Original Paper

Clinical Decision Support System for Patients With Poorly Controlled Type 2 Diabetes in Chinese Primary Care: Retrospective Propensity Score–Matched Cohort Study

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Abstract

Background: Type 2 diabetes management in Chinese primary health care (PHC) is constrained by clinical inertia, fragmented information systems, and limited physician training. Clinical decision support systems (CDSSs) may improve diabetes care, but real-world evidence from integrated PHC settings in China remains scarce.

Objective: This study evaluated the effectiveness of a comprehensive CDSS-based intervention on glycemic and metabolic outcomes and hospitalization among patients with poorly controlled type 2 diabetes in PHC institutions.

Methods: This retrospective cohort study included adults with type 2 diabetes and baseline glycated hemoglobin (HbA_{1c}) 7.0% or greater attending 16 community health service centers in Kunshan, China (January 1 to September 30, 2024), with 1-year follow-up (data cutoff September 30, 2025). Patients receiving CDSS-assisted care were compared with those receiving routine care using one-to-one nearest-neighbor propensity score matching without replacement (caliper 0.1 SD of the logit of the propensity score). Primary outcomes were 1-year HbA_{1c} change and glycemic control rate (HbA_{1c} <8.0%, an individualized target; the strict <7.0% target was also assessed). Secondary outcomes included fasting plasma glucose, lipids, blood pressure, and all-cause, atherosclerotic cardiovascular disease (ASCVD)–related, and diabetes-related hospitalization. Multivariable regression, subgroup analyses with interaction tests, and sensitivity analyses (inverse probability weighting; E-values) were performed.

Results: Of 18,873 eligible patients (6235 through CDSS, 12,638 through routine care), 12,272 (6136 matched pairs) were matched; all postmatching standardized mean differences were <0.1. At 1 year, the CDSS group had a greater HbA_{1c} reduction (–0.90% vs –0.20%; difference –0.70 percentage points, 95% CI –0.76 to –0.63; P<.001) and a higher glycemic control rate (63.9% vs 47.4%; difference 16.5 percentage points, 95% CI 14.8 to 18.3; P<.001; strict<7.0%: 30.7% vs 19.8%). The CDSS group also showed greater improvements in fasting plasma glucose, lipids, and diastolic blood pressure and lower all-cause (23.4% vs 37.6%; difference –14.2 percentage points, 95% CI –15.8 to –12.6), ASCVD-related, and diabetes-related hospitalization (all P<.001). In multivariable models, CDSSs were independently associated with greater HbA_{1c} reduction (β=–.68, 95% CI –0.73 to –0.63) and higher odds of glycemic control (odds ratio [OR 2.40, 95% CI 2.21-2.59). Benefits were greater in older patients, those with longer diabetes duration, and those with comorbidities (all interactions P<.05). Results

were consistent in sensitivity analyses (inverse probability weighting: HbA_{1c}-change difference –0.53 percentage points; E-value 4.2).

Conclusions: Among patients with poorly controlled type 2 diabetes in PHC, CDSS-assisted management was associated with clinically meaningful improvements in glycemic control, metabolic indicators, and hospitalization at 1 year. Controlled trials and economic evaluation are needed to confirm causality and cost-effectiveness before wide adoption.

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Keywords: clinical decision support system; primary health care institutions; diabetes mellitus; blood glucose control; metabolic indicators

Introduction

Burden of Diabetes and the Role of Primary Care in China

Over the past 40 years, the prevalence of diabetes in China has increased from less than 1.0% in 1980 to 12.4% in 2018, making China home to the world's largest population of people with diabetes [1]. According to the International Diabetes Federation, approximately 537 million adults worldwide were living with diabetes in 2021, with China accounting for roughly one-quarter of these cases [2]. Diabetes and its complications impose a substantial economic burden: direct costs of diabetes management are projected to rise from US $190.2 billion in 2020 to US $337.8 billion in 2030, while indirect costs from premature death and disability are expected to double from US $60 billion to US $122.6 billion over the same period [3]. Consequently, diabetes management has been prioritized within the "Healthy China 2030" initiative and the 14th Five-Year Plan (2021-2025) for National Health [4].

In China, primary health care (PHC) institutions are the first point of contact for most people with diabetes [5]. Since 2009, the National Basic Public Health Service Program (NBPHSP) has included type 2 diabetes management—screening, regular follow-up, and health education—as a core funded service [6]. Despite these investments, effective diabetes management in PHC remains challenging: practitioners have varying qualification levels and high workloads, clinical care and public health services remain fragmented, and opportunities for training are insufficient [5,7]. PHC settings also show lower diagnosis and treatment quality and lower patient trust than tertiary hospitals [8]. National data consequently show a persistent glycemic control rate of approximately 50% and high hospitalization and readmission rates [9-11].

Clinical Decision Support Systems: Evidence and Gaps

Clinical decision support systems (CDSSs) are information systems embedded in or linked to electronic medical records that provide clinicians with real-time, patient-specific, evidence-based suggestions [12,13]. Evidence suggests CDSSs can improve glucose, blood pressure, and lipid management without increasing hypoglycemia risk [14-16], and meta-analyses of controlled clinical trials have shown absolute improvements in processes of care [14,15]. A scoping review of 85 studies found that CDSSs are widely used by primary care physicians and endocrinologists, particularly for insulin titration and medication adjustment [17]. Their integration into telemedicine for patients with multimorbidity has also been reviewed [18]. In China, however, existing studies have mostly examined single-function applications such as AI-based retinopathy screening [19], computer-aided self-monitoring [20], or mobile app–based decision support [21]. There is a lack of real-world evidence on comprehensive CDSS interventions that integrate clinical and public health data within PHC.

Study Objectives

The aim of this study was to evaluate the effectiveness of a comprehensive CDSS-based intervention—integrated with the NBPHSP and a municipal health information platform—on glycemic control, metabolic indicators, and hospitalization among patients with poorly controlled type 2 diabetes (glycated hemoglobin [HbA_{1c}] ≥7.0%) attending PHC institutions in Kunshan, China. We hypothesized that, compared with routine care, CDSS-assisted management would be associated with a greater reduction in HbA_{1c}, a higher glycemic control rate, better metabolic profiles, and lower hospitalization rates at 1 year.

Methods

Data Sources and Study Population

Data were sourced from the Kunshan Municipal National Health Data Platform, which aggregates clinical records from medical institutions at all levels in the city and integrates geriatric physical examinations and NBPHSP follow-up records for patients with diabetes. The platform includes outpatient and inpatient registration, disease diagnoses, medication records, and laboratory results, alongside public health information such as regular physical examinations and follow-up management. Records were linked by unique patient identifiers to ensure longitudinal consistency.

The study population consisted of patients with diabetes who attended 16 community health service centers (CHSCs) in Kunshan between January 1 and September 30, 2024. Diabetes was diagnosed according to the Guidelines for the Prevention and Control of Type 2 Diabetes in China (2022 edition) [22]. Inclusion criteria were as follows: (1) baseline HbA_{1c} 7.0% or greater (poor glycemic control), (2) complete baseline health indicators, and (3) at least one HbA_{1c} measurement recorded during the 1-year follow-up window.

Patients were excluded if they had incomplete baseline data or severe comorbidities (end-stage renal or hepatic failure, malignant tumors) that prevented follow-up completion.

Ethical Considerations

The study was approved by the Ethics Committee of the National Center for Chronic and Non-communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention (approval number 202329). As a retrospective analysis of deidentified routinely collected health data, the requirement for individual informed consent was waived by the ethics committee. All records were pseudonymized before analysis using unique encrypted patient identifiers; direct identifiers were removed, and data access was restricted to authorized study investigators under the data governance rules of the Kunshan Municipal Health Commission.

Study Design and Patient Flow

This study is reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement [23]. The completed STROBE checklist is provided in Checklist 1. This retrospective cohort study compared patients receiving routine care (routine care group) with those receiving CDSS-assisted care in addition to routine services (CDSS group). The baseline date was defined as the date of the first CDSS-assisted visit for the CDSS group and the first CHSC visit in the study period for the routine care group. The follow-up end date was 1 year after baseline. For patients enrolled in September 2024, the data cutoff was September 30, 2025; therefore, all included patients had at least 12 months of potential follow-up.

Patients were screened in a standardized sequence. Among patients with diabetes attending any of the 16 CHSCs, those with missing baseline health indicators or test records, a baseline HbA_{1c} of less than 7.0%, or no $HbA_{1c,}$ a record in the 3 months before and after were excluded, yielding a poor-control cohort with complete baseline and follow-up data (N=18,873: CDSS group, n=6235; routine care group, n=12,638). One-to-one nearest-neighbor propensity score matching (PSM) was then used to balance baseline characteristics. Because the analysis dataset was assembled after these screening steps, the precise number of patients excluded at each screening step could not be enumerated retrospectively; this is acknowledged in the Limitations section.

Intervention Description

Overview

Patients in both groups received routine diabetes management for 1 year, comprising routine offline diagnosis and treatment by community doctors (diagnosis, medication, and treatment guidance based on clinical experience) and NBPHSP services (regular follow-up, health education, indicator monitoring, and family doctor contract services).

Patients in the CDSS group additionally received a 4-component intervention for 1 year.

Clinical Decision and Treatment Support

At the point of care, the CDSS automatically retrieved the patient's integrated longitudinal record—outpatient and inpatient diagnoses, medication prescriptions, and laboratory results from all medical institutions in Kunshan, linked with NBPHSP follow-up data—and generated patient-specific, guideline-based recommendations within the routine electronic workflow. Recommendations included suggested adjustment or titration of glucose-lowering therapy when HbA_{1c} exceeded the individualized target, reminders for guideline-recommended laboratory monitoring (eg, HbA_{1c}, renal function, lipids), and prompts for complication screening and referral. Recommendations were advisory: the final prescribing and referral decisions remained with the treating physician.

Health Assessment and Feedback

The system generated a comprehensive, structured health assessment report for each patient from clinical and follow-up data, covering glycemic, blood pressure, and lipid control, complication risk, and self-management behavior. Reports were released to patients through a mobile application and discussed during follow-up visits.

Remote Monitoring and Early Warning

Patients could self-report home blood pressure, blood glucose, and other indicators through the mobile app; community staff also entered follow-up measurements. When reported values exceeded predefined glycemic or blood pressure alert thresholds, the system pushed warning messages to the patient and to the responsible community medical staff, triggering earlier contact, intensified indicator monitoring, and, when indicated, earlier clinical review.

Linked Follow-Up Management

Community medical staff conducted the scheduled NBPHSP follow-ups augmented by CDSS prompts. Patients with alerts or worsening indicators received strengthened monitoring and health guidance, and community staff could review each patient's full longitudinal record during consultations.

The intervention was implemented in 16 CHSCs that had been equipped with the CDSS and the integrated data platform; patients presenting at the remaining CHSCs in the same city served as the routine care group. No formal quantitative assessment of clinician engagement (eg, recommendation acceptance or override rates) or patient app adherence was captured by the platform; this is acknowledged in the Limitations section.

Outcome Measures

Outcomes were assessed at 1 year of follow-up. For laboratory tests and blood pressure, values recorded within a window of three months before and three months after the 1-year anniversary of baseline were eligible; the single follow-up value for each indicator was the measurement closest to the 1-year time point. For HbA_{1c}, values are reported as percentages (National Glycohemoglobin Standardization Program [NGSP]–aligned units) throughout.

The primary outcomes were as follows: (1) the change in HbA_{1c} from baseline to 1 year (follow-up minus baseline; a negative value indicates improvement), and (2) the glycemic control rate at 1 year, defined as the proportion of patients with HbA_{1c} less than 8.0%, an individualized glycemic target consistent with Chinese guidance and with American Diabetes Association recommendations for older patients and those with multiple comorbidities [22,24], which characterizes this cohort. The proportion achieving the strict target of HbA_{1c} of less than 7.0% was also assessed as a prespecified complementary outcome.

Secondary outcomes were as follows: (1) changes in metabolic indicators from baseline to 1 year—fasting plasma glucose (FPG), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), systolic blood pressure (SBP), and diastolic blood pressure (DBP)—and (2) all-cause, ASCVD-related, and diabetes-related hospitalization during the 1-year follow-up. Hospitalization events were identified from hospitalization registration records; ASCVD-related hospitalization was defined by a principal diagnosis of ischemic heart or cerebrovascular disease according to the International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10: I20-I25, I60-I69), and diabetes-related hospitalization by a principal diagnosis of diabetes (ICD-10: E10-E14). The full code lists are provided in Multimedia Appendix 1.

Variable Collection

Demographic variables included baseline age and sex from treatment registration. Diabetes-related variables included diabetes duration (years from initial diagnosis to baseline) and baseline HbA_{1c} (mean of values recorded within the 6 months preceding baseline). Chronic comorbidities—hypertension, coronary heart disease (CHD), stroke, chronic kidney disease (CKD), heart failure, cancer, and chronic obstructive pulmonary disease—were identified by ICD-10 codes in hospital records between January 1, 2018, and baseline. Baseline medications (glucose-lowering drugs by class, antihypertensives, lipid-lowering drugs, antiplatelet agents) were defined by prescriptions within 3 months before baseline. Baseline laboratory variables (FPG, LDL-C, HDL-C, TC, SBP, DBP) were the mean of each indicator's values within the 6 months preceding baseline.

Statistical Analysis

Analyses were performed in R (version 4.2.0; R Foundation for Statistical Computing) with 2-sided significance tests at α=.05.

Propensity Score Model

The propensity score—the probability of receiving CDSS-assisted care given baseline characteristics—was estimated by multivariable logistic regression. Following a directed acyclic graph that specified baseline patient characteristics as common causes of CDSS uptake and of glycemic and clinical outcomes, the model included sex; age; diabetes duration; baseline HbA_{1c}, FPG, LDL-C, HDL-C, TC, SBP, and DBP; comorbidities (hypertension, CHD, stroke, CKD, heart failure); and baseline glucose-lowering drug classes (metformin, sulfonylureas, glinides, α-glucosidase inhibitors, thiazolidinediones, dipeptidyl peptidase-4 inhibitors, glucagon-like peptide-1 receptor agonists, sodium-glucose cotransporter-2 inhibitors, insulin). Cancer, chronic obstructive pulmonary disease, and antihypertensive, lipid-lowering, and antiplatelet use were not included in the propensity model but were assessed in balance diagnostics and outcome comparisons.

Matching and Balance Diagnostics

Following established matching methodology [25,26], patients were matched 1:1 by nearest-neighbor matching without replacement on the logit of the propensity score, with a caliper of 0.1 SDs of the logit of the propensity score (the value reported as "0.02" in the original manuscript was a typographical error). Balance was assessed with standardized mean differences (SMDs) for every baseline covariate before and after matching; an absolute SMD of less than 0.1 indicated adequate balance. Because hypothesis tests of baseline differences add little information beyond SMDs when assessing balance in matched samples, baseline balance is reported using SMDs and descriptive distributions only.

Outcome Analysis

Between-group differences in the matched cohort were estimated as mean differences with 95% CIs (Welch 2-sample *t* test) for continuous outcomes and as risk differences with 95% CIs (2-sample test for equality of proportions) for binary outcomes. To account for the matched design, treatment-effect variances were estimated treating each matched pair as a stratum; results were materially unchanged when using unstratified robust SEs, and the latter are reported for simplicity.

Multivariable Models

Multivariable linear regression (for change in HbA_{1c}) and multivariable logistic regression (for achieving HbA_{1c} <8.0%) were fitted in the matched cohort. The CDSS intervention was the exposure of interest; adjustment covariates were baseline HbA_{1c}, sex, diabetes duration, age, hypertension, CHD, stroke, CKD, heart failure, LDL-C, and SBP. Regression coefficients, odds ratios (ORs) with 95% CIs, and *P* values are reported; covariate estimates are descriptive and are not interpreted as independent "predictors."

Subgroup Analyses

To explore effect heterogeneity for the primary outcome (change in HbA_{1c}), the difference in HbA_{1c} change between groups was estimated within subgroups defined by age group, sex, diabetes duration (<5 vs ≥5 years), baseline HbA_{1c} category, and each comorbidity. Additive interaction was tested by including group-by-subgroup product terms in linear models; subgroup results are exploratory and interaction *P* values are reported with subgroup-specific sample sizes.

Sensitivity Analyses

Three sensitivity analyses addressed residual confounding and robustness of the matching specification: (1) inverse probability weighting (IPW) on the full prematching cohort using the same propensity model (average treatment effect weights; stabilized), (2) rematching with an alternative caliper of 0.2 SDs, and (3) E-values to quantify the minimum strength of association an unmeasured confounder would need with both the intervention and the outcome, conditional on measured covariates, to explain away the observed association [27]. The potential for differential outcome ascertainment (eg, more frequent testing in the CDSS group) is discussed in the Limitations section.

Results

Patient Flow and Baseline Characteristics

Of 18,873 patients with poor baseline glycemic control and complete baseline and follow-up HbA_{1c}, 6235 received CDSS-assisted care and 12,638 received routine care (Figure 1). Before matching, the CDSS group was older (mean 63.68, SD 11.40 years vs mean 56.71, SD 14.90 years), had longer diabetes duration (mean 5.73, SD 3.38 years vs mean 3.58, SD 3.54 years), and had higher prevalences of hypertension (4580/6235, 73.5% vs 5738/12,638, 45.4%), stroke (32.5% vs 20.9%), and CHD (24.5% vs 16.5%), with larger SMDs for diabetes duration (0.62), hypertension (0.60), age (0.53), and SBP (0.49) (Table 1 and Figure 2). After 1:1 matching, 6136 matched pairs (12,272 patients) were retained; 99 CDSS patients (1.6%) and 6502 routine care patients (51.4%) were excluded by the matching caliper or the without-replacement constraint. All postmatching absolute SMDs were less than 0.1 (largest: 0.097 for diabetes duration), indicating good baseline balance (Table 1 and Figure 2).

Figure 1. Patient flow through screening, propensity score matching (PSM), and analysis. CDSS: clinical decision support system; HbA_{1c}: glycated hemoglobin.

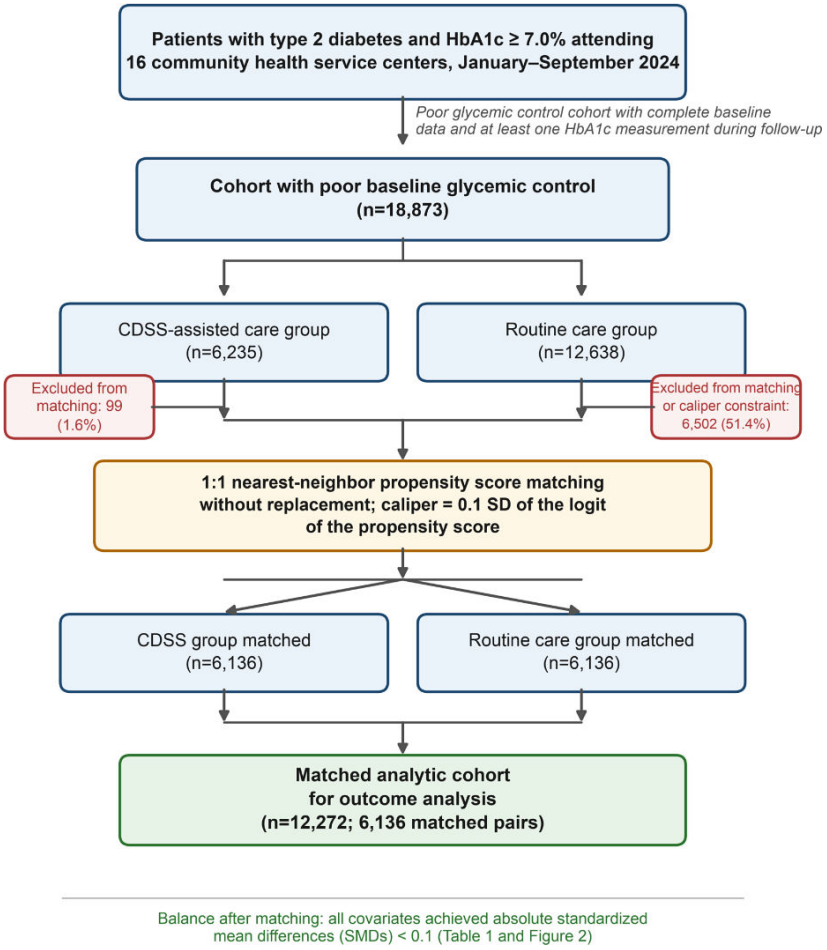


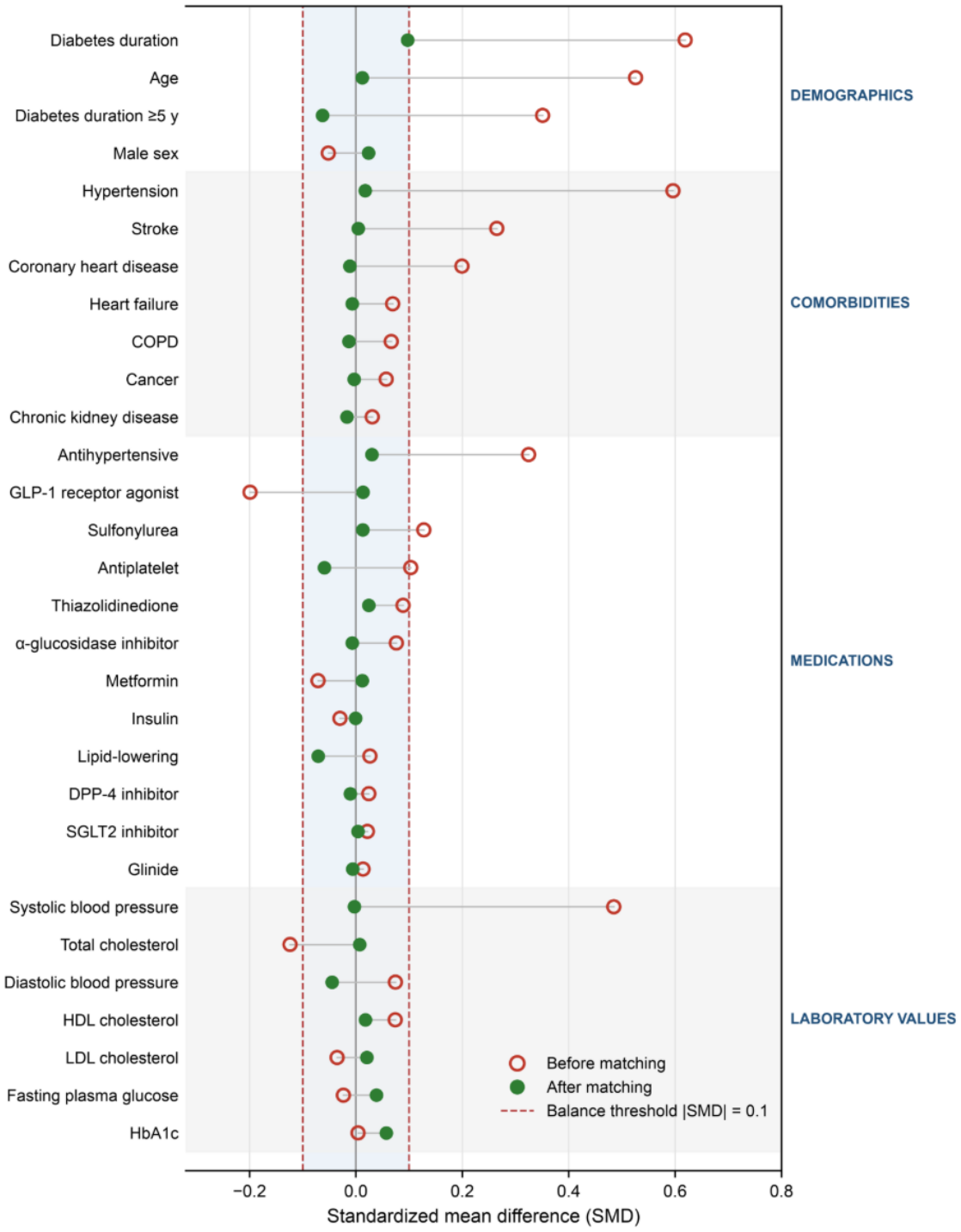
Table 1. Baseline characteristics of the study population before and after propensity score matching.

Characteristic	Before PSM[a]: CDSS[b] (n=6235)	Before PSM: routine care (n=12,638)	Before PSM: SMD[c]	After PSM: CDSS (n=6136)	After PSM: routine care (n=6136)	After PSM: SMD
Demographics						
Male sex, n (%)	3393 (54.4)	7202 (57.0)	–0.05	3331 (54.3)	3258 (53.1)	0.02
Age (years), mean (SD)	63.68 (11.40)	56.71 (14.90)	0.53	63.50 (11.35)	63.36 (13.07)	0.01
Diabetes duration (years), mean (SD)	5.73 (3.38)	3.58 (3.54)	0.62	5.65 (3.34)	5.30 (3.84)	0.10
Diabetes duration ≥5 years, n (%)	2949 (47.3)	3847 (30.4)	0.35	2852 (46.5)	3044 (49.6)	–0.06
Comorbidities, n (%)						
Hypertension	4580 (73.5)	5738 (45.4)	0.60	4481 (73.0)	4433 (72.2)	0.02
Coronary heart disease	1527 (24.5)	2083 (16.5)	0.20	1508 (24.6)	1538 (25.1)	–0.01
Stroke	2027 (32.5)	2640 (20.9)	0.26	1986 (32.4)	1973 (32.2)	0.00
Chronic kidney disease	234 (3.8)	403 (3.2)	0.03	234 (3.8)	254 (4.1)	–0.02
Heart failure	279 (4.5)	398 (3.1)	0.07	273 (4.4)	282 (4.6)	–0.01
Cancer	792 (12.7)	1373 (10.9)	0.06	781 (12.7)	788 (12.8)	–0.00
COPD[d]	244 (3.9)	344 (2.7)	0.07	235 (3.8)	251 (4.1)	–0.01
Medications, n (%)						
Metformin	2692 (43.2)	5903 (46.7)	–0.07	2650 (43.2)	2614 (42.6)	0.01
Sulfonylurea	2063 (33.1)	3442 (27.2)	0.13	2013 (32.8)	1976 (32.2)	0.01
Glinide	175 (2.8)	327 (2.6)	0.01	173 (2.8)	179 (2.9)	–0.01
α-Glucosidase inhibitor	1064 (17.1)	1807 (14.3)	0.08	1046 (17.0)	1062 (17.3)	–0.01
Thiazolidinedione	374 (6.0)	513 (4.1)	0.09	356 (5.8)	322 (5.2)	0.02
DPP-4[e] inhibitor	1124 (18.0)	2161 (17.1)	0.02	1107 (18.0)	1132 (18.4)	–0.01
GLP-1[f] receptor agonist	96 (1.5)	642 (5.1)	–0.20	96 (1.6)	86 (1.4)	0.01
SGLT2[g] inhibitor	1815 (29.1)	3555 (28.1)	0.02	1785 (29.1)	1774 (28.9)	0.00
Insulin	1981 (31.8)	4192 (33.2)	–0.03	1961 (32.0)	1963 (32.0)	–0.00
Antihypertensive	3039 (48.7)	4168 (33.0)	0.32	2964 (48.3)	2872 (46.8)	0.03
Lipid-lowering	1840 (29.5)	3578 (28.3)	0.03	1815 (29.6)	2017 (32.9)	–0.07
Antiplatelet	1358 (21.8)	2234 (17.7)	0.10	1338 (21.8)	1491 (24.3)	–0.06
Laboratory examination						
HbA_{1c}[h] (%), mean (SD)	8.71 (1.57)	8.70 (1.61)	0.00	8.69 (1.56)	8.60 (1.59)	0.06
FPG[i] (mmol/L), mean (SD)	10.31 (2.90)	10.38 (3.03)	–0.02	10.30 (2.89)	10.19 (2.96)	0.04
LDL-C[j] (mmol/L), mean (SD)	2.63 (0.84)	2.66 (0.87)	–0.04	2.63 (0.84)	2.61 (0.84)	0.02
HDL-C[k] (mmol/L), mean (SD)	1.25 (0.29)	1.22 (0.38)	0.07	1.25 (0.29)	1.24 (0.29)	0.02
TC[l] (mmol/L), mean (SD)	4.53 (0.98)	4.66 (1.09)	–0.12	4.53 (0.98)	4.53 (1.04)	0.01
SBP[m] (mmHg), mean (SD)	129.38 (6.98)	124.83 (11.31)	0.48	129.24 (6.90)	129.27 (10.19)	–0.00
DBP[n] (mmHg), mean (SD)	78.65 (4.04)	78.26 (6.26)	0.07	78.67 (4.03)	78.89 (5.65)	–0.04

[a]PSM: propensity score matching. An absolute SMD <0.1 was considered adequate balance.
[b]CDSS: clinical decision support system.
[c]SMD: standardized mean difference.
[d]COPD: chronic obstructive pulmonary disease.
[e]DPP-4: dipeptidyl peptidase-4.
[f]GLP-1: glucagon-like peptide-1.
[g]SGLT2: sodium-glucose cotransporter 2.
[h]HbA_{1c}: glycated hemoglobin.

[i]FPG: fasting plasma glucose.
[j]LDL-C: low-density lipoprotein cholesterol.
[k]HDL-C: high-density lipoprotein cholesterol.
[l]TC: total cholesterol.
[m]SBP: systolic blood pressure.
[n]DBP: diastolic blood pressure.

Figure 2. Standardized mean differences (SMDs) of baseline covariates before and after propensity score matching (Love plot), grouped by covariate domain. Open circles: before matching; filled circles: after matching; shaded band and dashed lines: |SMD|=0.1 balance threshold. COPD: chronic obstructive pulmonary disease; DPP-4: dipeptidyl peptidase-4; GLP-1: glucagon-like peptide-1; HbA_{1C}: glycated hemoglobin; HDL: high-density lipoprotein; LDL: low-density lipoprotein; SGLT2: sodium-glucose cotransporter 2.



Primary Outcomes

At 1 year, the mean HbA_{1c} reduction was –0.90% (SD 1.67) in the CDSS group versus –0.20% (SD 1.97) in the routine care group, a difference of –0.70 percentage points (95% CI –0.76 to –0.63; *P*<.001). The glycemic control rate (HbA_{1c} <8.0%) was 3923/6136 (63.9%) in the CDSS group versus 2909/6136 (47.4%) in the routine care group, a difference of 16.5 percentage points (95% CI 14.8 to 18.3; *P*<.001). For the strict target (HbA_{1c} <7.0%), the corresponding rates were 1885/6136 (30.7%) versus 1217/6136 (19.8%; difference 10.9 percentage points, 95% CI 9.4 to 12.4; *P*<.001).

Secondary Outcomes

The CDSS group showed significantly greater reductions than the routine care group in FPG (–1.14 vs –0.33 mmol/L; difference –0.82 mmol/L, 95% CI –0.95 to –0.68), TC (–0.31 vs –0.11 mmol/L; difference –0.21 mmol/L, 95% CI –0.25 to –0.17), LDL-C (–0.22 vs 0.01 mmol/L; difference –0.23 mmol/L, 95% CI –0.27 to –0.19), and DBP (–1.25 vs –0.53 mm Hg; difference –0.72 mm Hg, 95% CI –0.92 to –0.53; all *P*<.001; Table 2). Differences in HDL-C change (–0.01 mmol/L, 95% CI –0.02 to 0.00; *P*=.059) and SBP change (0.12 mm Hg, 95% CI –0.23 to 0.47; *P*=.51) were not statistically significant.

Table 2. Primary and secondary outcomes at 1 year in the matched cohort. Changes are follow-up minus baseline; negative differences indicate greater reduction in the CDSS (clinical decision support system) group. Differences are CDSS minus routine care with 95% CIs; for continuous outcomes, mean differences; for binary outcomes, risk differences in percentage points.

Outcome	CDSS (n=6136)	Routine care (n=6136)	Difference (95% CI)	*P* value
Primary outcomes				
Change in HbA_{1c}[a], %, mean (SD)	–0.90 (1.67)	–0.20 (1.97)	–0.70 (–0.76 to –0.63)	<.001
HbA_{1c} <8.0% at 1 year, n/N (%)	3,923/6,136 (63.9)	2,909/6,136 (47.4)	16.5 (14.8 to 18.3)	<.001
HbA_{1c} <7.0% at 1 year, n/N (%)	1,885/6,136 (30.7)	1,217/6,136 (19.8)	10.9 (9.4 to 12.4)	<.001
Secondary outcomes: change from baseline, mean (SD)				
FPG[b], mmol/L	–1.14 (3.50)	–0.33 (3.92)	–0.82 (–0.95 to –0.68)	<.001
TC[c], mmol/L	–0.31 (0.98)	–0.11 (1.07)	–0.21 (–0.25 to –0.17)	<.001
LDL-C[d], mmol/L	–0.22 (0.87)	0.01 (0.92)	–0.23 (–0.27 to –0.19)	<.001
HDL-C[e], mmol/L	–0.03 (0.26)	–0.02 (0.27)	–0.01 (–0.02 to 0.00)	.059
SBP[f], mm Hg	–2.85 (7.58)	–2.97 (11.63)	0.12 (–0.23 to 0.47)	.51
DBP[g], mm Hg	–1.25 (3.92)	–0.53 (6.48)	–0.72 (–0.92 to –0.53)	<.001
Hospitalization during 1-year follow-up, n/N (%)				
All-cause	1,436/6,136 (23.4)	2,307/6,136 (37.6)	–14.2 (–15.8 to –12.6)	<.001
ASCVD-related[h]	229/6,136 (3.7)	432/6,136 (7.0)	–3.3 (–4.1 to –2.5)	<.001
Diabetes-related	438/6,136 (7.1)	584/6,136 (9.5)	–2.4 (–3.4 to –1.4)	<.001

[a]HbA_{1c}: glycated hemoglobin.
[b]FPG: fasting plasma glucose.
[c]TC: total cholesterol.
[d]LDL-C: low-density lipoprotein cholesterol.
[e]HDL-C: high-density lipoprotein cholesterol.
[f]SBP: systolic blood pressure.
[g]DBP: diastolic blood pressure.
[h]ASCVD: atherosclerotic cardiovascular disease.

Hospitalization during follow-up was less frequent in the CDSS group for all-cause (1436/6136, 23.4% vs 2307/6136, 37.6%; difference –14.2 percentage points, 95% CI –15.8 to –12.6), ASCVD-related (229/6136, 3.7% vs 432/6136, 7.0%; difference –3.3 percentage points, 95% CI –4.1 to –2.5), and diabetes-related hospitalization (438/6136, 7.1% vs 584/6136, 9.5%; difference –2.4 percentage points, 95% CI –3.4 to –1.4; all *P*<.001; Table 2).

Multivariable Regression

In multivariable linear regression, the CDSS intervention was independently associated with a greater HbA_{1c} reduction (β=–.68, 95% CI –0.73 to –0.63; *P*<.001; Table 3), consistent with the unadjusted matched difference of –0.70 percentage points. Higher baseline HbA_{1c} (β=–.62 per 1%), longer diabetes duration (β=.11 per year), hypertension (β=–.07), CKD (β=–.18), higher LDL-C (β=.03), and higher SBP (β=.01) were also associated with HbA_{1c} change; sex and age were not.

In multivariable logistic regression, the CDSS intervention was associated with higher odds of achieving HbA_{1c} of less than 8.0% (OR 2.40, 95% CI 2.21-2.59; *P*<.001). Higher baseline HbA_{1c} (OR 0.66 per 1%), longer diabetes duration (OR 0.85 per year), and CKD (OR 1.28) were also associated with the outcome (Table 3).

Table 3. Multivariable regression for the primary outcomes in the matched cohort. The CDSS (clinical decision support system) intervention is the exposure of interest; all other rows are adjustment covariates and their estimates are descriptive. Models were fitted in the matched cohort (n=12,272).

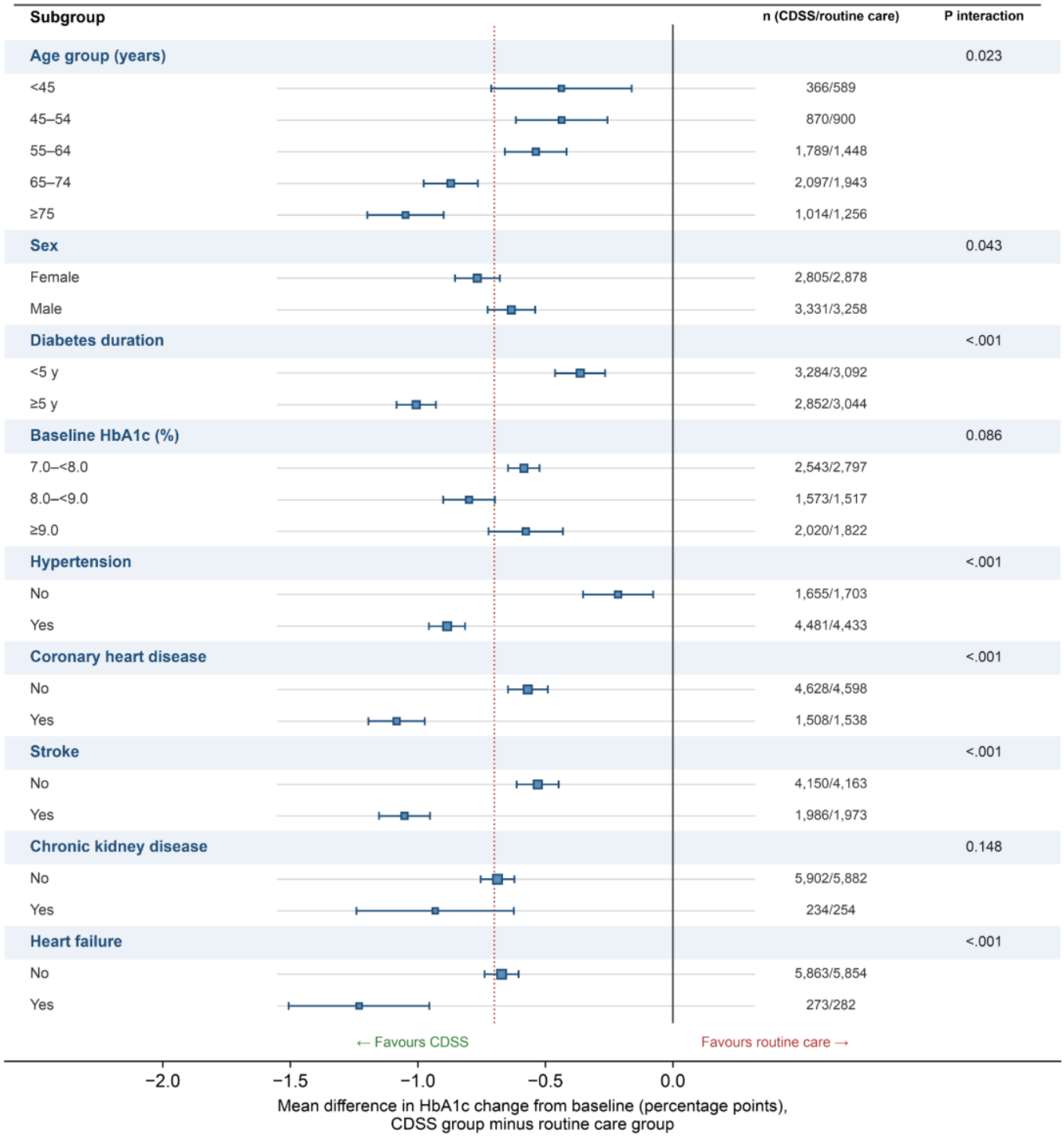
Variable	Linear regression: change in HbA_{1c}[a] (%), β[b] (95% CI)	*P* value	Logistic regression: HbA_{1c} <8.0%, OR[c] (95% CI)	*P* value
CDSS intervention	–.68 (–0.73 to –0.63)	<.001	2.40 (2.21 to 2.59)	<.001
Baseline HbA_{1c}, per 1%	–.62 (–0.64 to –0.61)	<.001	0.66 (0.64 to 0.68)	<.001
Sex (male)	.03 (–0.03 to 0.08)	.31	0.93 (0.85 to 1.00)	.058
Diabetes duration, per year	.11 (0.10 to 0.12)	<.001	0.85 (0.84 to 0.86)	<.001
Age, per year	–.00 (–0.00 to 0.00)	.63	1.00 (1.00 to 1.01)	.33
Hypertension	–.07 (–0.14 to –0.01)	.027	1.07 (0.97 to 1.18)	.16
Coronary heart disease	.01 (–0.06 to 0.08)	.78	0.98 (0.89 to 1.08)	.65
Stroke	–.03 (–0.09 to 0.03)	.30	0.96 (0.88 to 1.05)	.39
Chronic kidney disease	–.18 (–0.31 to –0.04)	.010	1.28 (1.05 to 1.56)	.016
Heart failure	.09 (–0.04 to 0.22)	.17	0.90 (0.75 to 1.09)	.30
LDL-C[d], per mmol/L	.03 (0.00 to 0.06)	.046	0.97 (0.92 to 1.01)	.16
SBP[e], per mmHg	.01 (0.00 to 0.01)	<.001	0.99 (0.99 to 1.00)	<.001

[a]HbA_{1c}: glycated hemoglobin.
[b]β: regression coefficient.
[c]OR: odds ratio.
[d]LDL-C: low-density lipoprotein.
[e]SBP: systolic blood pressure.

Subgroup Analyses

For the primary outcome (change in HbA_{1c}), the CDSS benefit was present in all prespecified subgroups and was significantly larger among older patients (interaction *P*=.023; difference ranging from –0.44 percentage points at <45 years to –1.05 at ≥75 years), patients with diabetes duration of 5 or more years (interaction *P*<.001), females (interaction *P*=.043; –0.77 vs –0.63 percentage points in males), and patients with hypertension, CHD, stroke, or heart failure (all interaction *P*≤.001; Figure 3). The interaction was not statistically significant for baseline HbA_{1c} category (interaction *P*=.086) or CKD (interaction *P*=.15); the nominally largest effect at baseline HbA_{1c} 8.0% to less than 9.0% (–0.80 percentage points) should be interpreted cautiously. Subgroup analyses were exploratory.

Figure 3. Difference in glycated hemoglobin (HbA_{1c}) change between the clinical decision support system (CDSS) and routine care groups within subgroups of the matched cohort (primary outcome). Squares are proportional to subgroup sample size; the dotted line indicates the overall matched difference (–0.70 percentage points). *P* values are for additive interaction.



Sensitivity Analyses

Inverse probability weighting on the full prematching cohort (n=18,873) yielded an average treatment effect on HbA_{1c} change of –0.53 percentage points (95% CI –0.58 to –0.47) and a glycemic control rate difference of 15.9 percentage points, directionally consistent with the matched estimates. Rerunning the matching with a 0.2 SD caliper retained 6000 pairs and produced virtually identical outcome differences (difference in HbA_{1c} change –0.71 percentage points). The E-value for the adjusted association between the CDSS intervention and the glycemic control rate (OR 2.40) was 4.2, indicating that an unmeasured confounder would need to be associated with both CDSS uptake and glycemic control by a risk ratio of at least 4.2-fold, above and beyond the measured covariates, to explain away the observed association. Full sensitivity results are provided in Multimedia Appendix 1.

Discussion

Principal Findings

In this retrospective propensity score–matched cohort of 12,272 patients with poorly controlled type 2 diabetes in Chinese PHC institutions, CDSS-assisted management was associated with a 0.70-percentage-point greater HbA_{1c} reduction, a 16.5-percentage-point higher glycemic control rate, greater reductions in FPG, TC, LDL-C, and DBP, and substantially lower all-cause, ASCVD-related, and diabetes-related hospitalization at 1 year, compared with routine care. The benefit was consistent across multivariable models and subgroup and sensitivity analyses, and it was largest among older patients, those with longer diabetes duration, and those with comorbidities.

Quality of Diabetes Management in PHC and Comparison With Previous Studies

PHC institutions are the cornerstone of an efficient medical system in China, but the quality of diabetes care they provide remains suboptimal. In a 2024 standardized-patient study, only 21.4% of surveyed PHC physicians completed the standardized management process, 17.8% reached a correct diagnosis, and only 45.6% of those cases received correct treatment [28]. These deficits reflect high workloads, limited specialist training, and the increasing complexity of guideline-directed therapy, particularly for insulin titration [7]. CDSSs address these gaps by increasing guideline adherence, supporting diagnosis, providing clinical alerts, and identifying opportunities for preventive care [12,17]. In our study, 1 year of CDSS-assisted management produced an additional 0.70-percentage-point HbA_{1c} reduction relative to routine care, at a time when China's national glycemic control rate remains approximately 50% [10].

Our results extend three large Chinese studies. A CDSS developed at Peking University People's Hospital prompted adherence to Chinese Diabetes Society guidelines and raised statin and aspirin prescription rates to approximately 60% among more than 20,000 patients [29]. The SMARTDiabetes cluster randomized trial in Hebei combined a physician-facing CDSS, a patient self-management app, and family health promoters; risk-factor improvement was driven mainly by glycemic control, with no change in blood pressure or LDL-C [30]. The D4C trial in Xiamen showed that adding a CDSS to team-based care produced an additional 0.2-percentage-point HbA_{1c} reduction, an additional 0.17 mmol/L LDL-C reduction, and an additional 1.5 mm Hg SBP reduction versus team-based care alone [31]. Our observed glycemic effect (–0.70 percentage points) exceeds both digital trials, and, unlike SMARTDiabetes, we also observed lipid and DBP improvements. Two design features may explain this difference: the Kunshan CDSS was integrated with a municipal platform, giving physicians real-time access to each patient's full–life cycle health record spanning all local institutions and NBPHSP follow-up data, and the intervention coupled physician-facing decision support with patient-facing assessment reports, remote monitoring, and alert-triggered follow-up. The integration of public health and clinical information addresses the fragmentation that has long limited PHC data access and supports recommendations to prioritize the organic integration of these systems [7,11].

Implementation Considerations

Translating this model to other settings requires prerequisite infrastructure: an integrated regional data platform linking clinical and public health records, a functioning CDSS with guideline-based rules, staffing capacity for alert-triggered follow-up, and patient access to smartphones for the mobile app. In Kunshan, the intervention operated within existing PHC staffing and did not alter payment or salary structures, but it did rely on sustained investment in the municipal information platform and system maintenance, and staff training was required at onboarding. We therefore caution against interpreting the model as being resource free; a formal costing and cost-effectiveness evaluation, which was outside the scope of this study, should precede adoption in lower-resource settings, where feasibility may be constrained by weaker digital infrastructure and lower patient smartphone access.

Strengths and Limitations

The strengths of this study include the use of an integrated municipal health data platform combining clinical and public health data, a large sample (12,272 matched patients) with rigorous PSM and full balance diagnostics (all postmatching SMDs <0.1), a detailed description of the multicomponent intervention, and systematic outcome evaluation including interaction tests and sensitivity analyses.

Several limitations should be noted. First, the retrospective, nonrandomized design cannot exclude residual confounding by unmeasured factors such as care intensity, physician characteristics, follow-up frequency, medication adherence, and socioeconomic status; the E-value of 4.2 suggests the observed association is unlikely to be fully explained by such confounding, but causality cannot be established. Second, the intervention bundle could change outcome ascertainment: CDSS patients may have undergone more frequent testing, and more complete hospitalization capture cannot be excluded; while the inclusion of a follow-up HbA_{1c} as a cohort criterion mitigates differential loss to measurement, surveillance bias cannot be excluded. Third, no quantitative data on intervention fidelity—clinician recommendation acceptance or override rates or patient app engagement—were captured, so the "dose" of the intervention received is unknown. Fourth, the precise number of patients excluded at each screening step (missing baseline data, HbA_{1c} <7.0%, missing follow-up HbA_{1c}) before assembly of the 18,873-patient poor-control cohort could not be reconstructed from the analysis dataset; the patient flow diagram therefore starts from this fully characterized cohort, and the total figure of 27,494 reported in the original manuscript was inaccurate and has been corrected. The matched analytic cohort is on average older, with longer diabetes duration and more comorbidity than the unmatched routine care population, which may limit generalizability to younger, healthier primary care populations. Fifth, the study

was conducted in Kunshan, a region with advanced health informatics infrastructure and higher economic development; the glycemic control rate (HbA_{1c} <8.0%) reflects an individualized target for this predominantly older, multimorbid population, and results for the strict target of less than 7.0% are also reported. Sixth, the 1-year follow-up precludes assessment of long-term complications, and new glucose-lowering drug uptake during follow-up was not individually captured, although baseline medication classes were balanced by matching.

Conclusions

Among patients with poorly controlled type 2 diabetes attending PHC institutions in Kunshan, China, a comprehensive CDSS-based intervention integrated with clinical and public health data was associated with clinically meaningful improvements in HbA_{1c}, glycemic control, metabolic indicators, and hospitalization at 1 year, with the largest benefits among older patients and those with complex comorbidities. Adoption requires an integrated data platform, trained staff, and patient-facing digital tools, and should be accompanied by controlled trials and economic evaluation to confirm causality, fidelity, and cost-effectiveness, particularly in regions with fewer digital resources.

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Generative AI Use

The authors declare that no generative AI tools were used in any portion of the preparation of this manuscript or during its revision.

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Data Availability

The individual-level data contain potentially identifiable health information and are governed by the Kunshan Municipal Health Commission; aggregated or deidentified data are available from the corresponding author upon reasonable request.

Authors’ Contributions

Conceptualization: ST, YB, MZ
Formal analysis: ST, YZ
Funding acquisition: MZ
Investigation: ST, JJ, AJ, YH
Resources: AJ, YH
Supervision: MZ
Writing - original draft: ST, JJ, YZ
Writing - review & editing: AJ, YH, YB, MZ

Conflicts of Interest

None declared.

Multimedia Appendix 1

Supplementary methods and analyses.
[DOCX File (Microsoft Word File), 43 KB-Multimedia Appendix 1]

Checklist 1

STROBE checklist.
[DOCX File (Microsoft Word File), 72 KB-Checklist 1]

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Abbreviations

ASCVD: atherosclerotic cardiovascular disease
CDSS: clinical decision support system
CHD: coronary heart disease
CHSC: community health service center
CKD: chronic kidney disease
DBP: diastolic blood pressure
FPG: fasting plasma glucose
HbA_{1C}: glycated hemoglobin
HDL-C: high-density lipoprotein cholesterol
ICD-10: International Statistical Classification of Diseases and Related Health Problems, 10th Revision
IPW: inverse probability weighting
LDL-C: low-density lipoprotein cholesterol
NBPHSP: National Basic Public Health Service Program
NGSP: National Glycohemoglobin Standardization Program
OR: odds ratio
PHC: primary health care
PSM: propensity score matching
SBP: systolic blood pressure
SMD: standardized mean difference
STROBE: Strengthening the Reporting of Observational Studies in Epidemiology
TC: total cholesterol

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