Journal of Advanced Nursing

WILEY

JAN Leading Global Nursing Research

EMPIRICAL RESEARCH QUANTITATIVE OPEN ACCESS

Predictive Model for Hypoglycaemia Risk in Type 2 Diabetes Mellitus Patients During the Peri-Colonoscopy Period: A Retrospective Cohort Study

Haiyan Yang[1] | Linlin Zhang[1] | Huiling Liu[1] | Shuqiao Hu[1] | Qiuping Yang[1] | Jianan Wu[1] | Mingming Xu[2] | Shufang Chu[1]

[1]Department of Endocrinology, Shenzhen Traditional Chinese Medicine Hospital, Shenzhen, People's Republic of China | [2]Nursing Department, Shenzhen Hospital of Traditional Chinese Medicine, Shenzhen, People's Republic of China

Correspondence: Mingming Xu (1192428426@qq.com) | Shufang Chu (chushufanggzhtcm@163.com)

Received: 20 August 2024 | **Revised:** 17 December 2024 | **Accepted:** 29 January 2025

Funding: This work was supported by Sanming Project of Medicine in Shenzhen (No. SZZYSM202411016).

Keywords: chronic illness | diabetes | nursing models | patient safety | risk management

ABSTRACT

Aims: To identify factors influencing hypoglycaemia in patients with type 2 diabetes mellitus (T2DM) undergoing colonoscopy and to construct a predictive model for assessing hypoglycaemia risk.

Design: A retrospective cohort study.

Methods: We retrospectively collected data on 598 T2DM patients who underwent colonoscopy and randomised them into a developmental cohort and a validation cohort in a 7:3 ratio. We used multivariate logistic regression to develop a predictive model for hypoglycaemia during colonoscopy and identify independent predictors in pre- and post-colonoscopy hypoglycaemia groups.

Results: We identified 112 of 598 (18.7%) T2DM patients who experienced hypoglycaemia during the peri-colonoscopy period: 43 pre-colonoscopy, 61 post-colonoscopy and 8 at both junctures. Ultimately, five predictors—insulin, SGLT2 inhibitors, fasting after colonoscopy, fasting C-peptide and estimated glomerular filtration rate (eGFR)—were integrated into the predictive model. The AUC for predicting hypoglycaemia was 0.78 (95% CI, 0.71–0.84) and 0.82 (95% CI, 0.74–0.90) in the development and validation cohort, respectively. Variables associated with pre-colonoscopy hypoglycaemia included SGLT2 inhibitors, fasting C-peptide and eGFR, whereas the post-colonoscopy hypoglycaemia group was associated with metformin, duration of diabetes, fasting C-peptide and fasting after the examination.

Conclusion: This study successfully developed and validated a predictive model for assessing hypoglycaemia risk in T2DM patients during peri-colonoscopy.

Implications for the Profession and/or Patient Care: Early identification of patients at high risk for peri-colonoscopy hypoglycaemia allows nurses to implement personalised preventive strategies. The predictive model enables clinical nurses to deliver tailored interventions based on individual risk factors, potentially reducing hypoglycaemia-related complications and improving patient safety outcomes.

Impact: This study provides nurses with a validated risk prediction tool for identifying high-risk type 2 diabetes patients during colonoscopy, enabling targeted blood glucose monitoring protocols and preventive interventions in clinical practice.

The first two authors contributed equally to this article and should be considered co-first authors.

Reporting Method: This study follows the STROBE guidelines for reporting cohort studies.
Patient or Public Contribution: Diabetes patients contributed electronic health record datasets.

1 | Introduction

Colonoscopy is an essential procedure for the screening of colorectal cancer and the management of gastrointestinal health, particularly among patients with type 2 diabetes mellitus (T2DM) who are at an increased risk for the development of colorectal cancer (Lawler et al. 2023; Li et al. 2024). Patients with T2DM are susceptible to a heightened risk of hypoglycaemia, particularly during periods of fasting and procedural preparation (Lu et al. 2023). The preparatory phase for a colonoscopy typically involves a low-fibre diet, an extended fasting period, the ingestion of bowel-cleansing agents and adjustment of antihyperglycaemic medications, all of which can disrupt normal glucose homeostasis (Hochberg et al. 2019). Hypoglycaemia not only complicates procedural outcomes and detracts from the patient's medical experience but also constitutes a serious and potentially life-threatening condition characterised (Chen et al. 2023; Kattan and Abduljawad 2019). Symptoms of hypoglycaemia can range from mild (e.g., sweating, trembling) to severe (e.g., seizures, loss of consciousness), and severe hypoglycaemia can even lead to death if not promptly addressed (Schwartz et al. 2023).

Initial findings from our research indicated that the incidence of hypoglycaemia in patients undergoing colonoscopy is 16.2%, which is substantially higher than those not undergoing the procedure, at 10.1%. After adjusting for demographics and other influencing factors, the risk of hypoglycaemia in the colonoscopy group was approximately twice that of the non-colonoscopy group (Yang et al. 2023), highlighting the imperative for effective risk stratification and management strategies.

Nurses play a pivotal role in preventing and managing hypoglycaemia during colonoscopy procedures. As front-line healthcare providers, they are responsible for continuous blood glucose monitoring, early detection of hypoglycaemic symptoms and timely interventions throughout the peri-colonoscopy period. The development of evidence-based risk prediction tools is particularly crucial for nursing practice, as it enables nurses to identify high-risk patients and implement preventive measures proactively.

2 | Background

The predictors for the occurrence of hypoglycaemia in patients undergoing colonoscopy are multifactorial and complex. The conceptual framework for predicting hypoglycaemia risk during colonoscopy in T2DM patients is based on three interrelated domains: patient characteristics, treatment factors and procedure-specific variables. This framework is supported by previous research (Bakewell et al. 2021; Hochberg et al. 2019; Lee, Jain, and Rajala 2020; Lu et al. 2023; Yang et al. 2023) demonstrating the complex interplay between these factors in determining hypoglycaemia risk.

Patient-specific characteristics play a crucial role in determining hypoglycaemia risk. Studies have identified that patients with longer duration of diabetes demonstrate increased susceptibility to hypoglycaemic events, likely due to progressive beta-cell dysfunction and altered counter-regulatory responses (Cruz 2020; Hochberg et al. 2019). Low C-peptide levels, reflecting impaired endogenous insulin secretion, have been consistently associated with increased glycaemic variability and hypoglycaemia risk (Hochberg et al. 2019; Tseng et al. 2015). Renal function, as measured by estimated glomerular filtration rate (eGFR), is another important predictor as it affects both medication clearance and glucose homeostasis. Additionally, the presence of diabetes-related complications, particularly autonomic neuropathy, may affect both the recognition of hypoglycaemic symptoms and the quality of bowel preparation (Cruz 2020; Tseng et al. 2015). Treatment-related factors significantly influence hypoglycaemia risk during colonoscopy preparation. Insulin therapy, particularly multiple daily injections, has been identified as a major risk factor (Hochberg et al. 2019). The use of SGLT2 inhibitors requires special consideration due to their unique mechanism of action and potential effects on fluid balance during bowel preparation. Metformin, while not directly causing hypoglycaemia, needs careful management due to the risk of lactic acidosis in the context of potential dehydration during bowel preparation (Lewandowski et al. 2021). Procedure-specific variables introduce additional layers of risk. The duration of fasting, which can vary based on procedure scheduling and bowel preparation protocols, directly impacts glycaemic control (Lu et al. 2023). Post-procedure dietary restrictions, particularly in cases requiring polypectomy, can extend the period of altered nutrition, potentially increasing hypoglycaemia risk. The type and timing of bowel preparation agents may also influence fluid status and glucose homeostasis (Yang et al. 2023). However, significant gaps exist in our understanding of how these various factors interact to predict hypoglycaemia risk specifically in the context of colonoscopy. The integration of these factors into a single predictive model allows for comprehensive risk assessment that accounts for the multifaceted nature of hypoglycaemia risk in the peri-colonoscopy period.

Relevant studies have predominantly focused on the occurrence of hypoglycaemia during bowel preparation (Bakewell et al. 2021; Lu et al. 2023), whereas our previous study revealed that 67.6% of hypoglycaemia occurred post-colonoscopy, persisting even in the few days after the procedure (Yang et al. 2023), making it challenging for clinical nurses to identify high-risk patients and implement appropriate preventive strategies. Given the intricate interplay of factors affecting hypoglycaemia risk, there is a critical requirement for robust predictive tools that can guide clinical decision-making and improve patient outcomes. The objective of our study was to identify the factors influencing hypoglycaemia during colonoscopy in patients with T2DM and to develop clinical predictive models for hypoglycaemia during the peri-colonoscopy period. The intention was to provide a

theoretical basis for healthcare professionals to identify individuals at high risk of hypoglycaemia in a timely manner.

3 | The Study

The primary aim was to develop and validate a predictive model for hypoglycaemia risk in T2DM during colonoscopy procedures. Secondary objectives included identifying distinct risk factors for pre- and post-colonoscopy hypoglycaemia to guide targeted preventive interventions.

4 | Methods

4.1 | Design

We performed a retrospective cohort observational study of patients with T2DM who underwent colonoscopy between 1 January 2021 and 31 May 2024, utilising data from the hospital's electronic information system.

4.2 | Study Participants

4.2.1 | Inclusion Criteria

Adult patients (≥18 years); diagnosed with T2DM according to the International Classification of Diseases, Tenth Revision (ICD-10: E11); hospitalised during the study period.

4.2.2 | Exclusion Criteria

Patients with incomplete clinical data; hospital stays of less than 24 h; hypoglycaemia occurring outside of the colonoscopy period; colonoscopy was not completed. In the model analysis of the relationship between predictors and hypoglycaemia, we further excluded patients with missing information on colonoscopy factors, including those with unclear timing of colonoscopy and inadequately documented hypoglycaemia.

4.3 | Data Collection

The researchers designed a data collection form to collect information including basic patient information, date of colonoscopy, whether hypoglycaemia occurred during the period, when hypoglycaemia occurred, and predictors. Based on published literature (Lu et al. 2023; Mosquera-Lopez et al. 2023; Uemura et al. 2022), previous studies (Yang et al. 2023) and clinical expertise, predictors included in the analysis encompassed patient information (e.g., age, gender, days of hospital stay, body mass index (BMI)); disease characteristics (e.g., duration of diabetes mellitus, diabetic complications: diabetic retinopathy, diabetic peripheral neuropathy, diabetic peripheral vascular disease); laboratory indices (e.g., glycosylated haemoglobin A1c (HbA1c), fasting and postprandial 2 h C-peptide, fasting and postprandial 2 h glucose, eGFR); colonoscopy information (e.g., duration of fasting prior to colonoscopy, fasting after colonoscopy). Medication variables primarily refer to antihyperglycaemic medications administered on the day preceding colonoscopy, including insulin, metformin, sulfonylureas, alpha-glucosidase inhibitors, thiazolidinediones, dipeptidyl peptidase-4 (DPP-4) inhibitors and sodium-glucose cotransporter 2 (SGLT2) inhibitors.

We extracted data from the hospital information system for this study. Data collection was standardised using structured Excel forms with built-in validation rules and uniform documentation protocols. The data entry process involved double entry by two independent researchers (HY Yang and LL Zhang). We cross-checked electronic health records with paper records, validated laboratory results and randomly selected 10% of cases for review, paying particular attention to key variables such as hypoglycaemic events and medication records. Outliers and extreme cases were additionally reviewed for accuracy.

4.4 | Definitions of Clinical Endpoints

The clinical endpoint of our study was the occurrence of hypoglycaemia during the peri-colonoscopy period, defined as a blood glucose level <70 mg/dL (3.9 mmol/L) (American Diabetes Association Professional Practice Committee 2024). In our study, blood glucose was measured using point-of-care capillary blood glucose testing with standard hospital grade glucometers (Rightest GM700) during the colonoscopy procedure. All glucometers undergo regular calibration and quality control checks according to our hospital's standard operating procedures, and all measurements were performed by trained nursing staff. Hypoglycaemia was determined based on the documentation in the Nursing Electronic Case and Hospital Information System. The peri-colonoscopy period was defined as the time from gastrointestinal preparation (oral laxatives starting at 8 PM the night before the procedure) until the patient began consuming regular meals after completing the colonoscopy.

4.5 | Statistical Analysis

We used the method of mean imputation to deal with missing data. Missing data included BMI (1.17%), 2-h C-peptide (0.72%), postprandial 2-h glucose (0.67%), eGFR (0.67%) and HbA1c (0.50%). Data processing and analysis were performed using R version 4.3.0 and SPSS 25.0. Continuous variables were evaluated for normality via the Kolmogorov–Smirnov method and were presented as mean (standard deviation, SD) or median (interquartile range, IQR) depending on whether they follow a normal distribution. In univariate analysis, continuous variables were compared by *t* test or Mann–Whitney *U* test depending on the distribution, and categorical variables, expressed as number and/or percentage of patients, were compared by χ^2 test. We used multivariable logistic regression modelling to identify independent predictors of hypoglycaemia events. Model performance was evaluated using area under the receiver operating characteristic curve (AUC) analysis. The AUC measures the model's ability to correctly classify patients with and without hypoglycaemia events, with values >0.7 considered good

discrimination (Alba et al. 2017). Calibration was assessed using the Hosmer–Lemeshow goodness-of-fit test and calibration plots comparing predicted versus observed probabilities. Net benefit was determined using decision curve analysis.

4.6 | Development and Validation of the Hypoglycaemia Model

The study cohort was randomly divided into derivation (70%, $n = 418$) and validation (30%, $n = 180$) cohorts using computer-generated random numbers. Univariate analyses of all descriptive variables were performed with the occurrence of hypoglycaemia (yes/no) as the dependent variable at a significance level of $p < 0.10$ to screen candidates for multivariate analysis. Subsequently, independent variables were identified through a multivariate logistic regression analysis (backward stepwise approach), and a predictive model for hypoglycaemia during the peri-colonoscopy period in T2DM patients was constructed. The application of this model is illustrated through a nomogram. Additionally, we categorised the data into pre-colonoscopy and post-colonoscopy hypoglycaemia groups based on the timing of hypoglycaemia onset. Logistic regression was then conducted on selected variables to determine their independent effects on hypoglycaemia in separate multivariate regression models for each group.

4.7 | Ethical Considerations

The study was approved by the Ethics Committee of Shenzhen Hospital of Traditional Chinese Medicine (approval number K2022-148-01). Given that the patient files used in this study were acquired from previous clinical data, the hospital ethics committee granted the waiver of informed consent. Patient information was kept confidential under the law and no private information such as the name, address and telephone number of the subjects was collected.

5 | Results

5.1 | Patient Characteristics

Among 1195 patients who underwent colonoscopy between 1 January 2021 and 31 May 2024, a total of 598 patients diagnosed with T2DM were included in the final analysis (Figure 1). The mean age of the included patients was 55.65 years (standard deviation ±9.94), with 61.20% of the cohort being male, and the median duration of diabetes among them was 9 years. During the peri-colonoscopy period, 112 patients (18.7%) reported hypoglycaemia, with 43 patients occurring before the colonoscopy, 61 after the procedure and 8 patients experiencing hypoglycaemia both before and after the colonoscopy. Table 1 delineates the patient characteristics.

5.2 | Predictors Through Univariate and Multivariate Logistic Regression Analysis

We compared the intergroup differences between the non-hypoglycaemic and hypoglycaemic groups in the developmental cohort. As shown in Table S1, age, duration of diabetes, BMI, fasting and 2-h postprandial C peptide, fasting plasma glucose, eGFR, diabetic retinopathy, diabetic peripheral neuropathy, insulin, metformin, sulfonylureas, DPP-4 inhibitor, SGLT2 inhibitor and fasting after colonoscopy were entered into multivariate analysis as candidate variables ($p < 0.10$). Age, duration of diabetes, BMI, fasting and 2-h postprandial C-peptide, fasting plasma glucose and eGFR were considered as continuous variables in the model. Following multivariate logistic regression analysis, five predictors, insulin, SGLT2 inhibitors, fasting after colonoscopy, fasting C-peptide and eGFR, were identified for inclusion in the predictive model of hypoglycaemia risk during colonoscopy (Table 2). A nomogram of hypoglycaemia during colonoscopy in patients with T2DM was developed based on the results of logistic regression analysis and is presented in Figure 2.

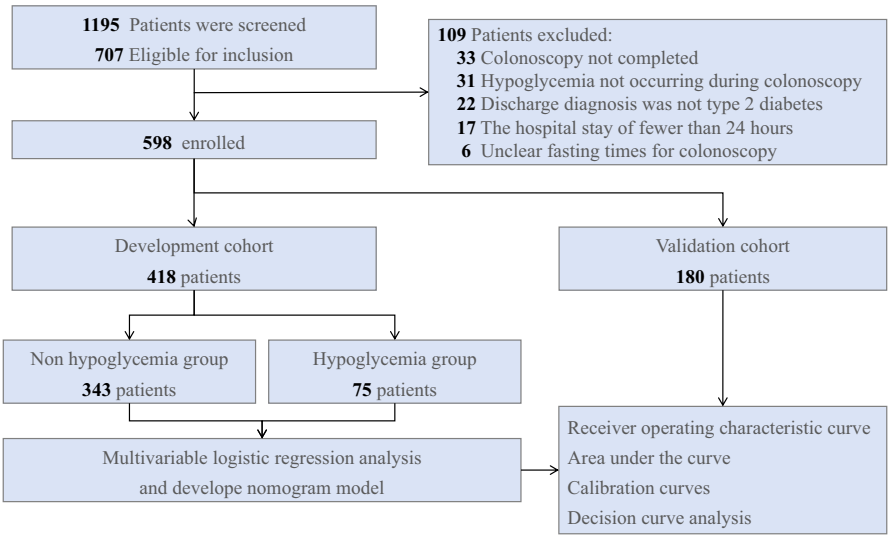

FIGURE 1 | Flowchart of study population selection and research procedure.

TABLE 1 | Baseline characteristics of patients included in the study ($n = 598$).

Variables	Total ($n = 598$)	Development cohort ($n = 418$)		Validation cohort ($n = 180$)	
		Non-hypoglycaemia ($n = 343$)	Hypoglycaemia ($n = 75$)	Non-hypoglycaemia ($n = 143$)	Hypoglycaemia ($n = 37$)
Age (years), Mean ± SD	55.65 ± 9.94	55.36 ± 9.85	57.84 ± 9.51	55.49 ± 9.37	54.46 ± 13.13
Sex, *n* (%)					
Male	366 (61.20)	218 (63.56)	43 (57.33)	83 (58.04)	22 (59.46)
Female	232 (38.80)	125 (36.44)	32 (42.67)	60 (41.96)	15 (40.54)
Days of hospital stay	9 (7, 11)	9 (7, 11)	11 (7, 13)	9 (7, 11)	11 (9, 14)
Duration of diabetes	9 (4, 15)	8 (3, 13)	12 (7, 17)	8 (3, 13)	13 (5, 22)
BMI (kg/m^2)	24.15 (22.08, 26.20)	24.32 (22.80, 26.41)	23.12 (21.17, 25.55)	24.40 (22.44, 26.65)	21.90 (20.70, 24.20)
HbA1c (%)	7.8 (6.9, 9.7)	7.8 (6.8, 9.5)	8.3 (7.1, 9.9)	7.5 (6.8, 8.8)	9.1 (7.2, 12.8)
Fasting plasma glucose (mmol/L)	6.78 (5.58, 8.79)	6.83 (5.81, 9.09)	6.28 (4.62, 8.25)	6.70 (5.47, 8.07)	7.11 (5.29, 11.24)
Postprandial 2h glucose (mmol/L)	11.27 (8.63, 14.18)	11.47 (8.89, 14.56)	10.42 (8.04, 13.09)	11.20 (8.43, 13.87)	11.60 (8.96, 15.06)
Fasting C-peptide (mmol/L)	1.59 (0.92, 2.24)	1.71 (1.12, 2.34)	0.89 (0.40, 1.43)	1.75 (1.19, 2.45)	0.71 (0.48, 1.14)
Postprandial 2h C-peptide (mmol/L)	4.07 (2.41, 6.88)	4.40 (2.78, 7.16)	2.65 (1.06, 3.83)	5.20 (2.95, 7.29)	2.07 (0.86, 3.48)
eGFR ($mL/min/1.73\,m^2$)	97.00 (86.00, 105.00)	97.00 (87.00, 104.00)	95.00 (73.50, 103.00)	100.00 (88.50, 105.00)	96.00 (76.00, 105.00)
Diabetic retinopathy, *n* (%)	174 (29.10)	93 (27.11)	33 (44.00)	33 (23.08)	15 (40.54)
Diabetic peripheral neuropathy, *n* (%)	338 (56.52)	184 (53.64)	52 (69.33)	83 (58.04)	19 (51.35)
Diabetic peripheral vascular disease, *n* (%)	412 (68.90)	232 (67.64)	53 (70.67)	101 (70.63)	26 (70.27)
Insulin, *n* (%)	260 (43.48)	133 (38.78)	52 (69.33)	50 (34.97)	25 (67.57)
Metformin, *n* (%)	248 (41.47)	151 (44.02)	18 (24.00)	68 (47.55)	11 (29.73)
Sulfonylureas, *n* (%)	81 (13.55)	53 (15.45)	5 (6.67)	21 (14.69)	2 (5.41)
α-Glucosidase inhibitors, *n* (%)	43 (7.19)	26 (7.58)	5 (6.67)	8 (5.59)	4 (10.81)
Thiazolidinediones, *n* (%)	12 (2.01)	8 (2.33)	1 (1.33)	3 (2.10)	0 (0.00)
DPP-4 inhibitors, *n* (%)	195 (32.61)	119 (34.69)	18 (24.00)	51 (35.66)	7 (18.92)
SGLT2, *n* (%)	205 (34.28)	130 (37.90)	16 (21.33)	52 (36.36)	7 (18.92)

(Continues)

TABLE 1 | (Continued)

Variables	Total ($n = 598$)	Development cohort ($n = 418$)		Validation cohort ($n = 180$)	
		Non-hypoglycaemia ($n = 343$)	Hypoglycaemia ($n = 75$)	Non-hypoglycaemia ($n = 143$)	Hypoglycaemia ($n = 37$)
Duration of fasting before colonoscopy, *n* (%)					
≤ 12 h	295 (49.33)	170 (49.56)	38 (50.67)	69 (48.25)	18 (48.65)
> 12 h	303 (50.67)	173 (50.44)	37 (49.33)	74 (51.75)	19 (51.35)
Fasting after colonoscopy, *n* (%)					
no	469 (78.43)	284 (82.80)	49 (65.33)	112 (78.32)	24 (64.86)
yes	129 (21.57)	59 (17.20)	26 (34.67)	31 (21.68)	13 (35.14)

Note: Data are reported as median (1st quartile, 3rd quartile) unless otherwise noted.
Abbreviations: BMI, body mass index; DPP-4, dipeptidyl peptidase-4; eGFR, estimated glomerular filtration rate; HbA1c, Glycated haemoglobin; SD, standard deviation; SGLT2, Sodium-glucose cotransporter protein 2.

5.3 | The Performance of Development and Validation Cohorts

The AUC for predicting hypoglycaemia was 0.78 (95% CI, 0.71–0.84) and 0.82 (95% CI, 0.74–0.90) in the development and validation cohorts, respectively (Figure 3), indicating that the model demonstrated a good discrimination ability in the validation cohort. The calibration curves revealed a favourable alignment between predicted and observed probabilities in the cohorts, with the Hosmer–Lemeshow goodness-of-fit test yielding a p value of 0.154 (Figure 4A) for the development cohort and a p value of 1.00 (Figure 4B) for the validation cohort. According to the decision curve analysis, when the model's threshold is set between 6% and 85%, the decision curve lies above the none line and the all line (Figure 5). This indicates that, within this range, the model provides a positive net benefit.

5.4 | Analysis of Pre-Colonoscopy and Post-Colonoscopy Impact Factors

The results of the univariate analysis of pre-colonoscopy and post-colonoscopy hypoglycaemia groups are shown in Table S2. In a subsequent analysis, we repeated the multivariable regression on the entire cohort of 598 patients for two different hypoglycaemia definitions: pre-colonoscopy hypoglycaemia ($n = 51$) and post-colonoscopy hypoglycaemia ($n = 69$) according to the onset of hypoglycaemia in relation to colonoscopy. The pre-colonoscopy hypoglycaemia group was found to be associated with SGLT2 inhibitors, fasting C-peptide and eGFR, whereas the post-colonoscopy hypoglycaemia group was associated with metformin, duration of diabetes, fasting C-peptide and fasting after the examination (Table 2).

6 | Discussion

6.1 | Model Overview and Clinical Significance

The clinical predictive model for hypoglycaemia developed in T2DM patients undergoing colonoscopy presented in this study offers several noteworthy advantages and innovations compared to existing models. First, our model addresses a critical and frequently overlooked clinical scenario: hypoglycaemia during colonoscopy in T2DM patients. The incidence of hypoglycaemia in our study was 18.7%, which is slightly higher than in previous studies (Lu et al. 2023; Yang et al. 2023), suggesting that the incidence of hypoglycaemia in this context was likely underestimated. This finding emphasises the crucial role of nursing staff in enhancing blood glucose monitoring during colonoscopy procedures. Furthermore, our study uniquely analysed the complete peri-colonoscopy period, revealing that 54.5% of hypoglycaemia events occurred post-colonoscopy. This significant finding indicates the need for extended nursing surveillance, particularly during the post-procedure recovery period.

Previous studies (Gao and Zhao 2023; Park et al. 2022; Thomsen et al. 2023) have predominantly focused on the incidence of hypoglycaemia in T2DM patients in general clinical settings or under specific treatments, with a paucity of research targeting the peri-colonoscopy period. Our study endeavours to bridge this

TABLE 2 | Multivariate logistic regression analysis of predictors for hypoglycaemia during the peri-colonoscopy in patients with type 2 diabetes mellitus.

Domain	Variables	β	S.E	Z	p	OR (95% CI)
Development cohort ($n = 418$)	Intercept	3.07	1.35	2.28	0.023	21.64 (1.53 ~ 305.37)
	Insulin	0.72	0.32	2.26	0.024	2.05 (1.10 ~ 3.83)
	SGLT2 inhibitors	−0.70	0.32	−2.14	0.032	0.50 (0.26 ~ 0.94)
	Fasting after colonoscopy	0.92	0.31	2.94	0.003	2.50 (1.36 ~ 4.60)
	BMI	−0.08	0.05	−1.62	0.105	0.92 (0.83 ~ 1.02)
	Fasting C-peptide	−0.63	0.20	−3.18	0.001	0.53 (0.36 ~ 0.79)
	eGFR	−0.02	0.01	−3.04	0.002	0.98 (0.96 ~ 0.99)
Pre-colonoscopy hypoglycaemia ($n = 598$)	Intercept	3.09	1.51	2.04	0.041	21.90 (1.13 ~ 425.72)
	Insulin	0.57	0.37	1.55	0.120	1.77 (0.86 ~ 3.65)
	SGLT2 inhibitors	−1.15	0.43	−2.68	0.007	0.32 (0.14 ~ 0.73)
	BMI	−0.09	0.06	−1.59	0.111	0.91 (0.81 ~ 1.02)
	Fasting C-peptide	−0.69	0.24	−2.92	0.004	0.50 (0.31 ~ 0.80)
	eGFR	−0.03	0.01	−3.21	0.001	0.97 (0.96 ~ 0.99)
Post-colonoscopy hypoglycaemia ($n = 598$)	Intercept	−1.41	1.11	−1.27	0.204	0.24 (0.03 ~ 2.16)
	Metformin	−0.78	0.32	−2.40	0.016	0.46 (0.24 ~ 0.87)
	Duration of diabetes	0.04	0.02	2.10	0.036	1.04 (1.01 ~ 1.08)
	Fasting C-peptide	−0.59	0.19	−3.18	0.001	0.55 (0.39 ~ 0.80)
	eGFR	−0.01	0.01	−1.45	0.146	0.99 (0.97 ~ 1.00)
	HbA1c	0.12	0.06	1.94	0.052	1.13 (1.00 ~ 1.28)

Abbreviations: BMI, body mass index; CI, Confidence interval; eGFR, estimated glomerular filtration rate; HbA1c, glycosylated haemoglobin A1c; OR: Odds ratio; SGLT2, sodium-glucose cotransporter protein 2.

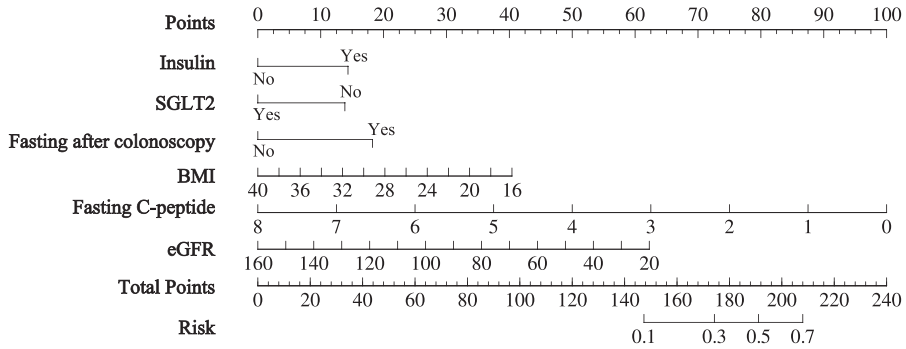

FIGURE 2 | Nomogram for predicting hypoglycaemia during peri-colonoscopy in patients with type 2 diabetes mellitus. BMI, body mass index; eGFR, estimated glomerular filtration rate; SGLT2, Sodium-glucose cotransporter protein 2.

gap by providing a specialised model tailored to the unique physiological and procedural stressors associated with colonoscopy. This specialised approach enables nursing staff to implement evidence-based, targeted interventions throughout the entire procedure cycle, significantly improving patient care quality.

A pivotal advancement of our model is its inclusion of both pharmacological and physiological variables. By integrating insulin therapy, SGLT2 inhibitors, fasting after colonoscopy, fasting C-peptide levels, BMI and eGFR, our model captures a comprehensive picture of patient risk. This multifaceted approach allows for more precise predictions compared to models constricted to a more limited array of factors.

The predictive performance of our model, with an AUC of 0.78 in the development cohort and 0.82 in the validation cohort, demonstrates its robustness and reliability. These metrics indicate good discrimination ability, which is crucial for clinical decision-making. Moreover, the internal validation process underscores the model's potential for generalisability and application in diverse clinical settings. For nursing practice, this comprehensive risk assessment facilitates the early

identification of high-risk patients and guides the development of individualised care plans. Nurses can utilise this model to adjust monitoring frequencies and implement preventive measures based on specific predictors.

6.2 | Key Predictive Factors and Clinical Implications

The inclusion of specific predictive predictors in our model bears substantial clinical implications. Each factor was selected based on its statistical significance and clinical relevance, providing valuable insights for patient management during the peri-colonoscopy period.

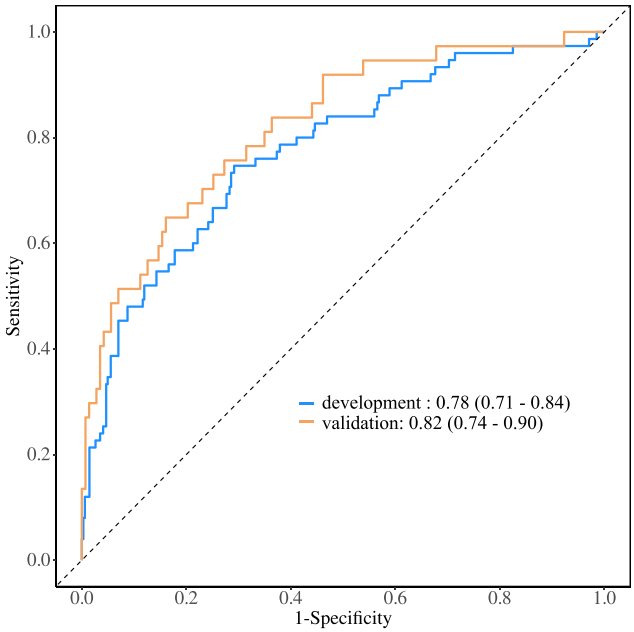

FIGURE 3 | The receiver operating characteristic curve and area under the receiver operating characteristic curve for the prediction of hypoglycaemia during peri-colonoscopy in patients with type 2 diabetes mellitus.

6.2.1 | Insulin Use

Insulin is a substantial contributor to the risk of hypoglycaemia in T2DM patients (Sanchez-Rangel, Deajon-Jackson, and Hwang 2022). Its inclusion in our model emphasises the imperative for careful monitoring and adjustment of insulin therapy around the time of colonoscopy. Clinicians should consider reducing insulin dosage or increasing the frequency of glucose monitoring as a precautionary measure against hypoglycaemia. Future clinical research should be directed towards developing and validating tailored protocols for insulin adjustment that are specifically designed for the peri-colonoscopy period. Randomised controlled trials could serve to compare different insulin dosing strategies, such as reduced pre-procedure dosage regimens versus continuous glucose monitoring-guided adjustments, to determine the most effective approach for maintaining euglycaemia. Nurses should implement more frequent blood glucose monitoring for insulin-treated patients and be prepared to respond promptly to any signs of hypoglycaemia.

6.2.2 | SGLT2 Inhibitors

In our predictive model for assessing hypoglycaemia risk during colonoscopy, the utilisation of SGLT2 inhibitors emerged as a significant protective factor. SGLT2 inhibitors lower blood glucose levels by facilitating the excretion of glucose in the urine (Dharia et al. 2023). Unlike other antidiabetic medications that increase insulin levels or enhance insulin sensitivity, SGLT2 inhibitors reduce glucose reabsorption in the kidneys. This mechanism is independent of insulin secretion and is less likely to cause hypoglycaemia, especially in the fasting state (Vallon and Verma 2021). Clinical trials and real-world studies have consistently demonstrated that SGLT2 inhibitors are associated with a lower risk of hypoglycaemia compared to other glucose-lowering medications in comparison to other glucose-lowering medications such as sulfonylureas or insulin (GRADE Study Research Group et al. 2022). This is particularly relevant during periods of fasting, such as before a colonoscopy, where the risk of hypoglycaemia is heightened. Patients prescribed SGLT2 inhibitors might represent a subgroup with superior overall diabetes

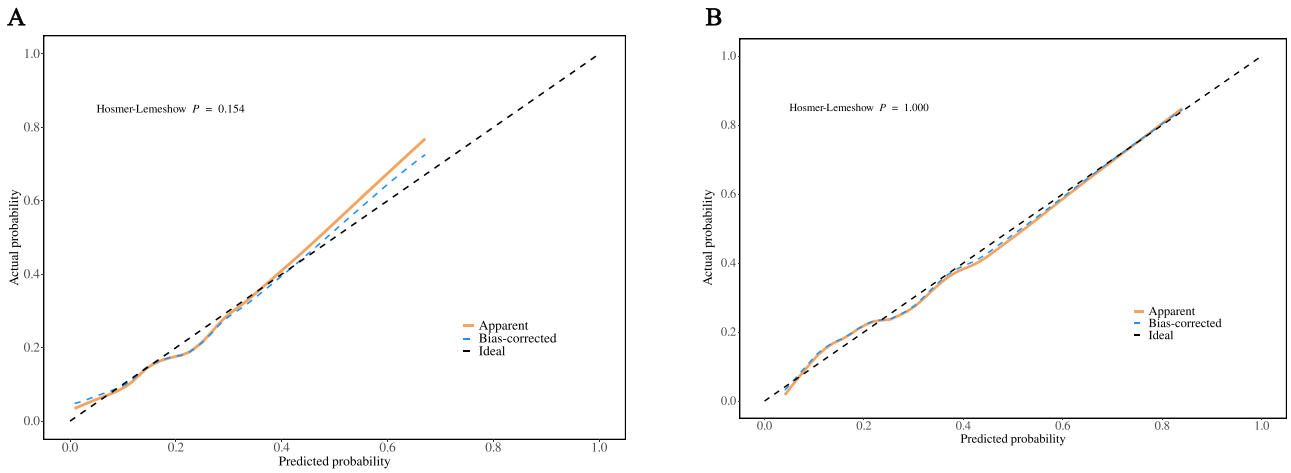

FIGURE 4 | Calibration curve for the prediction of hypoglycaemia during peri-colonoscopy in patients with type 2 diabetes mellitus. (A) Development cohort; (B) Validation cohort.

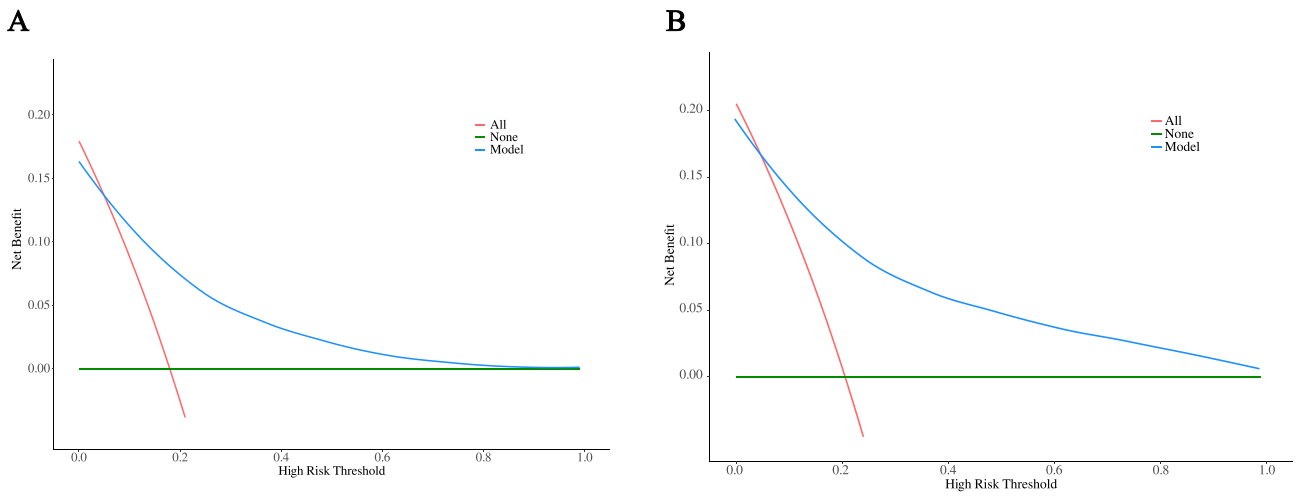

FIGURE 5 | Decision curve analysis for predicting hypoglycaemia during peri-colonoscopy in patients with type 2 diabetes mellitus. (A) Development cohort; (B) Validation cohort.

management and adherence to therapeutic protocols. This could reflect a selection bias where patients on SGLT2 inhibitors are more likely to exhibit well-controlled diabetes and, consequently, a reduced baseline risk of hypoglycaemia. Further studies are warranted to explore the protective role of SGLT2 inhibitors in different clinical settings and patient populations.

6.2.3 | Fasting C-Peptide Levels

Fasting C-peptide is a marker of endogenous insulin secretion. Lower levels of it may indicate impaired beta-cell function and a higher propensity for hypoglycaemia (Christensen et al. 2020). Including fasting C-peptide in the model provides a physiological foundation for assessing hypoglycaemia risk, allowing for more personalised strategies for patient management. Nurses should pay particular attention to patients with low C-peptide levels, implementing more intensive monitoring protocols and ensuring prompt nutritional support when appropriate.

6.2.4 | eGFR

Renal function, as measured by eGFR, is a pivotal determinant of drug clearance and glucose homeostasis. Reduced eGFR can lead to the accumulation of hypoglycaemic agents and impaired gluconeogenesis (Galindo et al. 2023). By incorporating eGFR into the model, we account for the renal contribution to hypoglycaemia risk, thereby guiding clinicians in adjusting medication dosages and monitoring renal function closely. This emphasises the need for nursing staff to consider renal function when assessing hypoglycaemia risk and planning care interventions.

6.2.5 | Fasting After Colonoscopy

Extended fasting periods can precipitate hypoglycaemia (Herz et al. 2023), particularly in patients with compromised glucose regulation. In our study, a significant proportion of patients required prolonged fasting (up to 96 h) due to polypectomy procedures. This extended fasting necessity stems from the higher prevalence of adenomatous polyps in T2DM patients and their subsequent therapeutic requirements.

6.2.6 | Fasting Before Colonoscopy

Despite the clinical expectation that the duration of pre-colonoscopy fasting time would be a significant predictor of hypoglycaemia risk in T2DM patients, this variable was not included in our predictive model. In the original data of our study, elderly patients are typically scheduled for colonoscopy in the morning (with a fasting period of less than 12 h before the procedure). This age-related difference could introduce confounding effects, where the impact of fasting duration on hypoglycaemia risk is intertwined with age-related metabolic and physiological variations. Older patients may possess a higher baseline risk of hypoglycaemia due to factors such as longer disease duration, comorbidities and decreased physiological resilience, which could overshadow the effect of fasting duration. Future research should continue to explore the impact of fasting duration, possibly with more standardised fasting protocols.

6.3 | Pre- and Post-Colonoscopy Predictor Analysis

Our stratified analysis revealed distinct predictors associated with hypoglycaemia occurring before and after colonoscopy. This differentiation is of clinical significance as it allows for targeted interventions based on the timing of hypoglycaemia onset.

6.3.1 | Pre-Colonoscopy Hypoglycaemia

This group was found to be associated with SGLT2 inhibitors, fasting C-peptide and eGFR. The association with SGLT2 inhibitors and eGFR suggests that renal function and medication management play crucial roles in pre-procedural hypoglycaemia risk. Monitoring and potentially potential adjustment of SGLT2 inhibitor use before colonoscopy, especially in patients with lower eGFR, could mitigate this risk. Additionally, lower

fasting C-peptide levels signify the necessity for vigilant monitoring of endogenous insulin secretion and potential adjustments in insulin therapy.

6.3.2 | Post-Colonoscopy Hypoglycaemia

This group was associated with the utilisation of metformin, duration of diabetes, fasting C-peptide levels and fasting after the examination. The inclusion of metformin suggests that the use of metformin may influence post-procedural hypoglycaemia risk. Clinicians should consider these factors when planning post-colonoscopy care, ensuring prompt nutritional support and monitoring glucose levels. The longer duration of diabetes indicates that patients with a longer history of the disease may require more intensive monitoring and management. This temporal differentiation of predictors enables nurses to adjust their monitoring focus and interventions according to the procedure phase, enhancing the efficiency and effectiveness of patient care.

6.4 | Study Limitations

Despite the strengths of our study, there are several limitations that should be acknowledged. First, the retrospective design inherently limits the scope for ascertaining causality. While our model identifies associations between predictors and the occurrence of hypoglycaemia, prospective studies are necessary to confirm these findings and refine the model further. Second, the study population was drawn from a single hospital's electronic information system, which may limit the generalisability of the results. Although internal validation was performed, external validation in diverse populations and assorted care settings is necessary to confirm the model's universal applicability across different clinical environments. Third, the reliance on electronic health records (EHR) data introduces potential biases related to the fidelity and exhaustiveness of these records. Misclassification of hypoglycaemia events or incomplete documentation of relevant variables could impact the model's output. It is therefore incumbent upon future research to supplement and validate EHR data via direct clinical observations and patient self-reporting to fortify the model's reliability. Fourth, the study did not explore the impact of different colonoscopy preparation protocols on hypoglycaemia risk. Variations in preparation methods, such as the type and timing of bowel-cleansing agents, may influence glucose levels and hypoglycaemia risk. Furthermore, our study was conducted in a setting where T2DM patients are typically admitted for colonoscopy procedures, which differs from the outpatient-based approach common in North America and Europe. This difference in healthcare delivery models may affect the generalisability of our findings to healthcare systems where colonoscopy is primarily performed on an outpatient basis. The intensive monitoring possible in an inpatient setting may have influenced both the detection of hypoglycaemic events and the timing of interventions. Future studies should validate these findings in outpatient settings to better understand how different healthcare delivery models might impact hypoglycaemia risk assessment and management.

6.5 | Implications for Future Nursing Research

This study provides important directions for future nursing research. First, external validation studies in diverse clinical settings, particularly in outpatient colonoscopy centres, are needed to evaluate the model's generalisability. Second, based on the identified risk factors, standardised nursing protocols should be developed, including specific measures for blood glucose monitoring frequency, timing of nutritional support and complication prevention. Additionally, nurse-led intervention studies are necessary to evaluate the impact of prediction model-based nursing interventions on patient outcomes and nursing efficiency. Given the high incidence of post-procedure hypoglycaemia, future research should focus on developing post-procedure nursing management strategies, including optimisation of patient education and dietary guidance. These studies will help enhance the evidence base for nursing practice and improve the quality of patient care.

7 | Conclusion

This predictive model has several important implications for clinical practice. Healthcare institutions should integrate this risk assessment tool into their colonoscopy preparation protocols, with specific guidelines for medication adjustment and monitoring frequencies based on individual risk factors. Nursing departments should develop standardised protocols for blood glucose monitoring and intervention based on the model's risk stratification. Policy makers should consider incorporating risk-based screening into quality metrics for endoscopy units. Future work should focus on: (1) external validation studies in diverse healthcare settings, particularly in outpatient facilities; (2) development of automated risk calculation tools integrated into electronic health records; (3) evaluation of the model's impact on patient outcomes and healthcare costs; and (4) adaptation of the model for special populations such as elderly patients or those with comorbidities. Implementation studies examining the model's integration into clinical workflows and its effect on nursing efficiency are also warranted.

Author Contributions

Made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data: H.Y. Yang, L.L. Zhang, H.L. Liu, S.Q. Hu, Q.P. Yang, J.N. Wu. Involved in drafting the manuscript or revising it critically for important intellectual content: H.Y. Yang, L.L. Zhang, S.F. Chu, M.M. Xu. Given final approval of the version to be published; each author should have participated sufficiently in the work to take public responsibility for appropriate portions of the content: H.Y. Yang, L.L. Zhang, H.L. Liu, S.Q. Hu, Q.P. Yang, J.N. Wu, S.F. Chu, M.M. Xu. Agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: H.Y. Yang, L.L. Zhang, S.F. Chu, M.M. Xu.

Acknowledgements

We appreciate the participants for their contributions.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from Shenzhen Hospital of Traditional Chinese Medicine but restrictions apply to the availability of these data, which were used under ethics approval K2022 14801 for the current study, and so are not publicly available. De identified data may be available from the corresponding author upon reasonable request and with permission from the Shenzhen Hospital of Traditional Chinese Medicine Ethics Committee.

Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/jan.16806.

References

Alba, A. C., T. Agoritsas, M. Walsh, et al. 2017. "Discrimination and Calibration of Clinical Prediction Models." *JAMA* 318, no. 14: 1377. https://doi.org/10.1001/jama.2017.12126.

American Diabetes Association Professional Practice Committee. 2024. "6. Glycemic Goals and Hypoglycemia: Standards of Care in Diabetes-2024." *Diabetes Care* 47, no. Suppl 1: S111–S125. https://doi.org/10.2337/dc24-S006.

Bakewell, C., L. J. Howarth, A. Rodrigues, and R. Rogers. 2021. "Hypoglycaemia: A hidden risk in paediatric colonoscopy." *Archives of Disease in Childhood* 106, no. 1: 102.1–102.103. https://doi.org/10.1136/archdischild-2019-318713.

Chen, S., J. Lu, D. Peng, et al. 2023. "Incidence Rate and Risk Factors for Hypoglycemia Among Individuals With Type 1 Diabetes or Type 2 Diabetes in China Receiving Insulin Treatment." *Diabetes Research and Clinical Practice* 206: 110987. https://doi.org/10.1016/j.diabres.2023.110987.

Christensen, M. B., P. Gæde, E. Hommel, A. Gotfredsen, and K. Nørgaard. 2020. "Glycaemic Variability and Hypoglycaemia Are Associated With C-Peptide Levels in Insulin-Treated Type 2 Diabetes." *Diabetes & Metabolism* 46, no. 1: 61–65. https://doi.org/10.1016/j.diabet.2019.02.002.

Cruz, P. 2020. "Inpatient Hypoglycemia: The Challenge Remains." *Journal of Diabetes Science and Technology* 14, no. 3: 560–566. https://doi.org/10.1177/1932296820918540.

Dharia, A., A. Khan, V. S. Sridhar, and D. Z. I. Cherney. 2023. "SGLT2 Inhibitors: The Sweet Success for Kidneys." *Annual Review of Medicine* 74: 369–384. https://doi.org/10.1146/annurev-med-042921-102135.

Galindo, R. J., I. H. de Boer, J. J. Neumiller, and K. R. Tuttle. 2023. "Continuous Glucose Monitoring to Optimize Management of Diabetes in Patients With Advanced CKD." *Clinical Journal of the American Society of Nephrology* 18, no. 1: 130–145. https://doi.org/10.2215/CJN.04510422.

Gao, H., and Y. Zhao. 2023. "A Prediction Model for Assessing Hypoglycemia Risk in Critically Ill Patients With Sepsis." *Heart & Lung* 62: 43–49. https://doi.org/10.1016/j.hrtlng.2023.05.010.

GRADE Study Research Group, D. M. Nathan, J. M. Lachin, et al. 2022. "Glycemia Reduction in Type 2 Diabetes—Glycemic Outcomes." *New England Journal of Medicine* 387, no. 12: 1063–1074. https://doi.org/10.1056/NEJMoa2200433.

Herz, D., S. Haupt, R. T. Zimmer, et al. 2023. "Efficacy of Fasting in Type 1 and Type 2 Diabetes Mellitus: A Narrative Review." *Nutrients* 15, no. 16: 3525. https://doi.org/10.3390/nu15163525.

Hochberg, I., O. Segol, R. Shental, P. Shimoni, and R. Eldor. 2019. "Antihyperglycemic Therapy During Colonoscopy Preparation: A Review and Suggestions for Practical Recommendations." *United European Gastroenterology Journal* 7, no. 6: 735–740. https://doi.org/10.1177/2050640619846365.

Kattan, W. M., and A. A. Abduljawad. 2019. "Predicting Different Factors That Affect Hospital Utilization and Outcomes Among Diabetic Patients Admitted With Hypoglycemia Using Structural Equation Modeling." *Diabetes Research and Clinical Practice* 153: 55–65. https://doi.org/10.1016/j.diabres.2019.05.031.

Lawler, T., Z. L. Walts, M. Steinwandel, et al. 2023. "Type 2 Diabetes and Colorectal Cancer Risk." *JAMA Network Open* 6, no. 11: e2343333. https://doi.org/10.1001/jamanetworkopen.2023.43333.

Lee, B., D. Jain, and M. Rajala. 2020. "A Survey of Peri-Colonoscopy Management of Anti-Diabetic Medications." *Clinical Endoscopy* 53, no. 5: 623–626. https://doi.org/10.5946/ce.2020.021.

Lewandowski, K., G. Rydzewska, and T. K. Ledwoń. 2021. "Preparation for Endoscopic Examinations in Patients With Diabetes and Hypoglycaemia." *Gastroenterology Review* 16, no. 4: 297–305. https://doi.org/10.5114/pg.2021.111763.

Li, Y., J. Tian, T. Hou, et al. 2024. "Association Between Age at Diabetes Diagnosis and Subsequent Incidence of Cancer: A Longitudinal Population-Based Cohort." *Diabetes Care* 47, no. 3: 353–361. https://doi.org/10.2337/dc23-0386.

Lu, X., L. Xie, W. Zhao, C. Zhang, X. Luo, and Y. Zhou. 2023. "Prediction of Hypoglycemia in Diabetic Patients During Colonoscopy Preparation." *Experimental and Clinical Endocrinology & Diabetes* 131, no. 5: 274–281. https://doi.org/10.1055/a-2044-0685.

Mosquera-Lopez, C., K. L. Ramsey, V. Roquemen-Echeverri, and P. G. Jacobs. 2023. "Modeling Risk of Hypoglycemia During and Following Physical Activity in People With Type 1 Diabetes Using Explainable Mixed-Effects Machine Learning." *Computers in Biology and Medicine* 155: 106670. https://doi.org/10.1016/j.compbiomed.2023.106670.

Park, J.-U., Y. Kim, Y. Lee, E. Urtnasan, and K.-J. Lee. 2022. "A Prediction Algorithm for Hypoglycemia Based on Support Vector Machine Using Glucose Level and Electrocardiogram." *Journal of Medical Systems* 46, no. 10: 68. https://doi.org/10.1007/s10916-022-01859-3.

Sanchez-Rangel, E., J. Deajon-Jackson, and J. J. Hwang. 2022. "Pathophysiology and Management of Hypoglycemia in Diabetes." *Annals of the New York Academy of Sciences* 1518, no. 1: 25–46. https://doi.org/10.1111/nyas.14904.

Schwartz, M. W., J. S. Krinsley, C. L. Faber, I. B. Hirsch, and M. Brownlee. 2023. "Brain Glucose Sensing and the Problem of Relative Hypoglycemia." *Diabetes Care* 46, no. 2: 237–244. https://doi.org/10.2337/dc22-1445.

Thomsen, H. B., M. M. Jakobsen, N. Hecht-Pedersen, M. H. Jensen, and T. Kronborg. 2023. "Prediction of Hypoglycemia From Continuous Glucose Monitoring in Insulin-Treated Patients With Type 2 Diabetes Using Transfer Learning on Type 1 Diabetes Data: A Deep Transfer Learning Approach." *Journal of Diabetes Science and Technology* 19, no. 3: 722–728. https://doi.org/10.1177/19322968231215324.

Tseng, Y.-H., Y.-T. Tsan, W.-C. Chan, W. H.-H. Sheu, and P.-C. Chen. 2015. "Use of an α-Glucosidase Inhibitor and the Risk of Colorectal Cancer in Patients With Diabetes: A Nationwide, Population-Based Cohort Study." *Diabetes Care* 38, no. 11: 2068–2074. https://doi.org/10.2337/dc15-0563.

Uemura, F., Y. Okada, T. Mita, et al. 2022. "Risk Factor Analysis for Type 2 Diabetes Patients About Hypoglycemia Using Continuous Glucose Monitoring: Results From a Prospective Observational Study." *Diabetes Technology & Therapeutics* 24, no. 6: 435–445. https://doi.org/10.1089/dia.2021.0465.

Vallon, V., and S. Verma. 2021. "Effects of SGLT2 Inhibitors on Kidney and Cardiovascular Function." *Annual Review of Physiology* 83: 503–528. https://doi.org/10.1146/annurev-physiol-031620-095920.

Yang, H., D. Liu, L. Zeng, S. Peng, and H. Liu. 2023. "Associations of Colonoscopy and Risk of Hypoglycemia in Patients With Type 2

Diabetes." *Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy* 16: 893–900. https://doi.org/10.2147/DMSO.S401903.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.