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RESEARCH ARTICLE

Effectiveness of quality of care for patients with type 2 diabetes in China: findings from the Shanghai Integration Model (SIM)

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Abstract **This cross-sectional study aimed to investigate the quality of care of diabetes in Shanghai, China. A total of 173 235 patients with type 2 diabetes in 2017 were included in the analysis. Profiles of risk factors and intermediate outcomes were determined. The patients had a mean age of 66.43 ± 8.12 (standard deviation (SD)) years and a mean diabetes duration of 7.95 ± 5.53 (SD) years. The percentage of patients who achieved the target level for HbA_{1c} (< 7.0%) was 48.6%. Patients who achieved the target levels for blood pressure (BP) < 130/80 mmHg and low-density lipoprotein-cholesterol (LDL-c) < 2.6 mmol/L reached 17.5% and 34.0%, respectively. A total of 3.8% achieved all three target levels, and the value increased to 6.8% with an adaptation of the BP target level (< 140/90 mmHg) for those over 65 years. Multivariable analysis identified the factors associated with a great likelihood of achieving all three target levels: male, young age, short diabetes duration, low body mass index, macrovascular complications, no microvascular complications, prescribed with lipid-lowering medication, and no prescription of antihypertensive medication. In conclusion, nearly 50% and one-third of the patients with diabetes met the target levels for HbA_{1c} and LDL-c, respectively, with a low percentage achieving the BP target level. The percentage of patients who achieved all three target levels needs significant improvement.**

Keywords type 2 diabetes; quality of care; macrovascular complication; microvascular complication; treatment pattern; epidemiology

Introduction

Diabetes has become a critical public health concern worldwide and in China, causing tremendous socio-economic burden. In national representative studies of China, the prevalence of diabetes in adults increased rapidly from 0.67% in 1980 to 9.7% in 2007 and slightly increased to 11.2% in 2017, with nearly a quarter of global cases being found in China [1–5]. In 2019, approximately 824 000 adults were estimated to die as a result of diabetes and related complications in China, with its estimated diabetes-related health expenditures ranking second to that of the United States worldwide [1]. To curb the rapid increase in diabetes, high avoidable mortality, and related substantial economic burden, the World Health Organization (WHO) member states proclaimed the goal of halting the rise of diabetes by 2025 [6]. The United Nations (UN) member states agreed to reduce the premature mortality from non-communicable diseases by one third by 2030 [7]. In 2009, China initiated its new health-care reform, making remarkable progress in strengthening its primary health-care system. Since then, diabetes management services have been offered through community health centers (CHCs) as part of the government-mandated package of

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basic public health services (BPHS) [8,9].

The quality of care for patients with diabetes can be measured in terms of intermediate outcome measures, such as the achievement of risk factors, including glycemia, blood pressure (BP), and blood lipids [10]. For patients with diabetes, inadequate achievement of glycemia, BP, and blood lipid targets are risk factors for the development of cardiovascular disease and comorbidities [10,11]. Low-density lipoprotein-cholesterol (LDL-c) is a causal risk factor for atherosclerotic cardiovascular diseases (ASCVD) [12]. Thus, in terms of lipid lowering, LDL-c has been set as the primary goal to prevent ASCVD among patients with diabetes according to the American Diabetes Association and Chinese Diabetes Society guidelines [10,11]. Prior studies have reported the achievement of the targets for glycemia ($HbA_{1c} < 7\%$), BP ($< 130/80$ mmHg), and blood lipids (total cholesterol (TC) < 4.5 mmol/L) in China in 2010 and the achievement of glycemic control ($HbA_{1c} < 7\%$) in Shanghai, China in 2013 [13,14]. However, the latest population-based data on the management, clinical outcomes, and treatment patterns of patients with type 2 diabetes (T2D), including intermediate outcomes and process indicators for the assessment of quality of diabetes care to prevent cardiovascular disease and comorbidities in primary healthcare practice are limited in Chinese mainland.

Hence, we used the most recent large-scale community-based data from Shanghai, a megacity with approximately 24 million residents and diabetes prevalence of 17.6% in adults over 35 years old to assess the (1) quality of diabetes care in primary healthcare practice and (2) factors associated with it and to inform the design of targeted quality improvement interventions and strategies that give patients the best chance of achieving improved diabetes care and good control of cardiovascular risk factors in primary healthcare.

Materials and methods

Study design and participants

This research is a cross-sectional study that used baseline data from January to December in 2017 from a community-based, prospective, observational cohort on the improvements in diabetes management in CHCs in Shanghai.

In 2015, the Shanghai Municipal Health Commission initiated the Shanghai Integrated Diabetes Prevention and Care System, the "Shanghai Integration Model (SIM)," with a collaborative project between the Shanghai Technical Center for Diabetes Prevention and Clinical Care, the Shanghai Municipal Center for Disease Control & Prevention, and the Shanghai Eye Disease Prevention and Treatment Center. By 2016, approximately 630 000 patients with diabetes were being managed at the CHCs in Shanghai. All 240 CHCs in the 16 districts were invited to participate in the project, with funding support from the Shanghai government [15]. Through this project, prediabetes and diabetes screening for those at high risk, and complications screening for patients with diabetes were implemented in CHCs, facilitated by the use of city-wide electronic patient registries, care coordination, and support from secondary and tertiary hospitals.

Five standardized and structured training sessions with approximately 5 participants per CHC and 1350 participants in total were held to ensure the uniform implementation of the assessments. Secondary training sessions were arranged by the health staff in the 16 districts. For the establishment of baseline data, an average of 29.4% of patients who were registered for diabetes management in CHCs underwent a comprehensive assessment of metabolic control and microvascular complications. Two CHCs were excluded due to the lack of available staff resources to complete the assessment. Among the remaining 238 CHCs, 71% had participation rates between 20% and 40%.

After 2017, the SIM was incorporated into the framework for the integrated community management of chronic diseases that guided the routine diabetes management in CHCs in Shanghai. The study protocol and prospective analysis plan are included in the supplementary material. This study was approved by the local Clinical Research Ethics Committee.

Clinical data collection and measurements

Data were extracted from the linked central information system, that is, the "Shanghai Health Information Platform," and linked using the patients' unique identity card number, which is compulsory for all residents. Information-sharing mechanisms and protocols were formulated by the government, and they promoted sharing of clinical and follow-up record data. Regular BPHS follow-up records included age, sex, diabetes duration, family history of diabetes, and reports of current smoking and drinking. Past medical histories of macrovascular complications and treatment patterns for diabetes, hypertension, and use of lipid-lowering medication and aspirin were extracted from the clinical medical records.

Using a standardized structured protocol, assessments of the patients' metabolic control and microvascular complications were conducted by the CHC staff during the same visit.

Anthropometric parameters, including height, weight, and waist circumference (WC), were obtained with the patient barefoot and clad in light clothing. The WC was measured at the horizontal plane midway between the lower edge of the costal margin and the upper edge of the iliac crest in standing position. Physical examination and laboratory measurements included BP, HbA_{1c}, and fasting

plasma glucose (FPG) levels, lipid profile including TC, LDL-c, high-density lipoprotein-cholesterol (HDL-c), and triglyceride (TG) levels, and tests for renal function, liver function, and urine albuminuria. Blood samples and random urine samples were collected from the participants after an overnight fasting of at least 10 h. Standard laboratory tests were performed by regional medical institutions or laboratory centers accredited by the Shanghai Center for Clinical Laboratory.

Systems were developed to support diabetic retinopathy (DR) screening, remote reading, referral, and management systems at the CHCs. DR screening was implemented by fundus photography and performed by primary healthcare staff at each CHC using a standardized protocol. Retinal photographs were captured using desktop retinal cameras from Canon, ZEISS, and Topcon. Two retinal photographs (macular and optic-disc centered) were captured for each eye in accordance with the DR screening guidelines of the WHO [16,17]. The original retinal images were collected using a field screening information collection system in CHCs and uploaded to a remote reading system. The images of each eye were assigned separately to two authorized ophthalmologists from secondary or tertiary hospitals. They labeled the images using a remote reading system to diagnose DR. In the case of discordant findings, a senior ophthalmologist examined the images before making a final decision. The results of diagnoses were sent back to the CHCs through the system. All participating ophthalmologists underwent training by the Shanghai Eye Disease Prevention and Treatment Center to ensure standardized services.

In the first CHC that implemented this project in each district, on-site supervision, monitoring, and support were provided to ensure study fidelity and progress by a centralized project management team together with district-level management teams. The district-level management team was delegated the responsibility for the on-site monitoring of other CHCs in their districts. Quarterly reports of this project were sent to each district health commission to monitor the implementation of the project. Across all 238 CHCs, the percentages of patients with T2D who completed urine albumin-to-creatinine ratio (uACR), estimated glomerular filtration rate (eGFR), and DR assessments were 90.4%, 96.6% and 90.7%, respectively.

Outcome definitions and coding

Intermediate outcomes included HbA_{1c}, BP, and LDL-c levels. In accordance with the "Standards of Medical Care for Type 2 Diabetes in China 2019," the target levels for patients with T2D were defined as HbA_{1c} level $< 7\%$, systolic BP (SBP) < 130 mmHg and diastolic BP (DBP) < 80 mmHg, and LDL-c level < 2.6 mmol/L [10]. For patients over 65 years old, the goals for BP were further adjusted as SBP < 140 mmHg and DBP < 90 mmHg for the analysis [10,18]. Overweightness and obesity were defined as 24 kg/m$^2 \leqslant$ body mass index (BMI) < 28 kg/m^2 and BMI $\geqslant 28$ kg/m^2, respectively. Central obesity was defined as WC $\geqslant 90$ cm for men and $\geqslant 85$ cm for women [19]. The combination of all three target levels was defined as HbA_{1c} level $< 7.0\%$, BP $< 130/80$ mmHg or $< 140/90$ mmHg for those over 65 years old, and LDL-c level < 2.6 mmol/L [10].

Albuminuria was defined as spot uACR of 30 mg/g or higher [10]. The GFR was estimated from calibrated serum creatinine concentrations using the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation. Impaired eGFR was defined as an eGFR < 60 mL/min/1.73 m^2 [10]. Diabetes with CKD was defined as diabetes with albuminuria, impaired eGFR, or both. DR was diagnosed in accordance with the "International Clinical DR Classification Scale." [20] Microvascular complications were defined as DR, diabetes with CKD, or both.

Histories of macrovascular complications were extracted from the clinical medical records system and coded in accordance with the International Classification of Disease, Tenth Revision, Clinical Modification. Coronary heart diseases (CHDs) were coded from I20 to I25, including CHD or myocardial infarction, whereas cerebrovascular diseases, including ischemic stroke or hemorrhagic stroke [21–23], were coded as I60, I61, I63, and I64. Macrovascular complications were defined as CHD or cerebrovascular disease, or both.

Statistical analysis

For the descriptive analysis, normally distributed continuous variables were expressed as mean $\pm$ standard deviation (SD), and non-normally distributed variables were presented as medians (quartiles 25% and 75%). Categorical variables were expressed as percentages of the number of patients with available data for each variable. The results of between-group comparisons were analyzed using chi-square test for categorical variables and *t*-test for continuous variables. Missing data were not imputed, and patients with missing data for a variable were excluded in the analysis involving that particular variable.

To address potential confounding, we used multivariable logistic regression modeling to investigate potential factors independently associated with the achievement of each target level, $HbA_{1c} < 7\%$, BP $< 130/80$ mmHg, and LDL-c < 2.6 mmol/L, and the combination of all three target levels. A restricted cubic spline nested in logistic models was used to test whether a nonlinear association of the three continuous variables, namely, age, diabetes duration, and BMI, existed with the control of key intermediate outcome measures (Fig. S1).

Additionally, multivariable linear regression modeling was used to investigate factors independently associated

with the key intermediate outcome measures analyzed as continuous dependent variables. Potential factors that were included in the full multivariable logistic or linear regression models were age, diabetes duration, and BMI as continuous variables and sex, current smoker and current drinker status, having one or more microvascular diseases and one or more macrovascular diseases, and using prescription medication relevant to the respective outcome as categorical variables. A two-sided P value of < 0.05 was considered significant. Analysis was performed using the IBM SPSS Statistics for Windows, version 24.0 (IBM Corp., Armonk, New York, USA) and SAS for Windows, version 9.3 (SAS Institute, Inc., Cary, North Carolina, USA).

Results

Between January 1, 2017 and December 31, 2017, exactly 185 313 patients with diabetes from the 240 CHCs underwent a comprehensive assessment of metabolic control and microvascular complications in Shanghai. A total of 173 235 patients (78 042 men versus 95 193 women) with T2D from 238 CHCs were included in the final analysis after two CHCs lacking staff resources, patients with T1D (n = 6141) and other specific types or unknown types of diabetes (n = 1982), and patients without laboratory test results (n = 3955) were excluded (Fig. 1).

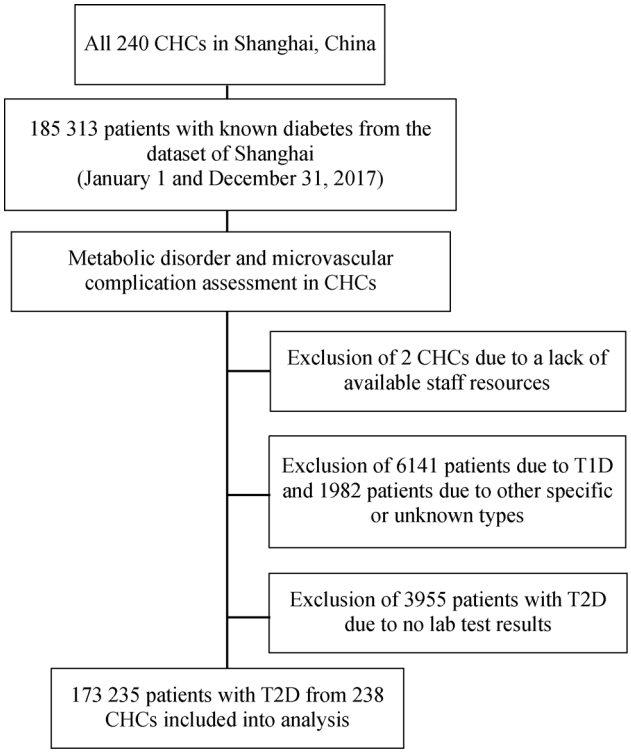

Fig. 1 Flow diagram of recruitment of participants. CHC, community health center; T1D, type 1 diabetes; T2D, type 2 diabetes.

Table 1 presents the general characteristics and age-stratified characteristics of 173 235 patients with T2D. Patients receiving diabetes management in the CHCs had a mean age of 66.43 ± 8.12 (SD) years and a mean diabetes duration of 7.95 ± 5.53 (SD) years, with a mean HbA_{1c} level of 7.22% ± 1.24% (SD). A total of 45% of patients were male, and microvascular and macrovascular complications were present in 44.7% and 51.0% of the patients, respectively. Prescriptions for glucose-lowering, antihypertensive, and lipid-lowering medications and aspirin, were documented in 80.3%, 70.1%, 29.3%, and 6.3% patients, respectively.

Achievement of intermediate outcome measures

Table 2 presents the intermediate outcomes categorized by demographic characteristics and risk factors in patients with T2D. Individual target levels for glycemia (HbA_{1c} level $< 7\%$), BP (BP $< 130/80$ mmHg), and lipid (LDL-c level < 2.6 mmol/L) were met by 48.6%, 17.5%, and 34.0%, respectively. After adjusting for age-stratified BP target levels, 20.4% of patients < 65 years old met the target level of BP $< 130/80$ mmHg, whereas 41.0% of those $\geqslant 65$ years old met the target level of BP $< 140/90$ mmHg. A total of 3.8% of patients achieved the combination of the treatment target levels of HbA_{1c}, BP, and LDL-c. This value increased to 6.8% after age-stratified modification of the target levels for BP.

Significantly more males than females met the target levels for BP, LDL-c, and the combination of all three, with the opposite being found regarding HbA_{1c}. Compared with elderly patients, those who were aged < 65 years were less likely to achieve the target levels for HbA_{1c} and LDL-c but were more likely to achieve the BP target level. Meanwhile, the control rates of all three parameters were significantly higher in current smokers and current drinkers, no significant associations were found when these comparisons were made using age-stratified target levels.

The percentages of the achievement of HbA_{1c} and combination of the three target levels declined with prolonged diabetes duration. For BP and LDL-c, the percentages that achieved the target levels varied minimally. For those with BMI $\geqslant 24$ kg/m^2 or central obesity, all the individual and combined control rates were significantly lower. Having microvascular complications (the presence of CKD, DR, or both) was associated with lower rates of achieving individual or the combination of all three target levels, with the exception of a modestly greater percentage for achieving the LDL-c target level. For macrovascular complications, the percentages that achieved the target levels for HbA_{1c} and the combination

Table 1 Gender-specific and age-stratified characteristics of 173 235 patients with T2D in Shanghai, China

Characteristics	Total	Male	Female	Age < 65 years	Age⩾ 65 years
Participants (*n* (%))	173 235 (100.0)	78 042 (45.0)	95 193 (55.0)	69 201 (39.9)	104 034 (60.1)
Demographics					
Age (year)	66.43±8.12	66.39±8.23	66.47±8.03	58.76±4.96	71.53±5.32
Sex (male/female) (%)	45.0/55.0	NA	NA	44.3/55.7	45.5/54.5
Current smoker (%)	9.5	17.3	3.1	12.9	7.2
Current drinker (%)	6.9	11.7	3.1	8.9	5.6
Family history of diabetes (%)	31.0	30.6	31.4	35.9	27.7
Diabetes duration					
Mean±SD (year)	7.95±5.53	7.77±5.49	8.10±5.55	6.92±5.01	8.65±5.75
0 to < 5 years (%)	30.9	32.2	29.9	36.7	27.0
5 to < 10 years (%)	35.2	35.3	35.1	36.6	34.2
⩾ 10 years (%)	33.9	32.5	35.0	26.7	38.8
Metabolic and related complications					
BMI					
Mean±SD (kg/m^2)	25.02±3.09	24.99±2.88	25.04±3.25	25.00±3.07	25.03±3.10
< 24 kg/m^2 (%)	38.5	37.3	39.5	38.6	38.5
24 to < 28 kg/m^2 (%)	44.4	47.6	41.8	44.6	44.3
⩾ 28 kg/m^2 (%)	17.1	15.1	18.7	16.8	17.2
Waist circumference (cm)	87.78±8.99	89.60±8.50	86.29±9.10	87.09±8.96	88.25±8.98
Central obesity[a] (%)	53.2	50.2	55.6	50.0	55.4
SBP (mmHg)	142.19±18.91	140.86±18.43	143.28±19.24	139.08±18.57	144.28±18.86
DBP (mmHg)	80.21±10.09	81.12±10.01	79.46±10.09	81.68±9.94	79.23±10.07
FPG (mmol/L)	7.64±1.95	7.75±1.97	7.56±1.93	7.79±2.01	7.55±1.91
HbA_{1c} (%)	7.22±1.24	7.29±1.26	7.16±1.23	7.27±1.28	7.18±1.22
TC (mmol/L)	4.93±1.02	4.67±0.98	5.14±1.00	5.02±1.00	4.87±1.03
TG (mmol/L)	1.58±0.70	1.51±0.70	1.64±0.70	1.61±0.73	1.56±0.69
HDL-c (mmol/L)	1.31±0.32	1.23±0.31	1.37±0.32	1.30±0.32	1.31±0.32
LDL-c (mmol/L)	2.97±0.88	2.83±0.85	3.09±0.89	3.03±0.87	2.94±0.88
uACR					
Median (Quartiles 25%, 75%) (mg/g)	16.17 (7.82, 41.00)	14.22 (6.69, 40.00)	17.75 (8.94, 41.90)	14.20 (7.10, 34.62)	17.80 (8.40, 45.90)
Albuminuria (⩾ 30 mg/g) (%)	31.8	30.5	32.8	28.1	34.2
eGFR					
Mean±SD (mL/min/1.73 m^2)	85.72±16.34	85.08±16.32	86.24±16.33	93.76±14.03	80.34±15.54
Impaired eGFR (<60 mL/min/1.73 m^2) (%)	8.1	8.3	7.9	2.9	11.6
DR (%)	19.3	19.0	19.6	20.5	18.4
One or more microvascular complications[b] (%)	44.7	43.4	45.8	40.8	47.7
One or more macrovascular complications[c] (%)	51.0	46.9	54.3	41.5	57.3
Treatment patterns					
Glucose-lowering medication	80.3	80.5	80.0	79.6	80.7
Insulin	11.7	12.3	11.3	11.7	11.7
Antihypertensive medication	70.1	67.1	72.6	61.3	76.0
RAS inhibitors	33.4	32.1	34.5	30.6	35.2
Lipid-lowering medication	29.3	26.4	31.6	23.9	32.8
Statins	22.5	21.0	23.7	17.6	25.7
Aspirin	6.3	5.7	6.7	4.1	7.7

[a]Central obesity was defined as waist circumference (male) ⩾ 90 cm, waist circumference (female) ⩾ 85 cm.
[b]One or more microvascular diseases included the presence of either diabetic retinopathy or diabetes with CKD, or both. Diabetes with CKD defined as existence of either albuminuria (uACR⩾ 30 mg/g) or impaired eGFR (eGFR (CKD-EPI) < 60 mL/min/1.73 m^2), or both.
[c]One or more macrovascular disease included the presence of either CHD or cerebrovascular disease, or both. CHD, coronary heart disease (ICD-10 code, I20–I25), including CHD or myocardial infarction. Cerebrovascular disease (ICD-10 code, I60, I61, I63, and I64), including ischemic stroke or hemorrhagic stroke.
NA, not applicable.

Table 2 HbA_{1c}, BP, LDL-c and all three targets control rates (%) by subgroups of demographic characteristics and risk factors in T2D participants (n = 173 235)

	$HbA_{1c} < 7\%$	BP			LDL-c < 2.6 mmol/L	All three targets[a] met	All three age-stratified targets[b] met
		<130/80 mmHg	<130/80 mmHg (< 65 years)	< 140/90 mmHg (⩾ 65 years)			
All	48.6	17.5	20.4	41.0	34.0	3.8	6.8
Sex							
Female	50.7	17.0	20.4	38.7	29.3	3.3	5.9
Male	46.0*	18.0*	20.3	43.6*	39.6*	4.3*	7.8*
Age							
< 65 years	47.2	20.4	20.4	NA	31.3	3.9	3.9
⩾ 65 years	49.5*	15.5*	NA	41.0	35.7*	3.7#	8.7*
Current smoker							
No	48.7	17.0	19.9	40.6	33.8	3.7	6.7
Yes	45.0*	21.6*	23.2*	45.3*	35.8*	4.4*	6.8
Current drinker							
No	48.3	17.2	20.3	40.8	33.8	3.7	6.7
Yes	48.7	19.8*	21.4#	42.3#	36.0*	4.5*	7.1
Duration[c]							
0 to < 5 years	$60.5^{\alpha,\gamma}$	$18.2^{\alpha,\gamma}$	20.3	$43.2^{\alpha,\gamma}$	33.1	$4.4^{\alpha,\gamma}$	$7.8^{\alpha,\gamma}$
5 to < 10 years	$49.2^{\alpha,\beta}$	17.2	20.2	39.8	33.0	$3.8^{\alpha,\beta}$	$6.5^{\alpha,\beta}$
⩾ 10 years	$37.4^{\beta,\gamma}$	17.5	$21.4^{\beta,\gamma}$	39.8	$35.3^{\beta,\gamma}$	$3.1^{\beta,\gamma}$	$6.0^{\beta,\gamma}$
BMI							
< 24 kg/m^2	52.1	23.1	27.6	47.6	34.8	5.2	8.6
⩾ 24 kg/m^2	46.8*	14.2*	16.3*	37.2*	34.2#	3.0*	5.8*
Central obesity							
No	52.3	21.3	24.5	46.5	34.7	4.8	8.1
Yes	45.6*	13.9*	16.0*	36.4*	33.9*	2.8*	5.5*
One or more microvascular complications[d]							
No	55.6	21.2	23.7	46.3	33.4	4.6	7.9
Yes	41.3*	13.5*	15.3*	34.2*	35.2*	2.6*	5.1*
One or more macrovascular complications[d]							
No	47.1	18.3	20.8	40.6	31.1	3.5	5.8
Yes	50.0*	16.6*	19.7*	41.3#	36.7*	4.0*	7.7*

[a]All three targets defined as $HbA_{1c} < 7.0\%$, BP < 130/80 mmHg, and LDL-c < 2.6 mmol/L.
[b] All three age-stratified targets defined as $HbA_{1c} < 7.0\%$, BP < 130/80 mmHg for patients with age < 65 years and BP < 140/90 mmHg for those aged ⩾ 65 years, and LDL-c < 2.6 mmol/L.
[c]Chi-square test results showed that the P value was < 0.001 for all except for the group with BP < 130/80 mm Hg (< 65 years; $P = 0.004$). Then, Bonferroni-adjusted multiple comparison was used to investigate the differences between each subgroup of diabetes duration. α, $P < 0.05$ for "0 to < 5 years" and "5 to < 10 years"; β, $P < 0.05$ for "5 to < 10 years" and " ⩾ 10 years"; γ, $P < 0.05$ for "0 to < 5 years" and "⩾ 10 years."
[d]One or more microvascular diseases included the presence of diabetic retinopathy or diabetes with CKD, or both. Diabetes with CKD defined as the existence of albuminuria (uACR⩾ 30 mg/g), impaired eGFR (eGFR (CKD-EPI) < 60 mL/min/1.73 m^2), or both. One or more macrovascular disease included the presence of CHD, cerebrovascular disease, or both. CHD, coronary heart disease (ICD-10 code, I20–I25), including CHD or myocardial infarction. Cerebrovascular disease (ICD-10 code, I60, I61, I63, and I64), including ischemic stroke or hemorrhagic stroke.
*$P < 0.001$, #$P < 0.05$. NA, not applicable. T2D, type 2 diabetes.

of all three target levels were higher. This condition was especially pronounced for LDL-c. The opposite was found regarding BP.

Factors associated with good quality of diabetes care

Complicated statistically significant associations emerged between potential predictors and individual intermediate outcome measures, such as categorical or continuous variables (Table 3). After adjusting for confounding, the results similar to those of univariate analysis were found regarding the associations between the three individual outcome measures and the following factors: age, BMI, and having one or more microvascular complications. However, multivariable analysis revealed several differences in the associations between the three individual outcome measures and sex, diabetes duration, current smoking, current drinking, and having one or more macrovascular complications. Current smoking was associated with a low likelihood of achieving the target levels for HbA_{1c} and LDL-c but a high likelihood of attaining the target level for BP. Patients having one or more macrovascular complications were more likely to achieve all the three individual targets.

Regarding the analysis of treatment patterns, patients with prescriptions for glucose-lowering and antihypertensive medications were less likely to achieve the target levels for HbA_{1c} and BP, whereas those prescribed with lipid-lowering medication were more likely to achieve the target level for LDL-c. Part B in Table 3 presents the parallel multivariable linear regression analyses with intermediate outcomes as continuous variables.

Further analysis (Table 3) identified that the achievement of the combination of the three target levels was positively associated with male sex (odds ratio (OR) 1.288, 95% confidence interval (CI) 1.204 to 1.378), having one or more macrovascular complications (OR 1.241, 95% CI 1.158 to 1.330), and being prescribed with lipid-lowering medication (OR 1.743, 95% CI 1.622 to 1.872) but was negatively associated with age (OR 0.994, 95% CI 0.990 to 0.999), diabetes duration (OR 0.972, 95% CI 0.965 to 0.978), BMI (OR 0.877, 95% CI 0.867 to 0.887), having one or more microvascular complications (OR 0.608, 95% CI 0.566 to 0.653), and being prescribed antihypertensive medication (OR 0.838, 95% CI 0.777 to 0.903). Associations between achieving the combination of the three target levels and the following variables were not significant: current smoking, current drinking, and prescription for glucose-lowering medication.

When age, diabetes duration, and BMI were further analyzed using restricted cubic splines nested in logistic models, similar results were observed except for a U-shaped association between age (reference set as 65 years old) and LDL-c ($P < 0.001$ for the trend) (Fig. S1). No significant association was found in patients < 50 years of age. Patients between 50 and 65 years old had a less likelihood of achieving the target level for LDL-c, whereas the likelihood of reaching the target level for LDL-c increased and became notably higher in patients aged over 65 years.

Treatment patterns

Table 4 presents the percentages of patients who achieved the intermediate outcomes disaggregated by prescribed medication. Older patients and those with prolonged diabetes duration were more likely to be prescribed each of the individual medications and all three together. The relationships between the prescribed medications and achievement of the target level for HbA_{1c} were minimal except that those prescribed with glucose-lowering medications had a substantially higher HbA_{1c} level (7.35% versus 6.67%) and were less likely to achieve the HbA_{1c} target level (43.4% versus 69.1%). Similarly, those prescribed with antihypertensive medication were less likely to achieve the BP target level (14.8% versus 23.8%). By contrast, the patients prescribed with lipid-lowering medication were likely to achieve the LDL-c target level (44.1% versus 29.8%). Among those with macrovascular diseases, 16.8% of the patients prescribed with lipid-lowering medication achieved the LDL-c target level (< 1.8 mmol/L), but it declined to 7.7% among those who were not prescribed with such medication.

Discussion

In this real-world observational study, using a large sample of adults with diabetes in primary healthcare settings in Shanghai, China, we determined the proportions that met the target levels for individual intermediate outcomes of HbA_{1c} (48.6%), BP (17.5%), and LDL-c (34.0%) and achieved the combination of all three goals at 3.8%, which increased to 6.8% when the BP target levels were adjusted for elderly patients. Overall, patients were likely to achieve the combination of all three target levels if they were male and young, had a short diabetes duration, a low BMI, one or more macrovascular complications, no microvascular complications, and were prescribed lipid-lowering medication but not antihypertensive medication.

Diabetes is associated with a dramatically increased risk of microvascular and macrovascular complications [24]. Early risk factor modification and screening for diabetic complications are expected to reduce these severe comorbidities [25–27]. Using the SIM, the Shanghai government incorporated a comprehensive assessment of diabetic complications as part of diabetes management in primary healthcare settings. Our study findings showed that in 2017, among patients with T2D registered for diabetes management, an average of 29.4% received a

Table 3 Multivariable logistic and linear regression analysis of potential factors influencing the adequate control of intermediate outcome measures (HbA_{1c}, BP, LDL-c, and all three targets) in T2D participants

Part A (binary outcomes)	$HbA_{1c} < 7\%$ OR (95% CI)	BP < 130/80 mmHg OR (95% CI)	LDL-c < 2.6 mmol/L OR (95% CI)	All three targets met[a] OR (95% CI)
Age	1.020 (1.018, 1.022)	0.983 (0.981, 0.985)	1.007 (1.005, 1.009)	0.994 (0.990, 0.999)
Male (vs. female)	0.800 (0.780, 0.821)	0.983 (0.951, 1.016)	1.703 (1.659, 1.749)	1.288 (1.204, 1.378)
Diabetes duration	0.935 (0.932, 0.937)	1.004 (1.001, 1.007)	1.002 (1.000, 1.005)	0.972 (0.965, 0.978)
Current smoker (vs. none)	0.832 (0.785, 0.881)	1.395 (1.303, 1.494)	0.944 (0.892, 0.999)	1.117 (0.973, 1.283)
Current drinker (vs. none)	1.307 (1.225, 1.394)	0.932 (0.862, 1.007)	1.070 (1.004, 1.141)	1.104 (0.946, 1.289)
BMI	0.957 (0.953, 0.961)	0.893 (0.888, 0.898)	0.986 (0.982, 0.990)	0.877 (0.867, 0.887)
One or more microvascular diseases (vs. none)	0.613 (0.597, 0.629)	0.633 (0.612, 0.654)	1.074 (1.046, 1.102)	0.608 (0.566, 0.653)
One or more macrovascular diseases (vs. none)	1.246 (1.214, 1.279)	1.119 (1.082, 1.158)	1.187 (1.156, 1.219)	1.241 (1.158, 1.330)
Glucose-lowering medication (vs. none)	0.417 (0.404, 0.431)	NA	NA	0.955 (0.880, 1.036)
Antihypertensive medication (vs. none)	NA	0.655 (0.633, 0.678)	NA	0.838 (0.777, 0.903)
Lipid-lowering medication (vs. none)	NA	NA	1.839 (1.788, 1.892)	1.743 (1.622, 1.872)

Part A: [a] All three targets met was defined as $HbA_{1c} < 7.0\%$, BP < 130/80 mmHg, and LDL-c < 2.6 mmol/L.

Part B (continuous outcomes)	HbA_{1c} β (95% CI)	SBP β (95% CI)	DBP β (95% CI)	LDL-c β (95% CI)
Age	–0.014 (–0.015, –0.013)	0.312 (0.298, 0.327)	–0.209 (–0.217, –0.201)	–0.004 (–0.004, –0.003)
Male (vs. female)	0.141 (0.127, 0.155)	–1.799 (–2.022, –1.576)	1.927 (1.807, 2.047)	–0.284 (–0.295, –0.274)
Diabetes duration	0.043 (0.041, 0.044)	0.055 (0.035, 0.075)	–0.111 (–0.122, –0.100)	–0.001 (–0.002, 0.000)
Current smoker (vs. none)	0.108 (0.076, 0.139)	–2.804 (–3.294, –2.315)	–1.234 (–1.498, –0.970)	0.007 (–0.016, 0.031)
Current drinker (vs. none)	–0.162 (–0.198, –0.127)	1.785 (1.238, 2.333)	0.654 (0.359, 0.949)	0.003 (–0.023, 0.029)
BMI	0.024 (0.022, 0.026)	0.889 (0.853, 0.924)	0.492 (0.473, 0.512)	0.006 (0.004, 0.008)
One or more microvascular diseases (vs. none)	0.373 (0.359, 0.387)	5.553 (5.334, 5.773)	1.553 (1.435, 1.671)	–0.017 (–0.028, –0.007)
One or more macrovascular diseases (vs. none)	–0.150 (–0.164, –0.136)	–1.482 (–1.707, –1.257)	–0.547 (–0.668, –0.426)	–0.066 (–0.077, –0.055)
Glucose-lowering medication (vs. none)	0.530 (0.513, 0.548)	NA	NA	NA
Antihypertensive medication (vs. none)	NA	3.702 (3.457, 3.947)	1.517 (1.386, 1.649)	NA
Lipid-lowering medication (vs. none)	NA	NA	NA	–0.243 (–0.255, –0.231)

Part B: Model for HbA_{1c}: $R = 0.344$, $R^2 = 0.118$, $R^2_{adj} = 0.118$, $P < 0.001$; Model for SBP: $R = 0.295$, $R^2 = 0.087$, $R^2_{adj} = 0.087$, $P < 0.001$; Model for DBP: $R = 0.272$, $R^2 = 0.074$, $R^2_{adj} = 0.074$, $P < 0.001$; Model for LDL-c: $R = 0.211$, $R^2 = 0.044$, $R^2_{adj} = 0.044$, $P < 0.001$.

Notes for Parts A and B: Potential factors that were included into the full multivariable logistic or linear regression model were as follows: age, diabetes duration, and BMI as continuous variables, and sex, current smoker, current drinker, one or more microvascular diseases, one or more macrovascular diseases, and prescription of medication relevant to the respective outcomes as categorical variables. One or more microvascular diseases included the presence of either diabetic retinopathy or diabetes with CKD, or both. One or more macrovascular disease included the presence of either CHD or cerebrovascular disease, or both. CHD, coronary heart disease (ICD-10 code, I20–I25), including CHD or myocardial infarction. Cerebrovascular diseases (ICD-10 code, I60, I61, I63, and I64), including ischemic stroke or hemorrhagic stroke. NA, not applicable. T2D, type 2 diabetes.

Table 4 General characteristics and HbA_{1c}, BP, LDL-c, and all three targets control rates (%) disaggregated by subgroups of different prescribed medications (n = 173 235)

	Glucose-lowering medication		Antihypertensive medication		Lipid-lowering medication		All three medication treatments[a]	
	No	Yes	No	Yes	No	Yes	No	Yes
Age (year)	66.00±8.07	66.54±8.13*	63.93±8.13	67.50±7.88*	65.80±8.18	67.95±7.77*	65.86±8.15	68.35±7.70*
Diabetes duration (year)	5.81±4.65	8.49±5.60*	7.43±5.27	8.18±5.62*	7.73±5.37	8.51±5.86*	7.65±5.38	8.99±5.89*
HbA_{1c} (%)	6.67±1.09	7.35±1.24*	7.26±1.28	7.20±1.23*	7.23±1.26	7.19±1.21*	7.20±1.25	7.27±1.21*
< 7% (%)	69.1	43.4*	47.6	49.0*	48.4	49.0#	49.4	45.8*
SBP (mmHg)	141.89±18.74	142.26±18.96#	138.02±18.50	143.97±18.81*	142.21±18.93	142.12±18.87	141.93±18.91	143.06±18.92*
DBP (mmHg)	80.87±10.04	80.05±10.09*	79.51±9.92	80.51±10.14*	80.53±10.06	79.43±10.10*	80.41±10.07	79.52±10.11*
BP (%)								
< 130/80 mmHg	17.1	17.6	23.8	14.8*	17.5	17.5	17.8	16.3*
< 130/80 mmHg (< 65 years)	20.3	20.4	26.9	16.3*	20.4	20.2	20.8	18.3*
< 140/90 mmHg (≥ 65 years)	40.9	41.0	47.9	38.8*	40.2	42.5*	40.9	41.1
LDL-c (mmol/L)	3.08±0.84	2.95±0.89*	3.06±0.84	2.94±0.90*	3.04±0.84	2.80±0.96*	3.04±0.85	2.76±0.95*
< 2.6 mmol/L (%)	28.6	35.3*	29.3	35.9*	29.8	44.1*	30.5	45.7*
< 1.8 mmol/L (%)[b]	7.8	11.8*	7.7	12.0*	7.7	16.8*	8.3	17.5*
All three targets[c] met (%)	4.2	3.6*	4.3	3.5*	3.3	5.0*	3.5	4.7*
All three age-stratified targets[d] met (%)	7.7	6.5*	6.4	6.9*	5.8	9.3*	6.2	8.9*

[a] All three medication treatments were defined as prescribed with glucose-lowering medication, antihypertensive medication, and lipid-lowering medication together.
[b] LDL-c achievement target (< 1.8 mmol/L) for those with CHD or cerebrovascular disease.
[c] All three targets defined as HbA_{1c} < 7.0%, BP< 130/80 mmHg, and LDL-c < 2.6 mmol/L.
[d] All three age-stratified targets defined as HbA_{1c} < 7.0%, BP < 130/80 mmHg for patients with age < 65 years and BP < 140/90 mmHg for those aged≥ 65 years, and LDL-c < 2.6 mmol/L.
*$P < 0.001$, #$P < 0.05$.

comprehensive assessment of their microvascular complications, with 71% of the 238 CHCs having participation rates between 20% and 40%. This level of testing was similar to that reported in Korea and lower than that reported in Norway [28,29]. The percentage of patients (48.6%) who achieved the HbA_{1c} target level of $< 7.0\%$ in this study was close to that reported in the United States (52.2%), Italy (50.0%), Hong Kong of China (50.0%), and in the general profile of eight European countries (53.6%) [30–33]. However, the percentages of patients who achieved the target levels for BP $<$ 130/80 mmHg or LDL-c $<$ 2.6 mmol/L were remarkably lower than those reported in these studies [30–33].

Exactly 3.8% achieved the combination of all of three target levels (HbA_{1c}, BP, and LDL-c), which increased to 6.8% after a minor adaptation of the BP target level for those over 65 years old. Similar to the results from eight European countries, this study discovered that patients with one or more macrovascular complications were more likely to achieve the combination of all three target levels [31]. However, our study showed that patients with microvascular complications (DR, CKD, or both) were less likely to achieve all three target levels after adjusting for potential confounding, which suggests that patients with macrovascular complications received more aggressive risk factor management, had higher self-efficacy in diabetes management, and better medication adherence than those who did not have these complications. The proportion that attained all three target levels increased to 6.8% with the age-stratified modification of target level for BP $<$ 140/90 mmHg, which is generally used in practice, for those over 65 years old.

The association between smoking and cardiometabolic factors is complicated. In a systematic review consisting of 14 observational studies, compared with smokers with diabetes, non-smokers had statistically significantly lower HbA_{1c} levels and more favorable LDL-c and HDL-c levels [34]. In our study, current smoking among patients with T2D was associated with a low likelihood of achieving the target levels for HbA_{1c} and LDL-c. Smoking causes an acute rise in BP, indicating that an elevated nicotine level mediates the increase in sympathetic nervous system activities and release of epinephrine, norepinephrine, and vasopressin hormones [35–38]. However, the long-term effect of smoking on BP remains controversial. In our study, current smokers were more likely to achieve the target level for BP control after adjusting for potential confounding. Similarly, a previous cross-sectional study consisting of general participants of Mongolian or Han ethnicity revealed that the adjusted BP was lower in current smokers compared with nonsmokers and former smokers [39]. Longitudinal studies also showed no significant increases in BP in participants after smoking cessation [40,41], whereas in other studies, greater increases in BP were reported in those who ceased smoking than in those who continued to smoke [42,43]. Thus, further studies are needed to clarify the long-term effect of smoking on BP. However, in patients with diabetes, smoking remains the strongest predictor of death and amplifies cardiovascular risks, whereas smoking cessation is recommended in most guidelines for patients with diabetes [10,11,44,45].

Prescriptions for lipid-lowering medications were associated with favorable status of LDL-c. By contrast, HbA_{1c} levels and BP values were high, and the percentages that achieved HbA_{1c} and BP target levels were low among those who were prescribed with glucose-lowering and antihypertensive medications, respectively. This finding suggests that blood glucose and BP were more difficult to manage by pharmaceutical interventions alone due to other influencing factors, such as diet and carbohydrate consumption, psychological factors, and sleep, and medication nonadherence.

Screening for microvascular complications has been further incorporated into diabetes management in primary healthcare in the "Healthy China Action Plan (2019–2030)." Thus, the eventual findings of the SIM study and those of this study can facilitate further the scale up and provide evidence for community-based strategies for the prevention and management of diabetic complications to other regions nationwide and globally. Screening for diabetic complication and improving self-management through patient education are equally important. Based on the components of diabetes management, patient education and life-style consultations should be offered through quarterly follow-ups and care in CHCs in China. Further, peer support arranged through CHCs and community self-management groups facilitates diabetes self-management in communities in Shanghai [15].

A major strength of this study was its sample size. The relatively rich clinical data and numerous events contributed to the robustness of the results. The data were extracted from administrative databases, avoiding the problem of differential recall bias. In addition, the data in this study were extracted from an integrated healthcare system, minimizing the influence of low accessibility to health care. Additionally, this study contributed to filling a gap in the literature regarding the benefits of including diabetes management in the BPHS as one of the key strategies of healthcare reform in China. Limitations of the study included the lack of data on socio-economic and self-management related factors, the possibility of reverse causation, and confounding by indication due to its cross-sectional nature. First, despite the rich clinical data, information regarding several socio-economic and self-management related factors, such as family income, education level, dietary factors, physical activities, previous smoking or drinking habits, and medication adherence, were lacking. Second, the cross-sectional observational findings limited the causal evaluation and introduced the possibility of reverse causation.

Confounding by indication remains a possibility, particularly in the high-target-level attainment rates among current smokers and patients with presence of macrovascular complications. All of the findings should be interpreted with caution due to the limitations of the cross-sectional design. Third, the data were collected from the linked central information systems including 240 health centers. Therefore, systematic measurement errors are possible which may bias our findings. Finally, in a large sample, small differences may be statistically significant. Therefore, the distinction between statistically and clinically significant differences needs to be borne in mind.

In this study, nearly 50% of the patients and one-third of the patients with T2D met the target levels for HbA_{1c} and LDL-c in primary healthcare, respectively, with a notably lower percentage achieving the BP target level. The percentage of patients who achieved the combination of all three target levels needs significant improvement. Given the limitations of the cross-sectional design, prospective longitudinal follow-up studies should be designed for further investigation. Nevertheless, the findings of this study clarify that comprehensive diabetes management services, including the assessment of metabolic control and screening for microvascular complications, should be enhanced in primary healthcare settings.

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Compliance with ethics guidelines

Chun Cai, Yuexing Liu, Yanyun Li, Yan Shi, Haidong Zou, Yuqian Bao, Yun Shen, Xin Cui, Chen Fu, Weiping Jia, and the SIM Study Group declare that they have no conflicts of interest. All procedures were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the *Helsinki Declaration* of 1975, as revised in 2000. Informed consent was obtained from all patients for being included in the study.

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