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Original Research

Prevalence, diagnostic coverage, medication treatment, and glycaemic control of diabetes and associated factors in Cambodia: A cross-sectional study based on the 2023 World Health Survey Plus

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ABSTRACT

Objectives: This study aimed to estimate the national prevalence of type 2 diabetes (T2D), construct a cascade of care for T2D (CoC), and determine the factors associated with prevalence, not previously diagnosed (undiagnosed), and not undergoing medication treatment (untreated).
Study design: This study analysed cross-sectional data from the 2023 World Health Survey Plus in Cambodia, a nationally representative cross-sectional study of 5271 individuals aged ≥18 years.
Methods: The survey used a GIS-based multistage sampling for all 24 Cambodian provinces and the capital city. T2D was measured by haemoglobin A1c or was self-reported. Logistic regression was used to examine the association between outcomes of interest and socio-demographic, behavioural, and metabolic factors.
Results: The weighted prevalence of T2D was 16.0% (95% CI: 14.2-17.9%), with 58.2% (95% CI: 51.9-64.3%) undiagnosed. Of diagnosed individuals, 32.9% (95% CI: 24.2-42.9%) were untreated with medication, and among treated individuals, 61.5% (95% CI: 47.4-74.5%) had poor glycaemic control. T2D prevalence was higher among older age, urban residency, high socioeconomic status, obesity, and hypertension. The prevalence of undiagnosed T2D was higher among younger individuals, less physically active, and those with no history of hypertension. Higher untreated prevalence was associated with rural residency, young individuals, and lower socioeconomic status.
Conclusions: The high prevalence of T2D, of previously undiagnosed and poorly managed T2D, emphasises the need for national policies that strengthen prevention, screening, and equitable access to care through primary healthcare and community-based services in Cambodia.

1. Introduction

Type 2 diabetes (T2D) contributes to morbidity, premature death, and high healthcare costs.[1] Delayed diagnosis can lead to complications, including kidney damage, limb amputation, vision loss, and cardiovascular disease.[1] The International Diabetes Federation estimates that 589 million adults (11.1%) had diabetes globally in 2024, and projections to reach 853 million (13%) by 2040.[1] About 43% of individuals with T2D

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remain undiagnosed, with over 80% of people with T2D living in low- and middle-income countries (LMICs).[1] The prevalence of T2D exhibits variation across different populations and diagnostic methodologies, including Fasting Plasma Glucose (FPG), Glycated Haemoglobin (HbA1c), and the Oral Glucose Tolerance Test (OGTT)0.[2–4] Although no single diagnostic tool has been universally recognised by the World Health Organization (WHO) and the American Diabetes Association (ADA) as the definitive standard, OGTT is regarded as the most reliable method.[3] HbA1c and FPG are used as alternative measures when OGTT is not available.[5] In comparison with OGTT, the sensitivity of HbA1c and FPG is approximately 50%,[6,7] which has implications for prevalence estimation. In a regional context, a study conducted in Thailand reported a T2D prevalence of 19.7% among hospital patients using OGTT, compared to 11.1% using HbA1c, with a sensitivity of 32%.[8] Furthermore, a population-based cross-sectional survey of adults aged 30 or older in Viet Nam indicated a prevalence of 12.3% using HbA1c and 7.4% using FPG.[9]

Cambodia faces an emerging non-communicable disease burden while also addressing communicable diseases. National T2D prevalence among Cambodian adults aged 25-64, as measured by an NCD risk factor surveillance study, increased from 2.9% in 2010 to 7.6% in 2023. {Ministry of Health (MoH) and World Health Organization (WHO), 2023 #565} Another study in Cambodia observed a higher prevalence of 11% among the older population (40 years or older).[10] In addition to the increasing prevalence, T2D management remains limited.{Te, 2024 #581; Ministry of Health - Cambodia (MOH), 2018 #562} An evaluation found low performance across implementation domains: early detection, primary care treatment, health education, self-management support, structured collaboration, and care organisation.[11] While Cambodia's health system is pluralistic, the private sector dominates outpatient services, including T2D.[12,13] In 2020, 63% of T2D-related healthcare visits were to the private sector.[12] This has led to significant out-of-pocket expenses for T2D diagnosis and treatment among households of people with T2D in Cambodia.[12] In response, the Ministry of Health intensified T2D interventions in primary healthcare in 2024.[14]

T2D cascade of care (CoC) begins with prevalence, diagnosis, treatment, and glycaemic control achievement.[15–18] It serves as a metric for assessing health system performance in T2D service delivery.[15–18] CoC analytics identify well-performing steps and those needing additional attention (Fig. 1).[15–18] Several systematic literature review and meta-analysis studies suggest that T2D prevalence is associated with demographics (age, sex, location),[19,20] socioeconomic status (wealth, education), behavioural factors (diet, physical activity, smoking, alcohol),[19] metabolic risks (obesity, hypertension)[19,21] and family history.[19,22] Age affects T2D, as cells become insulin-resistant or produce insufficient insulin. Lifestyle factors are interrelated and linked to metabolic syndrome before T2D development.[23,24] Global T2D diagnosis and treatment rates vary based on demographics, affordability, and access to care.[1] Optimal glycaemic control may be influenced by the quality of care, which is not addressed here. In Cambodia, where the routine data for calculating T2D CoC has not been available, T2D CoC construction uses survey data.[10] A previous study using this approach found low diagnosis and glycaemic control rates, but only included participants aged 40 years or older from mostly rural areas.[10] With T2D increasing among younger populations,[25] this study aimed to estimate national T2D prevalence, construct a CoC, and determine factors associated with prevalence, undiagnosed cases, untreated cases, and poor glycaemic control, covering broader age ranges and geographical areas in Cambodia.

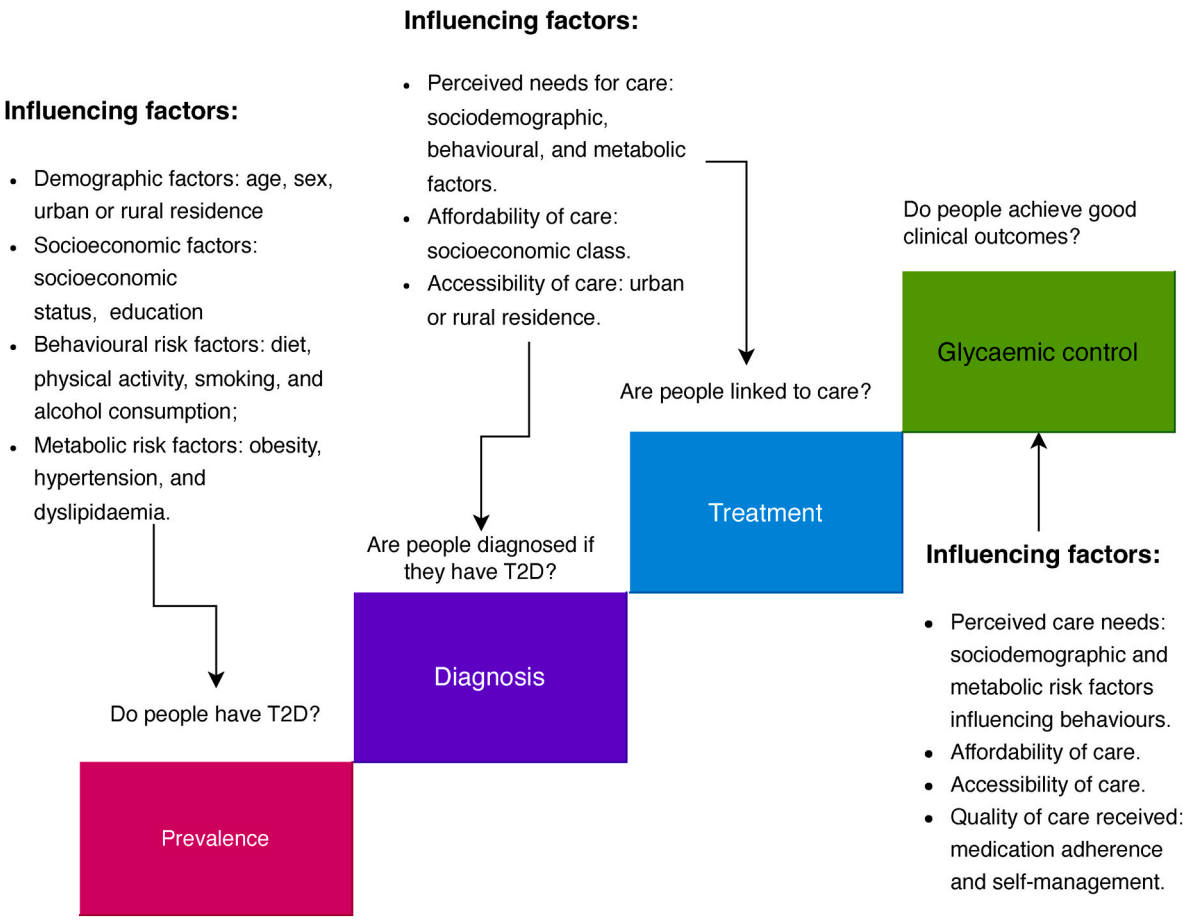

Fig. 1. Conceptual framework for understanding the burden of T2D and its progression through the care cascade.

2. Methods

2.1. Study design

Data were used from Cambodia's 2023 World Health Survey Plus (WHS+), a nationally representative cross-sectional study.[26] The World Health Organization (WHO) WHS+ is a global instrument for monitoring advancements towards country- and global health-related targets and goals.[26] WHS + Cambodia was implemented by the National Institute of Public Health in Cambodia, with technical support from WHO, University of Gothenburg (Sweden), University of Oregon (USA) and Australian National University (Australia), and logistical support from HelpAge International.

2.2. Participants

Refined from a sample of 5,271, this study included 4427 individuals aged 18 or older across all 24 provinces and the capital. Using three-stage sampling, 276 villages were randomly selected, proportional to their size. Households were selected using satellite imagery and GIS mapping, with 44 buildings randomly chosen per village based on the pre-test data. Eligible households required one permanent adult resident to reside there for at least six months in the previous year (n = 6154). One eligible adult per household was randomly selected for interviews, and household heads completed separate questionnaires. Of 6154 eligible households, 5271 completed the survey (85.6% response rate). The sample size was reduced to 4427 after excluding 844 respondents with missing HbA1c results or diabetes diagnosis [Supplementary Fig. 1]. Of the 844 missing records, 278 declined to provide blood samples, and 566 blood samples could not be tested by A1cNow+ due to haemoglobin levels that were too low, too high, and unknown error codes, which were automatically detected by the built-in device's function. The missing data imputation is described in the analysis section.

2.3. Procedures

Between March and May 2023, data were collected by 14 teams, each with a leader, interviewers, and a laboratory technician for biomarker and performance assessment. Team members completed a 10-day training session before data collection. The A1cNow+ (PTS Diagnostics Headquarters, Whitestown, IN, USA) device was used to measure HbA1c levels using non-fasting capillary blood, requiring 5 μL of blood and delivering results in 5 min.[27] The device's integrated quality control system ensures accuracy by identifying issues like inadequate blood volume and extreme temperatures.[28] This device serves research purposes when laboratory-based HbA1c is unavailable.[28]A meta-analysis showed low average bias (−0.70% to +0.67%) compared to laboratory testing.[29,30] Lipids and blood glucose were measured using a CardioChek PA Analyser (PTS Diagnostics Headquarters, Whitestown, IN, USA[28] and blood pressure using an Automatic Blood Pressure Monitor HEM-7120 (OMRON Healthcare, Kyoto, Japan).[31]

2.4. Outcomes

Although the CoC stages can vary slightly from one study to another, this study focused on four progressive stages of CoC.

- *Prevalence:* The first stage focuses on the weighted proportion of individuals with T2D in the study population. A T2D case is defined as an individual with an HbA1c level ≥6.5% or someone who reported using diabetes medication within the last two weeks, irrespective of their HbA1c levels.[32,33]
- *Diagnosis:* This stage measures the weighted proportion of people with T2D (from the prevalence group) who are aware of their condition. This was confirmed by self-reporting of a diagnosis by a doctor or another healthcare professional.
- *Medication treatment:* The third stage focused on the weighted proportion of diagnosed individuals who actively received medication treatment. Specifically, this was defined as the use of medications, including insulin, for diabetes within the last two weeks. It does not include other types of intervention, such as lifestyle modification or other non-pharmacological interventions.
- *Glycaemic control:* The final stage measures the weighted proportion of patients on medication who have achieved optimal glycaemic control, defined as an HbA1c level below 7%.[33]

The explanatory variables included place of residence (urban or rural), sex (male or female), age group (18-29, 30-39, 40-49, >50 years), level of education (none, primary completed, secondary completed, high school completed, or higher), and wealth quintile (from low to high, created using principal component analysis). Urban and rural classifications followed the criteria set by the National Institute of Statistics (NIS).[34] Behavioural and metabolic factors included obesity, physical activity, tobacco use, waist circumference, fruit and vegetable consumption, high blood pressure, total cholesterol, triglycerides, and alcohol consumption. Additional details of the measurements and definitions of these variables are provided in Table 1.

2.5. Statistical analysis

Of the 4427 remaining observations of the analysed dataset, 680 have missing data for one or more independent variables, such as total cholesterol (n = 288) and triglycerides (n = 255). To address the biases due to missing data, we employed Multiple Imputation by Chained Equations (MICE) in R, where all independent variables for this analysis, the weight variable and outcome variables were included. We generated 10 imputed datasets with 100 iterations. All imputed variables converged with categorical variables imputed via logistic regression and continuous variables via Predictive Mean Matching (PMM). After imputation, we excluded records with initially missing T2D outcomes because most missing outcomes (n = 566) resulted from device error codes triggered by physiological extremes (e.g., severe anaemia or polycythaemia), meaning that outcome non-observation is plausibly related to underlying health status. Under these circumstances, standard multiple imputation relying on a missing-at-random assumption may yield biased estimates. The results were pooled for reporting purposes. For comparison, we also included complete-case logistic regression analysis (Supplemental Table 1). This complete-case analysis identified the same factors associated with each outcome compared to the imputed data analysis.

Subsequently, a three-part analysis is performed. Univariate analysis provided individual-based weighted proportions for non-imputed data, matching Cambodia's age–sex population and urban/rural distribution. The cascade percentages were also weighted. Using the same weights, a bivariate analysis was performed using the chi-square test to compare categorical variables. We conducted logistic regression analyses on three outcomes: prevalence, undiagnosed cases, and untreated cases. Glycaemic control was not modelled due to limited sample size and insufficient events, which may produce unreliable results. For prevalence, undiagnosed cases, and untreated cases, we developed four hierarchical models: Model 1 incorporated sociodemographic variables; Model 2 included Model 1 plus behavioural factors; Model 3 added anthropometric factors to Model 2; and Model 4 included clinical factors. In the final models, we refined Model 4 by excluding non-significant variables. We used a generalised linear model (GLM) with binomial specification and weight design.

Multicollinearity was assessed via Variance Inflation Factors (VIF) averaged across 10 MICE-imputed datasets. Although all VIFs were below five, variables that posed a risk of mediation were excluded. Thus, BMI and hypertension were retained, while waist circumference,

Table 1
Categories and measurement of metabolic risk factors.

Variable	Category and measurement
Obesity	Obesity was defined using BMI where BMI was calculated as weight in kilograms divided by the square of height in meters (kg/m^2).[35] Underweight (BMI <18.5 kg/m^2), Normal weight (18.5 kg/m^2≤ BMI ≤25 kg/m^2), Overweight (25 kg/m^2 ≥ BMI <30 kg/m^2), Obese (BMI ≥30 kg/m^2)[35]
Physical activities	Weekly physical activity was assessed using Global Physical Activity Questionnaire (GPAQ) and converted to Metabolic Equivalents of Task (MET) minutes.[36–39] Participants self-reported the frequency and duration of moderate- and vigorous-intensity physical activity at work, non-work, and commuting. MET values were assigned (4 for moderate and 8 for vigorous), and the total weekly MET minutes were calculated.[37–39] Participants were then classified into two groups: <600 MET-minutes, and≥600 (recommended).[38,39]
Tobacco use	Regardless of number of cigarettes or amount of tobacco they used, based on self-reporting, participants were classified as current tobacco users (current smoking/smokeless use daily or less than daily), former users (previous smoking/smokeless use daily or less than daily, but not currently), and non-users. Electronic cigarette smokers were also included in this study. However, this does not include secondary smokers defining those who do not smoke or use tobacco themselves but affected by surrounded people who do.
Waist circumference	Normal (male: ≤102 cm, female: ≤88 cm), High (male: >102 cm, female: >88 cm)
Fruit and vegetable consumption	Fruit and vegetable consumption was classified as meeting WHO recommendations (≥ five servings per day or approximately 400 g of fruit and vegetables combined) or not (<5 servings per day).[40] It was assessed using an interviewer-administered questionnaire based on the WHO STEPS approach, rather than a full Food Frequency Questionnaire (FFQ) or daily food diary. The instrument focused on habitual intake over a 'typical week.' Participants reported the frequency of consumption (days per week) and quantity (servings per day) for both fruit and vegetables. To assist participants in estimating quantity, serving sizes were defined using visual aids (showcards). One serving was defined as around 90 g of fruit or vegetable.
High blood pressure	High blood pressure is classified as "Never," "Ever," and "Uncontrolled." Uncontrolled blood pressure is defined as an average systolic ≥140 mmHg or diastolic ≥90 mmHg from the last two of three measurements. "Ever" refers to individuals diagnosed with hypertension but not classified as uncontrolled during the survey. "Never" denotes those not diagnosed with hypertension by health professionals or detected in the survey.[41]
Total cholesterol level	Elevated (≥240 mg/dL)[42]
Triglyceride levels	Elevated (≥150 mg/dL)[43]
Alcohol consumption	Low risk, high risk (assessed using AUDIT-C)[44]

cholesterol, and triglycerides were removed. Tobacco use was also excluded due to its strong collinearity with gender in the Cambodian population, where prevalence of tobacco use is disproportionately high among males. All statistical analyses were conducted in R, using the MICE package integrated with the survey and MASS packages, and gt_summary, with a significance level of $p < 0.05$.

3. Results

3.1. Respondent characteristics

The weighted proportion of individuals residing in rural communities was 59.1% (95% CI: 56.5-61.6%), of whom 52.2% were female (95% CI: 49.6-54.7%) (see Table 2). The mean weighted age was 41.0 years (95% CI: 40.2-41.8). A large proportion of respondents were married or living together (80.3%, 95% CI: 78.1-82.3%). Approximately 67.9% (95% CI: 65.3-70.3%) of the participants had completed primary school or less.

Approximately 35.2% (95% CI: 32.7-37.7%) of the participants were classified as inactive according to the MET classification (Table 2), and more than half (56.4%, 95% CI: 53.8 -58.9%) did not meet the recommended daily intake of at least five servings of fruits and vegetables. Approximately one-fifth of the participants were current or former smokers (25.0%, 95% CI 22.9-27.3%). A significant proportion of the participants were either overweight (BMI ≥25 kg/m^2 and <30 kg/m^2) (27.7%, 95% CI: 25.5-30.1%) or obese (BMI ≥30 kg/m^2) (6.1%, 95% CI: 4.9-7.4%), and 10.9% (95% CI: 9.5-12.5%) had high waist circumference. A significant proportion of participants had high total cholesterol (12.8%, 95% CI: 11.1-14.6%), high total triglyceride levels (47.3%, 95% CI: 44.7-49.9%), and hypertension (22.5%, 95% CI: 20.5-24.7%).

3.2. T2D prevalence and cascade of care

Fig. 2 presents the weighted percentages of CoC. The weighted prevalence of T2D was 16.0% (95% CI: 14.2-17.9%). Among individuals with T2D, 58.2% (95% CI: 51.9-64.3%) were undiagnosed. Among those diagnosed, 32.9% (95% CI: 24.2-42.9%) did not receive medication treatment. Among those who were treated, 61.5% (95% CI: 47.4-74.5%) had poor glycaemic control.

Females exhibited a slightly higher diagnosis rate (44.4% vs. 38.3%) and medication treatment level (69.1% vs. 64.0%) than males, while their optimal glycaemic control was similar (38.0% vs. 39.3%). Individuals with T2D residing in urban areas showed a slightly higher prevalence of T2D than those in rural areas (22.0% vs. 11.8%), along with higher diagnosis (44.5% vs. 38.3%) and medication treatment rates (79.5% vs. 48.5%). However, there was no discernible difference in glycaemic control rates. Those in the highest wealth quintile had a higher medication treatment rate; however, this did not extend to diagnosis and glycaemic control rates.

3.3. Factors associated with T2D prevalence, being undiagnosed, being untreated, and poor glycaemic control: results of multivariate analysis

Table 3 present factors associated with T2D prevalence, undiagnosed, and untreated, from multiple logistic regression analyses, based on reduced models that include only selected significant variables. The results of bivariate analyses are presented in Supplementary Tables 2–5, and Supplementary Tables 6–8 show the complete hierarchy models.

3.4. Factors associated with T2D prevalence

The likelihood of having T2D was independently associated with urban residency (AOR 1.7, 95% CI 1.2-2.2), aged 40-49 years (AOR 2.1, 95% CI 1.4-3.1), age ≥50 years (AOR 3.4, 95% CI 2.3-4.9) compared to individuals aged 18-39 years, belonging to the non-poor quintile (middle/rich/richest) (AOR 1.5, 95% CI 1.1-2.1), obesity (AOR 3.0, 95% CI 1.8-5.0), and hypertension (AOR 2.2, 95% CI 1.6-3.1).

3.5. Factors associated with being undiagnosed

Factors independently associated with undiagnosed status included being aged 18-39 (AOR 2.5, 95% CI: 1.1-5.5) compared with those aged 50 years and above. Individuals who are physically inactive with a MET score <600 (AOR 2.4, 95% CI: 1.4-4.0), and having no history of hypertension (AOR 2.5, 95% CI: 1.4-4.4) were also associated with a higher likelihood of being undiagnosed.

3.6. Factors associated with being untreated

Being untreated or not undergoing medication treatment was associated with rural residency (AOR 5.2, 95% CI 2.0- 14), belonging to the 18-39 age group (AOR 8.4, 95% CI: 1.4, 50) compared to those aged 50

Table 2
Sociodemographic, behavioural, and metabolic characteristics of respondents.

	Unweighted		Weighted	
Characteristic	N = 4427	95% CI	N = 4427	95% CI
Type of community				
Rural	2750 (62·1)	60·7, 63·5	59·1	56·5, 61·6
Urban	1677 (37·9)	36·5, 39·3	40·9	38·4, 43·5
Sex of participant				
Male	1336 (30·2)	28·8, 31·5	47·8	45·3, 50·4
Female	3091 (69·8)	68·5, 71·2	52·2	49·6, 54·7
Age in years [mean (SD), mean (95%)]	47·3 (14·9)	46·9, 47·8	41·0	40·2, 41·8
Age group (years)				
18-39	1479 (33·4)	32·0, 34·8	53·3	50·8, 55·8
40-49	922 (20·8)	19·7, 22·0	17·7	15·9, 19·7
50+	2026 (45·8)	44·3, 47·2	29·0	26·9, 31·2
Marital status				
Married or living together	3452 (78·0)	76·7, 79·2	80·3	78·1, 82·3
Never married	242 (5·5)	4·8, 6·2	11·3	9·6, 13·2
Separated/divorced/windowed	733 (16·6)	15·5, 17·7	8·5	7·3, 9·8
Wealth quintile				
Poorest	873 (19·7)	18·6, 20·9	13·8	12·2, 15·6
Poor	886 (20·0)	18·9, 21·2	16·6	14·8, 18·5
Middle	897 (20·3)	19·1, 21·5	20·8	18·8, 22·9
Rich	891 (20·1)	19·0, 21·3	21·0	19·0, 23·1
Richest	880 (19·9)	18·7, 21·1	27·9	25·5, 30·3
Education level				
Primary school or less	3524 (79·6)	78·4, 80·8	67·9	65·3, 70·3
Secondary/middle school	537 (12·1)	11·2, 13·1	18·0	16·0, 20·2
High school+	366 (8·3)	7·5, 9·1	14·1	12·3, 16·2
MET category				
Active (≥600)	3027 (68·5)	67·1, 69·8	64·8	62·3, 67·3
Inactive (<600)	1395 (31·5)	30·2, 32·9	35·2	32·7, 37·7
Fruit & vegetable consumption				
≥5 (adequate)	1909 (43·1)	41·7, 44·6	43·6	41·1, 46·2
<5	2518 (56·9)	55·4, 58·3	56·4	53·8, 58·9
Tobacco use				
Current/former smoker	1173 (26·5)	25·2, 27·8	25·0	22·9, 27·3
Never	3254 (73·5)	72·2, 74·8	75·0	72·7, 77·1
Alcohol disorder category				
Low risk	3533 (79·8)	78·6, 81·0	75·6	73·3, 77·8
High risk	894 (20·2)	19·0, 21·4	24·4	22·2, 26·7
BMI [mean (SD), mean (95% CI)]	23·9 (4·1)	23·8, 24·0	23·7 (4·1)	23·4, 23·9
BMI category				
Underweight (<18·5 kg/m^2))	324 (7·4)	6·7, 8·2	9·1	7·7, 10·8
Normal (18·5-24·9 kg/m^2))	2472 (56·4)	54·9, 57·8	57·1	54·6, 59·7
Overweight (25·0-29·9 kg/m^2))	1278 (29·1)	27·8, 30·5	27·7	25·5, 30·1
Obese (≥30·0 kg/m^2))	311 (7·1)	6·4, 7·9	6·1	4·9, 7·4
Waist circumference category				
Normal	3729 (84·6)	83·5, 85·6	89·1	87·5, 90·5
High	680 (15·4)	14·4, 16·5	10·9	9·5, 12·5
Total cholesterol				
Normal	3529 (84·5)	83·4, 85·6	87·2	85·4, 88·9
Elevated (≥240 mg/dL)	648 (15·5)	14·4, 16·6	12·8	11·1, 14·6
Toal triglycerides				
Normal	2096 (49·8)	48·3, 51·3	52·7	50·1, 55·3
Elevated (≥150 mg/dL)	2111 (50·2)	48·7, 51·7	47·3	44·7, 49·9
Having hypertension	1316 (29·7)	28·4, 31·1	22·5	20·5, 24·7

Abbreviation: CI, Confidence Interval; BMI, Body Mass Index; MET, Metabolic Equivalent of Task.

years and above, being in poor quintile (poor/poorest) (AOR 4.0, 95% CI: 1.4, 11) compared with a group from combining middle, rich, and richest quintile.

4. Discussion

Our study showed high attrition across the CoC, with more noticeable diagnostic low and glycaemic control rates. T2D prevalence was higher in the population with urban residency, older age, obesity, higher wealth quintile, and hypertension. People with T2D were more likely to be undiagnosed if they were younger, physically inactive and had no history of hypertension. For diagnosed individuals, the likelihood of remaining untreated was higher in rural residents, younger age groups, and lower wealth quintiles.

4.1. T2D prevalence

The national T2D prevalence (16.0%) exceeded the global estimate of 11.1% based on FBG and was higher than the 6.3% prevalence found in the 2023 NCD risk factor surveillance survey in Cambodia using FBG.[45] A study in 2020 among Cambodians aged 40+ years, using FBG as the first screening and HbA1c as the confirmatory test, reported a prevalence of 11%, which may have underestimated the true prevalence.[10] The prevalence in our study surpassed that reported in neighbouring countries: 9.9% in Thailand (National Health Examination Survey 2014),[46] 4.1% in Viet Nam (2015),[47] 5.7% in Laos (2013),[48] all using FBG. This variation may be due to the use of HbA1c, which typically yields higher estimates than FBG, consistent with studies in Viet Nam,[49] Canada,[50] and Caribbean countries.[51] Despite the prevalence of T2D being higher by HbA1c than by FBG, they capture different

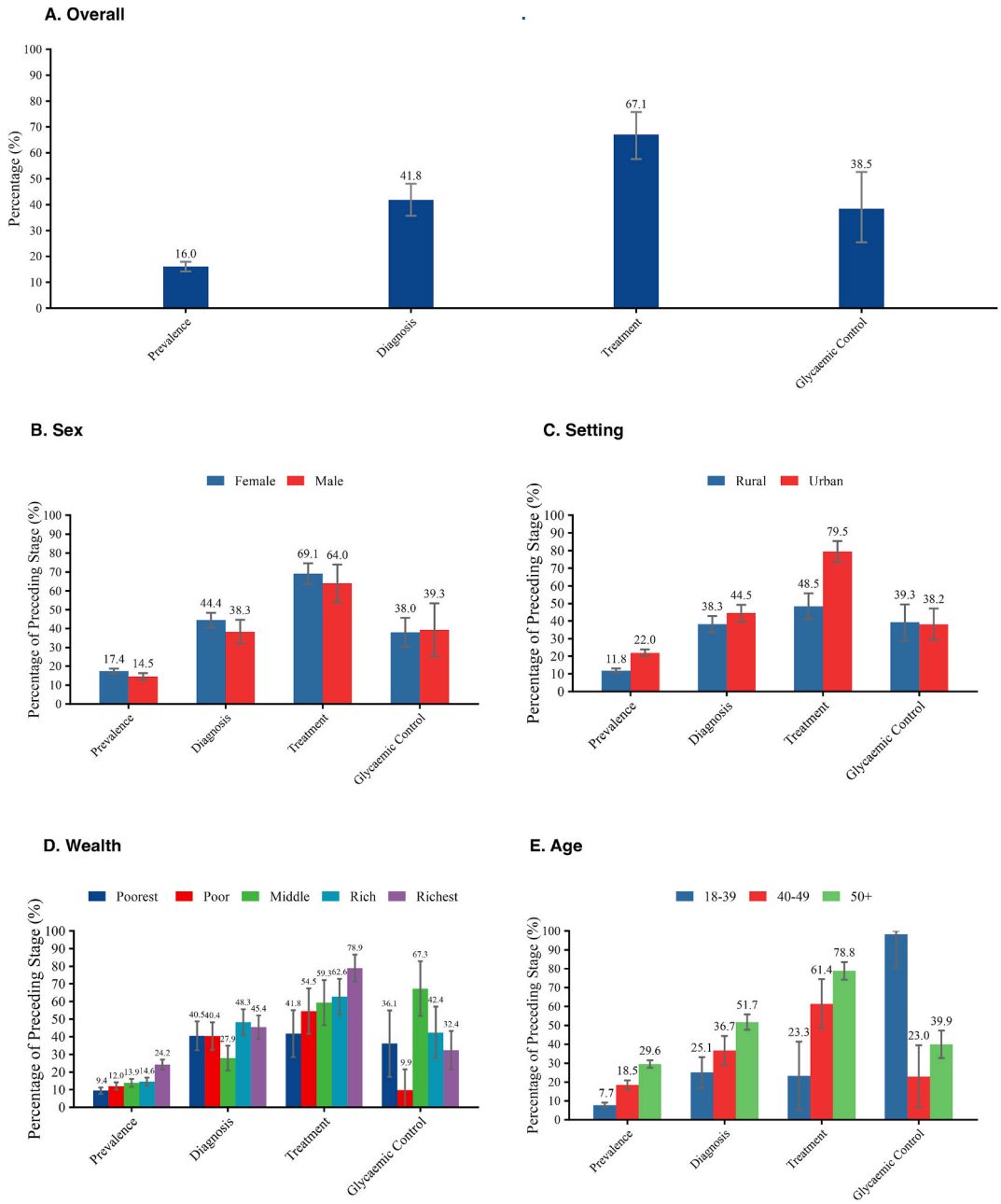

Fig. 2. Prevalence of T2D, diagnosis, medication treatment, and control rates.

populations with T2D, and OGTT remains superior for diagnosis in a clinical setting.[52] When OGTT is used as the reference, HbA1c shows a relatively low sensitivity of 51%, whereas for FBG it is 49%, with specificities of 96% for HbA1c and 98% for FBG.[52] The prevalence estimated in our study may be underestimated because the screening tool's capacity is limited. Consistent with studies in neighbouring countries (Viet Nam,[19,53,54] Laos,[48] Thailand[53,54]) and other settings (China,[55] Kenya,[56] Ethiopia[22]), older age, high BMI, and hypertension were associated with higher T2D prevalence in the final models.

Urban residence was associated with a higher risk of T2D in the final model, providing evidence that urban environments remain influential factors.[57] Urban settings promote shifts towards processed foods and sedentary behaviour, contributing to increased obesity and metabolic risk. This also means a rapid increase in urbanisation will increase the T2D burden in the future. The finding that a higher socioeconomic status was associated with T2D prevalence was aligned with a systematic meta-analysis in low-and middle-income countries, showing that people of high socioeconomic status were less physically active and consumed more fats, salt, and processed food than those of low socioeconomic status.[58]

4.2. *Diagnosis gap*

Our undiagnosed rate (58.2%) exceeded the global rate of 45% and rates in Laos (42%), Thailand (33.3%), and Viet Nam (37.8%) and Cambodian results from Te et al. (37%), the NCD risk factor surveillance survey in 2023 (52%).[1,10,45] The findings that younger individuals and those without a history of hypertension had higher chances of being undiagnosed, possibly due to T2D's asymptomatic nature and limited access to screening. In 2023, 70% of health centres lacked T2D diagnostic capacity.[14,55] Limited public awareness of diabetes symptoms and low health literacy may contribute.[55] To the best of our knowledge, the observation that individuals with T2D who are aware of their condition are more physically active than those who are not may be attributed to

Table 3
Factors associated with T2D prevalence, undiagnosed and untreated, from the multiple logistic regression analyses.

	Prevalence			Undiagnosed			Untreated		
Characteristic	AOR	95% CI	p-value	AOR	95% CI	p-value	AOR	95% CI	p-value
Type of community									
Rural	Ref.						5.2	2.0, 14	**<0.001**
Urban	1.7	1.2, 2.2	**<0.001**				Ref.		
Age group (years)									
18-39	Ref.			2.5	1.1, 5.5	**0.024**	8.4	1.4, 50	**0.020**
40-49	2.1	1.4, 3.1	**<0.001**	1.8	0.9, 3.5	0.084	Ref.		
50+	3.4	2.3, 4.9	**<0.001**	Ref.			0.4	0.1, 1.2	0.096
Socio-economic class									
Poor/Poorest	Ref.						4.0	1.4, 11	**0.010**
Middle/Rich/Richest	1.5	1.1, 2.1	**0.007**				Ref.		
MET category									
Active (≥600)				Ref.					
Inactive (<600)				2.4	1.4, 4.0	**0.001**			
MET category									
BMI Category									
Normal (18.5-24.9 kg/m^2)	Ref.								
Underweight (<18.5 kg/m^2)	1.2	0.7, 2.2	0.496						
Overweight (25.0-29.9 kg/m^2)	1.2	0.8, 1.7	0.323						
Obese (≥30.0 kg/m^2)	3.0	1.8, 5.0	**<0.001**						
Having hypertension history									
No	Ref.			2.5	1.4, 4.4	**0.001**			
Yes	2.2	1.6, 3.1	**<0.001**	Ref.					

Abbreviations: AOR = Odds Ratio, CI, Confidence Interval; BMI, Body Mass Index; MET, Metabolic Equivalent of Task.

the fact that those who know their status might begin to modify their lifestyle.

4.3. Medication treatment gap

The proportion of untreated with medication (32.9%) in our study exceeds the global rate of 10% using similar definition (currently treated with medication) but matches the rates in low- and middle-income countries (30%).[18] Our survey found that rural residents and those with lower socioeconomic status were more likely to be untreated with medication, indicating geographical and financial barriers to T2D medication treatment. Similar to diagnosis, the role of health centres and awareness of complications can be influential factors explaining this association.[56] Given that urban and higher-socioeconomic-status individuals have higher treatment rates, this may be due to the role of private healthcare, which is more accessible in urban settings and among those who can afford it.[12] This suggests that expanding medication treatment services, especially in rural areas, and social health protection is needed. As with diagnosis, intensifying awareness of appropriate T2D management based on context remains crucial.

4.3.1. Glycaemic control gap

The rate of poor glycaemic control in our study (61.5%) was higher than the global rate of 57.4% but lower than that in Oceania (75%).[18] Our study could not model glycaemic control because of the limited sample size and event. Studies targeting individuals with T2D undergoing medication treatment should be conducted.

4.4. Public health implications and policy recommendations

This study identified various gaps in the CoC. They suggested a multipronged approach that focused on strengthening prevention, early detection, improving access to medication treatment, and enhancing support for long-term management (Fig. 3). While existing interventions predominantly target individuals aged 40 years or older, our study's findings indicate that younger individuals exhibit a higher likelihood of being undiagnosed and remaining untreated. Therefore, prevention and management strategies should be redirected to include the young and newly diagnosed people with T2D, and further qualitative studies should explore the care-seeking behaviours among them.

4.5. Strengths and limitations

The key strengths of the current study include its nationally representative nature and the use of HbA1c measurements to define diabetes and assess glycaemic control, which improves accuracy compared to self-reported data.[29] The use of CoC analytics provides a holistic view of T2D management challenges.

This study has several limitations. The cross-sectional design prevents causal conclusions between the determinants and outcomes. Self-reported variables may be subject to recall or social desirability bias. Low sensitivity of HbA1c led to an underestimation of the burden of T2D in the Cambodian population. Excluding 844 respondents due to unavailable HbA1c results could have introduced selection bias, further affecting the prevalence estimates without a clear direction. However, an analysis comparing the characteristics of those with and without HbA1c measurements showed similar sociodemographic profiles [Supplementary Table 9], with slightly different behaviour and metabolic characteristics [Supplementary Table 10]. Glycaemic control could not be modelled due to the small sample size and the number of events.

4.6. Conclusion

Our analysis shows a high T2D prevalence in adult Cambodians, with significant attrition at each CoC stage, especially in diagnosis and glycaemic control. T2D prevalence was higher among urban residents, older individuals, obese people, those with higher wealth, and hypertension. Undiagnosed T2D was more common in younger, inactive, and hypertensive individuals. Untreated with medication was more likely in rural, younger, and lower-wealth groups quintiles. Contextualising prevention efforts and strengthening primary healthcare for T2D diagnosis and medication treatment, including community programs, are crucial for enhancing diabetes care in Cambodia. Studies focusing on glycaemic control and qualitative studies of patients, healthcare providers, and policymakers should provide insights into the barriers and facilitators of diabetes care in Cambodia, and further research should be conducted.

Ethical statement

The WHS + protocol was approved by the National Ethics Committee

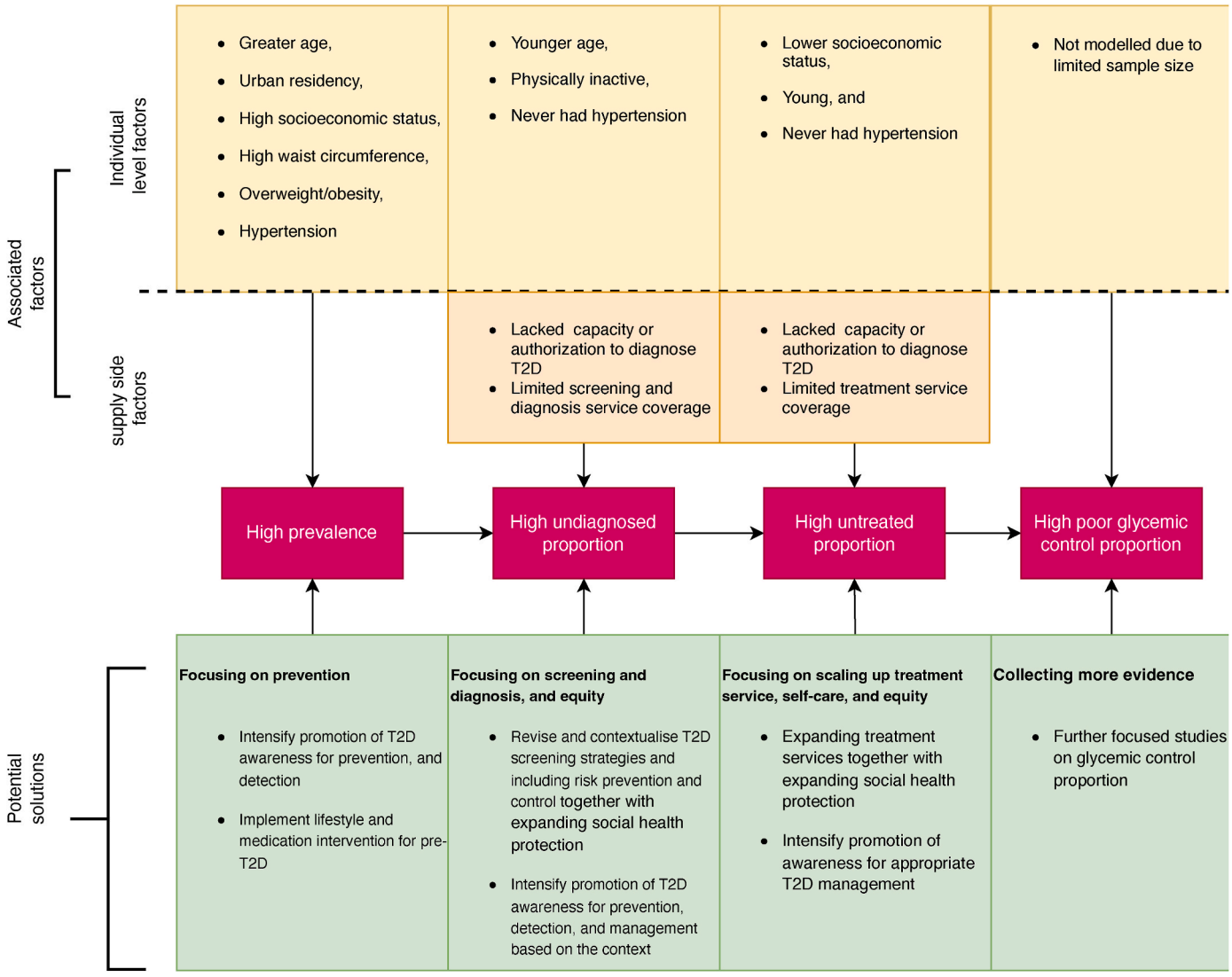

Fig. 3. Summary of public health implications and policy recommendations.

for Health Research (NECHR) in Cambodia on July 20, 2022 (Document No. 221 NECHR). All respondents provided verbal informed consent. All personal identifiers were removed from the dataset. Laboratory samples were analysed immediately and not stored.

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Declaration of competing interest

We declare no competing interests and have completed the ICMJE uniform disclosure form at www.icmje.org/disclosure-of-interest/.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2026.106226.

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