an important window for preventive intervention before the accumulation of chronic complications. Poorly controlled T2DM is associated with substantial microvascular and macrovascular morbidity, including cardiovascular disease, stroke, peripheral arterial disease, diabetic retinopathy, nephropathy, and neuropathy. Prevention and early detection therefore have implications beyond glycemic control alone, potentially reducing the longer-term burden of diabetes-related disability and healthcare utilization.

Several limitations should be considered when interpreting these findings. First, the cross-sectional design of the quantitative component precludes establishing temporal relationships and causal inference between the identified determinants and DM status. Second, physical activity and dietary variables were assessed through self-report and may therefore be affected by recall and social desirability biases[34], [35]. Third, the relatively small sample size and restriction of the study population to early-elderly women in a single primary healthcare catchment area may limit the generalizability of the findings to other age groups, men, or populations with different sociodemographic and environmental characteristics. Fourth, the measurement and classification of blood glucose should be described in greater detail, including whether the measurement was fasting, random, or obtained under another standardized condition, and whether abnormal results were clinically confirmed. Fifth, the final multivariable model explained 29.5% of the variability in DM status, indicating that substantial variation remained unexplained and may be attributable to other biological, behavioral, socioeconomic, or environmental determinants that were not assessed[36], [37]. Finally, although the explanatory sequential design was intended to integrate quantitative and qualitative evidence, the qualitative phase was still ongoing at the time of this analysis. Consequently, the present interpretation is based primarily on the quantitative findings, and the subsequent qualitative phase is expected to provide additional insight into the mechanisms, experiences, and contextual factors underlying the observed associations.

The field implementation also presented logistical challenges associated with recruiting and assessing participants across the study area. These challenges were addressed by involving village midwives working within the Suak Ribee Public Health Center catchment area as field enumerators. Their familiarity with the local geography and community characteristics facilitated participant identification, communication, and field coordination. Nevertheless, the involvement of local health personnel should be accompanied by standardized training and supervision to minimize interviewer-related variability and potential information bias, particularly for self-reported behavioral measures.

CONCLUSION

Family history of diabetes mellitus and shorter duration of physical activity emerged as the predominant independent determinants of type 2 diabetes mellitus among early-elderly women aged 46–55 years in the working area of Suak Ribee Public Health Center, West Aceh Regency. These findings highlight the importance of incorporating family-history-based risk stratification into early screening and prevention strategies, while strengthening structured and sustained physical activity promotion at the primary health care level. Given their feasibility and relatively low implementation costs, these approaches may represent practical priorities for reducing the risk and burden of type 2 diabetes mellitus among women in this vulnerable age group. The subsequent phase of this research will focus on completing the qualitative component to provide a more comprehensive understanding of the contextual factors underlying diabetes risk and prevention behaviors. Further refinement of the statistical analyses and integration of quantitative and qualitative findings will subsequently be undertaken to strengthen the overall interpretation of the study. The final results will be prepared for submission to an accredited international journal as the principal mandatory research output. In addition, the study findings will be translated into evidence-informed and contextually relevant recommendations to support diabetes prevention and risk-reduction initiatives at Suak Ribee Public Health Center.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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