Interaction between physical activity timing and behavioral determinants in predicting hypoglycemia among patients with type 2 diabetes mellitus

Interacción entre el momento de la actividad física y los determinantes conductuales en la predicción de la hipoglucemia en pacientes con diabetes mellitus tipo 2

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Abstract

Background: Hypoglycemia is a common complication among patients with type 2 diabetes mellitus and is influenced by physical activity and behavioral factors.
Objective: This study aimed to analyze the association between physical activity and behavioral determinants and the incidence of hypoglycemia.
Methods: A cross-sectional study was conducted among 106 participants in a primary healthcare setting. Physical activity was assessed using the International Physical Activity Questionnaire (IPAQ), dietary intake using the Food Frequency Questionnaire (FFQ), and medication adherence using the Morisky Medication Adherence Scale (MMAS-8). Data were analyzed using Chi-square tests, logistic regression, and Poisson regression.
Results: A total of 45.3% of participants experienced hypoglycemia, with a mean of 2.14 ± 1.26 episodes per month. Low physical activity was significantly associated with hypoglycemia (OR = 3.52; 95% CI: 1.55–7.98; p = 0.003), as were skipping meals (OR = 2.84; 95% CI: 1.26–6.38; p = 0.012), low medication adherence (OR = 2.97; 95% CI: 1.32–6.66; p = 0.008), and insulin use (OR = 2.45; 95% CI: 1.10–5.45; p = 0.028). Low physical activity was also associated with an increased number of hypoglycemic episodes (IRR = 1.92; 95% CI: 1.34–2.74; p = 0.001). A significant interaction was observed between pre-meal physical activity and hypoglycemia (OR = 2.36; 95% CI: 1.18–4.72; p = 0.015).
Conclusion: Physical activity and behavioral determinants, particularly timing-related factors, play a critical role in the occurrence of hypoglycemia among patients with type 2 diabetes mellitus.

Keywords

Behavioral factors; hypoglycemia; medication adherence; physical activity; type 2 diabetes mellitus.

Resumen

Antecedentes: La hipoglucemia es una complicación frecuente en pacientes con diabetes mellitus tipo 2 y está influenciada por la actividad física y los factores conductuales.
Objetivo: Este estudio tuvo como objetivo analizar la asociación entre la actividad física, los determinantes conductuales y la incidencia de hipoglucemia.
Métodos: Se realizó un estudio transversal con 106 participantes en un entorno de atención primaria de salud. La actividad física se evaluó utilizando el International Physical Activity Questionnaire (IPAQ), la ingesta dietética mediante el Food Frequency Questionnaire (FFQ) y la adherencia al tratamiento con la Morisky Medication Adherence Scale (MMAS-8). Los datos se analizaron mediante pruebas de Chi-cuadrado, regresión logística y regresión de Poisson.
Resultados: Un total del 45,3% de los participantes experimentó hipoglucemia, con un promedio de 2,14 ± 1,26 episodios por mes. La baja actividad física se asoció significativamente con la hipoglucemia (OR = 3,52; IC 95%: 1,55–7,98; p = 0,003), al igual que omitir comidas (OR = 2,84; IC 95%: 1,26–6,38; p = 0,012), la baja adherencia a la medicación (OR = 2,97; IC 95%: 1,32–6,66; p = 0,008) y el uso de insulina (OR = 2,45; IC 95%: 1,10–5,45; p = 0,028). La baja actividad física también se asoció con un mayor número de episodios hipoglucémicos (IRR = 1,92; IC 95%: 1,34–2,74; p = 0,001). Se observó una interacción significativa entre la actividad física antes de las comidas y la hipoglucemia (OR = 2,36; IC 95%: 1,18–4,72; p = 0,015).
Conclusión: La actividad física y los determinantes conductuales, especialmente los factores relacionados con el tiempo de realización, desempeñan un papel fundamental en la aparición de hipoglucemia en pacientes con diabetes mellitus tipo 2.

Palabras clave

Factores conductuales; hipoglucemia; adherencia a la medicación; actividad física; diabetes mellitus tipo 2.

Introduction

Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder characterized by impaired insulin secretion, insulin resistance, or both, resulting in persistent hyperglycemia (Kanaley et al., 2022; Tian et al., 2023). In diabetes management, achieving glycemic control while preventing complications remains a major therapeutic challenge. One of the most common acute complications is hypoglycemia, which may lead to dizziness, loss of consciousness, cardiovascular events, reduced quality of life, and even mortality (Nakhleh & Shehadeh, 2021).

Physical activity is an essential component of T2DM management because it improves insulin sensitivity and glycemic control (Azami et al., 2019; Rilstone et al., 2024) However, physical activity may also increase the risk of hypoglycemia, particularly when it is not balanced with adequate dietary intake or appropriate adjustment of antidiabetic medication and insulin therapy (Teich et al., 2019). Therefore, hypoglycemia in patients with T2DM is not only influenced by clinical factors but also by daily behavioral determinants, including dietary patterns and medication use.

Behavioral factors play an important role in maintaining glucose stability among patients with T2DM. Inadequate dietary intake, delayed meal timing, inappropriate medication use, and lack of understanding regarding physical activity adjustment may contribute to fluctuations in blood glucose levels and increase the risk of hypoglycemia (Porter et al., 2020; Riddell et al., 2023). In clinical practice, some patients tend to avoid physical activity because of fear of hypoglycemia, whereas others perform excessive activity without proper nutritional or medication adjustments. These conditions indicate that patients' daily behaviors substantially influence diabetes self-management and hypoglycemia prevention.

The global prevalence of diabetes mellitus continues to increase substantially. The International Diabetes Federation reported that approximately 537 million adults were living with diabetes in 2021, and this number is projected to rise further in the coming decades (Carrillo et al., 2026). Hypoglycemia remains highly prevalent among patients receiving insulin therapy and represents a major barrier to optimal diabetes management. Similar concerns are observed in Indonesia, where diabetes mellitus has become one of the leading non-communicable diseases with increasing morbidity burden (Kemenkes, 2023).

Previous studies have mainly examined hypoglycemia risk based on isolated factors, such as insulin therapy or treatment adherence. However, evidence regarding the combined influence of physical activity and behavioral determinants, particularly dietary intake and medication or insulin use, remains limited. In addition, the interaction between these factors in patients' daily routines has not been adequately explored, especially in primary healthcare settings (Gómez-Ruiz et al., 2024).

Understanding the interaction between physical activity and behavioral determinants is important for developing more effective strategies to prevent hypoglycemia in patients with T2DM. Therefore, this study aimed to analyze the relationship between physical activity, dietary intake, and medication or insulin use and the occurrence of hypoglycemia among patients with T2DM in the working area of Simpang IV Sipin Public Health Center.

Method

This study is an analytic observational study with a cross-sectional design, developed and reported in accordance with the STROBE Statement guidelines. This design was employed to analyze the relationship between physical activity and behavioral determinants with the occurrence of hypoglycemia at a single point in time without any intervention. The study was conducted in the working area of the Simpang IV Sipin Public Health Center from August to October 2025, within the outpatient care setting for patients with type 2 diabetes mellitus undergoing routine follow-up.

The target population comprised all patients with type 2 diabetes mellitus in the health center's catchment area, while the accessible population included patients attending the facility during the study period. Inclusion criteria were: age ≥18 years, diagnosis of type 2 diabetes mellitus for ≥6 months, currently receiving oral antidiabetic drugs and/or insulin therapy, able to communicate, and willing to par-

ticipate. Exclusion criteria included acute conditions (e.g., diabetic ketoacidosis), severe cognitive impairment, and severe physical limitations. A purposive sampling technique was applied. The sample size was calculated using the analytical cross-sectional formula for comparing two proportions, with a 95% confidence level and 80% power, resulting in a minimum of 96 respondents, which was increased by 10% to a total of 106 respondents.

The dependent variable was the occurrence of hypoglycemia, defined as a blood glucose level <70 mg/dL or the presence of clinical symptoms (e.g., tremor, cold sweating, dizziness, weakness). The outcome was measured in two forms: (1) categorical (yes/no) based on the presence of episodes within the past one month, and (2) numerical (number of episodes) within the same period. Additionally, hypoglycemia was classified based on timing: during physical activity, after physical activity, and nocturnal hypoglycemia. The diagnosis of type 2 diabetes mellitus followed the criteria established by the American Diabetes Association.

The primary independent variable was physical activity, defined as any bodily movement that increases energy expenditure. Physical activity was measured comprehensively, including frequency (days/week), duration (minutes/session), intensity (light, moderate, vigorous), type of activity (aerobic, occupational, exercise), and timing (morning/afternoon/evening, and before or after meals). Data were expressed in MET-minutes/week and categorized into low, moderate, and high levels of physical activity.

Behavioral determinants included: (1) Dietary intake, defined as eating behaviors that influence blood glucose levels, with indicators including meal frequency (regular/irregular), meal timing (before/after physical activity), adequacy of carbohydrate intake, and the habit of skipping meals. Assessment was conducted using a Food Frequency Questionnaire (FFQ), which has been widely used in nutritional epidemiology studies to describe dietary patterns over a specified period. (2) Medication/insulin use, including type of therapy (oral agents/insulin), level of medication adherence, self-adjustment of dosage, and the appropriateness of medication timing in relation to physical activity. Controlled confounding variables included age, sex, duration of diabetes, body mass index, and comorbidities. The timing of physical activity and meal timing were analyzed as effect modifiers in the relationship between physical activity and hypoglycemia.

Research instruments consisted of structured questionnaires and clinical measurement tools. Physical activity was assessed using the validated International Physical Activity Questionnaire (IPAQ) (Sember et al., 2020). Dietary intake was evaluated using the FFQ. Medication use and adherence were measured using the Morisky Medication Adherence Scale (MMAS-8) (Morisky et al., 2008). Hypoglycemia was assessed using a standardized glucometer, symptom history interviews, and supported by medical records and patient logbooks. All instruments underwent content validity assessment by experts and reliability testing through a pilot study.

Data were collected from both primary sources (interviews and direct measurements) and secondary sources (medical records). Measurements were conducted uniformly across all respondents to ensure comparability. Physical activity was calculated in MET-minutes/week, dietary intake was analyzed based on consumption frequency patterns and carbohydrate adequacy, and medication use was assessed based on type, dosage, and adherence.

Efforts to control bias included enumerator training, the use of validated instruments, standardized procedures, and data triangulation between interviews and medical records to reduce recall bias. Selection bias was minimized through clear inclusion and exclusion criteria, while information bias was reduced through the use of standardized instruments.

Data were collected after obtaining ethical approval and informed consent, and analyzed using IBM SPSS Statistics. Descriptive analysis was used to summarize respondent characteristics and study variables in the form of frequencies, percentages, means, and standard deviations. Bivariate analysis using the Chi-square test was conducted to assess crude associations between independent variables and hypoglycemia status (yes/no). Multivariate analysis was performed using binary logistic regression to identify independent predictors of hypoglycemia, with results presented as adjusted odds ratios (ORs) and 95% confidence intervals (CIs). For count data on the number of hypoglycemic episodes, Poisson regression was applied, with the choice between Poisson and negative binomial regression determined

based on overdispersion testing; since no overdispersion was observed, Poisson regression was considered appropriate, and results were reported as incidence rate ratios (IRRs). Interaction analysis was conducted by including interaction terms between physical activity and behavioral determinants in the logistic regression model, with additional subgroup analysis for specific patterns such as nocturnal hypoglycemia. Model fit was evaluated using the Hosmer–Lemeshow test, and multicollinearity was assessed using the Variance Inflation Factor (VIF). A p-value of < 0.05 was considered statistically significant.

Ethical Approval

Ethical clearance for this study was obtained from the Health Research Ethics Committee of Poltekkes Kemenkes Jambi with Ethical Exemption Number LB.02.06/2/0004.1/2025. The study was conducted in accordance with the principles of the Declaration of Helsinki. All participants were informed about the objectives and procedures of the study, and confidentiality of participant information was strictly maintained throughout the research process.

Results

A total of 106 patients with type 2 diabetes mellitus participated in this study. Most respondents were aged ≥45 years (83.0%) and female (62.3%). More than half had lived with diabetes for at least five years (56.6%), and overweight or obesity was highly prevalent (64.2%). Comorbid conditions were also common, affecting 60.4% of participants (Table 1).

Table 1. Characteristics of Respondents (n = 106)

Variable	n	%
Age		
<45 years	18	17.0
≥45 years	88	83.0
Sex		
Male	40	37.7
Female	66	62.3
Duration of diabetes		
<5 years	46	43.4
≥5 years	60	56.6
BMI status		
Normal	38	35.8
Overweight/obese	68	64.2
Comorbidities		
No	42	39.6
Yes	64	60.4

Nearly half of the respondents (45.3%) reported experiencing hypoglycemia within the previous month, with an average frequency of 2.14 ± 1.26 episodes. Hypoglycemia occurred most frequently after physical activity, followed by episodes during activity and nocturnal hypoglycemia (Table 2).

Table 2. Occurrence and Pattern of Hypoglycemia

Variable	Value
Hypoglycemia (yes)	48 (45.3%)
Hypoglycemia (no)	58 (54.7%)
Mean number of episodes	2.14 ± 1.26
Timing of hypoglycemia	
During physical activity	16 (33.3%)
After physical activity	20 (41.7%)
Nocturnal	12 (25.0%)

Low physical activity was identified in 39.6% of respondents, whereas only one-quarter reported high activity levels. Physical activity was most commonly performed in the afternoon, and more than half of participants exercised after meals (Table 3).

Table 3. Physical Activity Profile (IPAQ-based)

Variable	n	%
Physical activity level		
Low	42	39.6
Moderate	38	35.8
High	26	24.5
Timing of activity		
Morning	34	32.1
Afternoon	40	37.7
Evening	32	30.2
Activity relative to meals		
Before meals	44	41.5
After meals	62	58.5

Regarding behavioral determinants, irregular meal frequency and meal skipping remained common, affecting nearly half of the participants. Inadequate carbohydrate intake was also identified in a substantial proportion of respondents. In terms of treatment, oral antidiabetic therapy was the most frequently used regimen; however, low medication adherence and self-adjustment of medication doses were still reported among some participants (Table 4).

Table 4. Dietary Behavior and Treatment Characteristics (FFQ-derived indicators)

Variable	n	%
Meal frequency		
Regular	56	52.8
Irregular	50	47.2
Meal skipping		
Yes	46	43.4
No	60	56.6
Carbohydrate adequacy		
Adequate	58	54.7
Inadequate	48	45.3
Type of therapy		
Oral agents	52	49.1
Insulin	30	28.3
Combination	24	22.6
Medication adherence (MMAS-8)		
High	62	58.5
Low	44	41.5
Self-adjustment of dose		
Yes	28	26.4
No	78	73.6

Bivariate analysis demonstrated significant associations between several behavioral factors and hypoglycemia occurrence. Low physical activity, meal skipping, inadequate carbohydrate intake, low medication adherence, and insulin-based therapy were all significantly associated with increased hypoglycemia risk ($p < 0.05$) (Table 5).

Table 5. Bivariate Analysis (Chi-square Test)

Variable	Hypoglycemia n (%)	No Hypoglycemia n (%)	p-value
Low physical activity	28 (66.7)	14 (33.3)	0.001
Meal skipping	30 (65.2)	16 (34.8)	0.002
Inadequate carbohydrate intake	28 (58.3)	20 (41.7)	0.010
Low medication adherence	28 (63.6)	16 (36.4)	0.002
Insulin/combination therapy	26 (60.5)	17 (39.5)	0.018

After adjustment for age, sex, duration of diabetes, BMI, and comorbidities, low physical activity remained the strongest independent predictor of hypoglycemia (OR = 3.52; 95% CI: 1.55–7.98). Meal skipping, inadequate carbohydrate intake, low medication adherence, and insulin use also independently increased hypoglycemia risk (Table 6).

Table 6. Multivariate Logistic Regression Analysis (Adjusted Model)

Variable	OR	95% CI	p-value
Low physical activity	3.52	1.55–7.98	0.003
Meal skipping	2.84	1.26–6.38	0.012
Inadequate carbohydrate intake	2.31	1.05–5.08	0.037
Low medication adherence	2.97	1.32–6.66	0.008
Insulin use	2.45	1.10–5.45	0.028

Poisson regression analysis showed that low physical activity, meal skipping, and low medication adherence significantly increased the frequency of hypoglycemic episodes (Table 7). Low physical activity demonstrated the highest incidence rate ratio, indicating that respondents with insufficient activity levels experienced hypoglycemia episodes more frequently than those with more adequate activity patterns.

Table 7. Poisson Regression Analysis (Number of Hypoglycemic Episodes)

Variable	IRR	95% CI	p-value
Low physical activity	1.92	1.34–2.74	0.001
Meal skipping	1.63	1.14–2.31	0.007
Low medication adherence	1.78	1.25–2.54	0.002

Interaction analysis revealed that the timing of physical activity and behavioral patterns significantly modified hypoglycemia risk. Physical activity performed before meals increased the likelihood of hypoglycemia, while evening physical activity was significantly associated with nocturnal hypoglycemia. In addition, insulin use without proper meal timing control further amplified hypoglycemia risk (Table 8).

Table 8. Interaction Analysis (Effect of Timing and Behavior)

Interaction term	OR	95% CI	p-value
Activity before meals × hypoglycemia	2.36	1.18–4.72	0.015
Evening activity × nocturnal hypoglycemia	2.81	1.22–6.47	0.014
Insulin use without meal timing control × hypoglycemia	2.54	1.11–5.80	0.027

Discussion

This study demonstrates that hypoglycemia among patients with type 2 diabetes mellitus is not solely associated with pharmacological treatment but is strongly shaped by behavioral and contextual factors. Nearly half of the participants experienced hypoglycemia, indicating that glycemic instability remains a substantial challenge at the primary healthcare level. More importantly, the findings suggest that hypoglycemia should be understood as a multidimensional phenomenon influenced by the interaction between physical activity, dietary behavior, and medication management rather than as an isolated adverse effect of diabetes therapy alone.

One important finding of this study is that low physical activity emerged as the strongest independent predictor of hypoglycemia. At first glance, this result may appear counterintuitive because physical activity is generally considered protective in diabetes management. However, this finding likely reflects the complexity of physical activity patterns among patients with T2DM rather than simply the quantity of activity performed. Individuals categorized as having low physical activity may simultaneously demonstrate poorer overall self-management behaviors, irregular metabolic adaptation, and lower confidence in balancing exercise, food intake, and medication use. In this context, low activity may represent broader behavioral dysregulation rather than merely reduced energy expenditure. This interpretation expands previous research that primarily focused on exercise-induced hypoglycemia during moderate or vigorous activity (Handwerk, 2025; Muntis et al., 2023).

The interaction analysis provides additional insight into this relationship. Physical activity performed before meals significantly increased hypoglycemia risk, while evening activity was associated with nocturnal hypoglycemia. These findings suggest that the temporal mismatch between glucose utilization, insulin activity, and nutrient availability may be more clinically relevant than activity intensity alone. Previous studies have emphasized the metabolic effects of exercise on insulin sensitivity; however, the

current findings indicate that timing-related behavioral patterns may be equally important in determining hypoglycemia risk (Rilstone et al., 2024; Teich et al., 2019). This highlights the need for diabetes management approaches that integrate chronobiological and behavioral perspectives rather than focusing exclusively on pharmacological adjustment.

Dietary behavior also played a significant role in hypoglycemia occurrence. Meal skipping and inadequate carbohydrate intake independently increased hypoglycemia risk, supporting the concept that inconsistent nutritional patterns disrupt glucose homeostasis in patients receiving glucose-lowering therapy (Cryer & Polonsky, 2008; Mphasha & Vagiri, 2025). However, beyond the physiological explanation, these findings may also reflect socioeconomic and behavioral realities in daily life. Irregular eating patterns may be influenced by work schedules, limited nutritional knowledge, financial constraints, or low prioritization of dietary management. Therefore, hypoglycemia prevention strategies should not rely solely on standardized nutritional recommendations but should also consider the practical barriers faced by patients in maintaining dietary regularity (Ahrén, 2013).

Medication-related factors further reinforced the behavioral dimension of hypoglycemia risk. Low medication adherence and inappropriate insulin use remained significant predictors even after adjustment for confounding variables. Interestingly, some participants reported self-adjusting medication doses without professional supervision, which may indicate limited understanding of treatment regimens or insufficient access to continuous diabetes education. This finding suggests that hypoglycemia may partly reflect gaps in patient-provider communication and self-management support systems. Consequently, interventions targeting hypoglycemia prevention should move beyond medication prescription alone and prioritize patient-centered education regarding dose timing, meal coordination, and symptom recognition (Sims et al., 2022).

Another important aspect of this study is the identification of combined behavioral effects rather than isolated determinants. Most previous studies examined physical activity, dietary intake, or medication adherence separately. In contrast, this study demonstrates that these factors interact dynamically in everyday life. This multidimensional interaction may explain why some patients experience recurrent hypoglycemia despite receiving standard diabetes treatment. Therefore, a fragmented approach focusing on single risk factors may be insufficient to adequately address hypoglycemia prevention in primary care settings (Pilotto et al., 2014; Walz et al., 2014).

From a clinical perspective, the findings indicate that current diabetes education strategies may require refinement. Recommendations encouraging physical activity are often delivered in generalized terms without sufficient emphasis on meal timing, carbohydrate adjustment, or individualized insulin planning. Similarly, dietary counseling may focus predominantly on food restriction rather than behavioral synchronization between meals, activity, and medication use. The present findings suggest that integrated behavioral counseling approaches may be more effective in reducing hypoglycemia risk than isolated educational interventions.

Several methodological limitations should be critically considered when interpreting these findings. First, the cross-sectional design limits the ability to establish causal relationships between behavioral determinants and hypoglycemia. The observed associations may be bidirectional; for example, fear of hypoglycemia could itself reduce physical activity levels, rather than low physical activity directly causing hypoglycemia. Second, the use of self-reported instruments introduces potential recall bias and social desirability bias, particularly regarding dietary intake, medication adherence, and hypoglycemia episodes. Although triangulation with medical records was attempted, self-report measures remain vulnerable to underreporting and misclassification. Third, the relatively small sample size and single-center setting may reduce statistical power and limit the generalizability of findings to broader diabetes populations with different demographic or healthcare characteristics.

In addition, several potentially important variables were not comprehensively assessed, including psychological distress, health literacy, socioeconomic status, and detailed pharmacological dosing patterns, all of which may influence hypoglycemia risk and self-management behaviors. Residual confounding therefore remains possible despite multivariable adjustment. Future studies should consider longitudinal or prospective cohort designs, incorporate objective glucose monitoring methods such as continuous glucose monitoring (CGM), and include larger multicenter populations to better clarify temporal and causal relationships between behavioral determinants and hypoglycemia.

In conclusion, hypoglycemia among patients with type 2 diabetes mellitus is strongly influenced by the interaction between physical activity, dietary behavior, and medication management. The findings emphasize that behavioral synchronization particularly regarding activity timing, meal patterns, and treatment use may be as important as glycemic control itself in preventing hypoglycemia. A more integrated and behavior-oriented approach to diabetes management is therefore needed to improve patient safety and optimize long-term metabolic outcomes.

Conclusions

This study demonstrates that the incidence of hypoglycemia among patients with type 2 diabetes mellitus is relatively high and is influenced by both behavioral factors and physical activity. Low physical activity, skipping meals, inadequate carbohydrate intake, low medication adherence, and insulin use were significantly associated with an increased risk of hypoglycemia. In addition, timing-related factors, such as engaging in physical activity before meals and during the evening, were shown to further increase the risk, including nocturnal hypoglycemia. These findings indicate that hypoglycemia is not solely determined by medical therapy but also by the interaction between patient behaviors and daily activity patterns.

Patients with type 2 diabetes mellitus are advised to perform physical activity in a planned manner by considering meal timing and medication use to reduce the risk of hypoglycemia. Healthcare providers should deliver more comprehensive education focusing on the synchronization of physical activity, dietary patterns, and pharmacological therapy. Future studies are recommended to employ longitudinal designs and more objective measurement methods to strengthen causal evidence.

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