ORIGINAL RESEARCH

Glycemic Control of Type 2 Diabetes with the Chinese Metabolic Management Center and eKTANG

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ABSTRACT

Objective • Long-term management of patients with type 2 diabetes is a challenging clinical problem. The Metabolic Management Center (MMC) has been implemented in China to address metabolic diseases. This study aimed to evaluate the effectiveness of combining MMC with the eKTANG App, which is a fee-based blood glucose–monitoring platform, to improve outcomes for patients with diabetes.

Methods • We recruited 240 patients with type 2 diabetes to our randomized controlled trial; the patients were randomly assigned into a control group (n = 120) and an intervention group (n = 120). Participants in the control group received MMC management; those in the intervention group received MMC + eKTANG management. Serum samples were taken at 0, 3, 6, and 12 months to test liver and kidney function, blood lipids, uric acid, and blood glucose–related indicators. An oral glucose tolerance test and behavior questionnaires were administered and complications related to type 2 diabetes were noted at 0, 6, and 12 months.

Results • After up to 12 months of intervention with MMC + eKTANG, patients had improved mean (SEM) concentrations of hemoglobin A1c (6 months: control, 7.09% [1.32%] vs intervention, 7.19% [3.50%]; 9 months: control, 6.33% [0.31%] vs intervention, 6.50% [1.00%]; 12 months: control, 6.31% [2.30%] vs intervention, 6.01% [2.30%]), fasting plasma glucose (9 months: control, 7.20 [2.35] mmol/L vs intervention, 7.01 [0.56] mmol/L; 12 months: control, 6.98 [0.03] mmol/L vs intervention, 6.24 [2.03] mmol/L), and 2-hour postprandial plasma glucose (9 months: control, 9.85 [0.34] mmol/L vs intervention, 9.50 [0.23] mmol/L; 12 months: control, 9.55 [0.25] mmol/L vs intervention, 8.68 [0.87] mmol/L). The mean (SEM) concentrations of insulin and C-peptide measured during the oral glucose tolerance test also improved (measured as incremental area under the curve 0-180 min glucose; 6 months: control, 360.25 [2.30] mmol/L × min vs intervention, 352.24 [0.89] mmol/L × min; 12 months: control, 332.01 [2.32] mmol/L × min vs intervention, 300.32 [0.78] mmol/L × min). Moreover, the intervention ameliorated markers of lipid metabolism and liver and kidney function, and complications and behaviors related to diabetes.

Conclusion • The MMC + eKTANG intervention combines the convenience and efficacy of the internet for delivering timely medical care and guidance to individuals with diabetes with valuable information for managing diabetes in daily life. This innovative approach incorporates a fee-based system to enhance patient motivation and initiative, leading to a novel and effective perspective on diabetes management beyond traditional hospital settings. (*Altern Ther Health Med.* 2023;29(8):262-270).

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INTRODUCTION

According to the World Health Organization, the prevalence of type 2 diabetes (T2D) is growing year after year, and the latest data show that T2D affects around 465 million people worldwide.[1,2] China is the most populous country with patients with diabetes—the prevalence of adult diabetes is 11.6% and prediabetes is 50.1%.[3] Diabetes is always accompanied by several complications, including heart disease,[4-7] kidney diseases,[8,9] eye diseases,[10] and liver diseases.[11,12] If diabetes is not effectively treated, it negatively impacts the health and well-being of patients, resulting in a significant financial burden on people, families, and society.

The high number of patients with diabetes exerts a significant strain on the medical resources and the medical system in China, especially because of the limited availability of medical resources and the weakness of primary care

system. As a result, the availability of skilled medical specialists is limited and individuals are underinformed about diabetes and how to treat it. The current therapeutic care of diabetes is centered on injectable medicines, such as insulin and insulin-like substances, as well as oral pharmaceuticals such as metformin, sulfonylureas, α-glucosidase inhibitors, and thiazolidinediones. Patient self-management and out-of-hospital care in China for patients with diabetes is similarly chaotic and unmanaged, with an epidemiological study showing that only 39.7% of patients with diabetes in China achieve the ideal standard of glycemic control.[12,13] According to research by the China Cardiometabolic Disease and Cancer Cohort (4C) Study, the incidence of diabetes is increasing at a rate of 2% every year in China.[14,15] The prevention and management of diabetes are currently top priorities in the Chinese national health system.

The National Metabolic Care Center (MMC)[14,15] was founded in China in 2016 to address the challenges of managing metabolic disorders, such as diabetes and fatty liver diseases, and to standardize metabolic disease management across China. The MMC has been implemented as a "one center, one standard, one-stop" service that has been rolled out in approximately 100 hospitals. The MMC provides care to more than 40 000 patients with diabetes in China.[14] Smartphones and the internet make it possible for application of the fragmented time that belongs to the doctors for doctor-patient communication, and Internet of Things medical devices greatly facilitate the collection of medical health data from outpatients. The MMC software system uses this technology for inpatients and outpatients, both online and offline. The metabolic composite index of diabetes patients improved significantly after MMC management,[14,15] but according to current clinician feedback, patients still lack initiative and have low compliance when it comes to remote glucose management. As a result, the utility of the MMC software system is severely limited.

Although doctors have identified the value of using their fragmented time for doctor-patient interaction in the 5G era, this type of treatment lacks long-term incentives for patients. Patients obtain free treatment and information from the MMC, so the patients are not always appreciative.[16] As a result, this way of doctor-patient interaction may not reflect the value of the doctors' efforts accurately and this would not have the desired effect on patient compliance.

eKTANG,which is abbreviation of E Kong Tang in Chinese Pinyin and mean e-glucose-control platform, is a new medical system for diabetes patients that help them to monitor their blood glucose status, communicate with their doctors, record health data, and receive reminders about treatments out-of-hospital. It also helps patients to recover from diabetes and allows doctors to manage patients' data remotely and to provide diagnosis and treatment for patients in time. eKTANG is a kind of rechargeable electronic blood glucose–monitoring system which is based on the third-generation intelligent,[17] remote monitoring by physicians, management by nurses, guidance by expert mentors, and care by family members to achieve accurate outpatient blood glucose management and to achieve treatment and control of diabetes.

We applied eKTANG for diabetic patients to boost their motivation of blood glucose in this study. This may empower both doctors and patients, as well as enhance patient motivation. Both attending physicians and patients can be actively involved, transforming the prior passive management approach into an active one. If this approach is feasible, it might be included in the MMC management system to improve patient glycemic management and reduce the progression of diabetes.

Therefore, in this study, we investigated whether MMC + eKTANG management can improve the outcomes of patients with diabetes by increasing their motivation to treat and ameliorate complications of diabetes.

METHODS

Participants

We enrolled 240 patients with T2D who participated in National MMC management from Huizhou Central People's Hospital between 2020 and 2021.

Inclusion criteria: (1) 18 to 75 years of age; (2) diagnosed with T2D according to the World Health Organization criteria[18]; (3) has not received glycemic-lowering medications or is already receiving these medications but with poor glycemic control; and (4) 7.9 to 22.2 mmol/L postprandial 2-hour blood glucose.

Exclusion criteria: (1) diagnosed with type 1 diabetes or another type of diabetes(eg. insipidus diabetes, type A insulin resistance syndrome) that is not T2D; (2) acute complications of diabetes (eg. diabetic ketoacidosis and lactic acidosis); (3) severe microvascular complications, such as proliferative retinopathy; (4) urinary albumin excretion rate ≥300 mg/g, or positive urinary protein greater than 0.5 g/day; (5) uncontrolled painful diabetic neuropathy or significant diabetic vegetative neuropathy; (6) significant macrovascular complications, such as acute cerebrovascular accident, acute coronary syndrome, peripheral arterial disease requiring hospital admission, or amputation within 12 months prior to enrollment; (7) blood pressure higher than 180/110 mm Hg[18]; (8) blood creatinine clearance less than 50 mL/min; (9) alanine aminotransferase greater than or equal to 2.5 times the normal value, or total bilirubin greater than or equal to 1.5 times the normal value; (10) hemoglobin A1cless than 100 g/L, or the need to receive regular blood transfusions; (11) systemic infections or serious concomitant diseases; (12) malignancy or chronic diarrhea; (13) uncontrolled abnormality of endocrine gland function; (14) mental or communication disorders; (15) chronic cardiac insufficiency or cardiac function class III or above; or (16) subjects who are uncooperative.

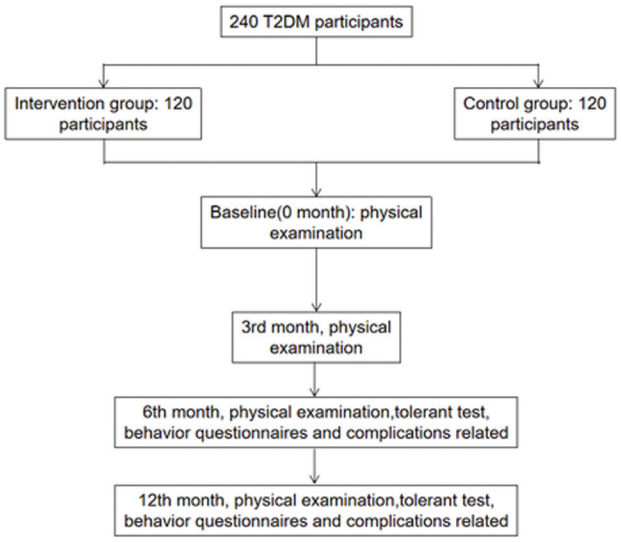
This study was approved by the Ethics Committee of Huizhou Central People's Hospital (KYLL2020056).

Study design

This was a randomized controlled trial with a parallel-group design. We randomly divided 240 participants into the

MMC management group (control group) and the MMC + eKTANG management group (intervention group). During the 12-month study period, both groups received MMC management. The control group came to the hospital for follow-up visits as needed. The intervention group received MMC management in combination with eKTANG management for 12 months, with assessments every 3 months. This study was designed in accordance with the CONSORT guidelines.[20] The flow chart of the study is displayed in Figure 1.

Figure 1. Study Characteristics



Abbreviation: T2D, type 2 diabetes.

Observation indicators

The primary outcome of the study was the index of glycemic control, which included results from glycated hemoglobin A_{1c}, fasting glucose, insulin, and oral glucose tolerance test (glucose, insulin, and C-peptide). The secondary outcomes were change in diabetes-related behaviors, urinary microalbumin to creatinine ratio, blood urea nitrogen, serum creatinine, albumin, aspartate aminotransferase, alanine aminotransferase, total bilirubin, γ-glutamyltransferase, uric acid, total cholesterol, triglycerides, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol and complications and associated risks of T2D.

Patient follow-up plan using eKTANG

After subscribing to the "discharge follow-up service" or "outpatient follow-up service," half of the patients were enrolled in the intervention group (patients in the control group did not receive this rechargeable follow-up plan), for which a physician developed an online discharge follow-up plan based on the particular patient's condition and conducted a 12-month rechargeable follow-up service. When patients returned home, they began a 12-month outpatient phase of comprehensive daily intervention. The attending physicians' daily treatment of patients entailed timely use of their fragmented time for daily blood glucose monitoring and patient coaching on nutrition and exercise. The physicians also provided feedback to patients by a blood glucose alert and to encourage the return of patients to the hospital for follow-up on schedule. Patients who needed to be hospitalized were followed up by online platform, outpatient clinic, and telephone to encourage their admission to hospital, and were then followed up during their hospital stay. Targeted indicators and certain assessment underneath were made every 3 months for 12 months, and improvements in patient management were made in accordance with the follow-up plan.

MMC procedure

The MMC managers in this study included 4 endocrinologists, 2 endocrinology nurses, and 1 quality controller, who were all trained and qualified by the National MMC quality control group. The endocrinologists were responsible for patients' whole management schedule, developing treatment plans and follow-up plans, and collecting data on and managing patients' metabolic parameters such as blood glucose. Nurses were in charge of patient registration, follow-up appointments, and health education. The quality control team monitored and evaluated the MMC process. Patients admitted to the MMC were registered, examined, and followed up using the MMC "One-Stop Service Standard," with treatment and follow-up directed by the MMC standard operating procedure.

The Metabolic All-in-One machine integrates existing and up-to-date MMC-related tests (eg, fundus photography) and allows patients to be evaluated for all metabolic disease–related issues in one place without relocating and was used to assess patients at the MMC. To collect personal history and test data in real-time, patient data is incorporated into a standardized data management system interfaced with the hospital information system and laboratory information management system. Patients can input data from home-testing devices, such as blood glucose meters and blood pressure monitors, as well as step counts, into the MMC system via the patient-controlled app, which is synchronized with the central database. Medical staff can control patient information in a timely manner via the medical app, allowing for real-time management of patients' health status.[4]

Behavioral questionnaires

We used 5 questionnaires[5] to evaluate diabetes-related behaviors: International Physical Activity Questionnaire，the Summary of Diabetes Self-Care Activities Questionnaire; the Self-Efficacy for Diabetes Scale; the Diabetes Distress Scale; and, to measure healthy eating, the self-made Fat, Fruit, and Vegetable Questionnaire. These were conducted at the 0th, 6th, and 12th month.

Assessment of complications related to T2D

A nerve conduction study, a pulse wave velocity and ankle-brachial index lower extremity artery ultrasonography,

a carotid artery ultrasonography, and a fundus examination were conducted at the 0th, 6th, and 12th month.

Nerve conduction study. Nerve conduction velocity testing was performed using an electromyograph at a room temperature of 25°C to 30°C with participants remaining calm and lying down. For motor nerve conduction testing, saddle electrodes were used to stimulate the carpal area of the median nerve and the elbow area of the ulnar nerve, and surface electrodes were used to record at the ventral areas of the thumb short adductor and the little finger adductor muscles to assess elbow-to-wrist conduction rate. We calculated the motor conduction velocity, distal motor latency, and compound muscle action potential wave amplitude.

Pulse wave velocity and ankle-brachial index lower extremity artery ultrasonography and carotid artery ultrasonography. An Omron Colin VP-2000 cardiovascular profiling system and a Philips iU22 color Doppler ultrasound machine with linear array probes that set up a range from 5 to 12 MHz frequency was used; 2 clinicians knowledgeable about vascular anatomy operated the machines and analyzed the data. Each patient was positioned in the prone position, and 2-dimensional ultrasonography was used to routinely monitor the lower vessels' wall and lumen stenosis of the carotid artery on a clinic protocol. Then, color Doppler flow imaging was used to identify the shape and categorization of plaque, as well as the direction and breadth of the blood flow and the existence of occlusion.

Fundus examination. A handheld nonmydriatic fundus camera was used to perform the fundus examination Two 45° fundus photographs were taken, centered on the macula and optic disc of 1 eye. The captured images were independently reviewed by an experienced ophthalmologist to determine if there was a suspicious fundus lesion.

Oral glucose tolerance test

Participants fasted for 8 to 12 hours before eating a 400-calorie mixed meal (noodles and sausage, containing 47.8 g carbohydrate, 28.3 g fat, and 20.6 g protein) within 15 minutes. Blood samples were taken 0, 30, 60,120,and 180 minutes after the meal to measure blood glucose, insulin, and C-peptide levels according to different researching purpose. These tests were conducted at the 0th, 6th, and 12th month.

Blood sample analysis

Blood samples were taken and reserved, a Roche cobas 8000 automatic biochemical analyzer was used to measure blood glucose, blood lipids, kidney function, and liver function. A chemiluminescence method was used to measure insulin with a Roche cobas e 411 analyzer and C-peptide with a Beckman Coulter UniCel DxI 800 immunoassay system. Hemoglobin Alc was measured using ion exchange chromatography.

Statistical analyses

Statistical results were analyzed using SPSS software version 19.0 (IBM Corp). Data with a normal distribution are displayed as mean (SD)and were statistically analyzed by *t* test. Categorical data, nonnormally distributed data, and rank data were statistically analyzed by chi-square test and nonparametric test. $P < .05$ was considered a statistically significant difference.

Table 1. Patient Clinical and Biochemical Characteristics at Baseline

Characteristic	Control (n = 120)	Intervention (n = 120)	*P* value
Sex, No. (%)			
Women	58 (48.3)	55 (45.8)	.21
Men	62 (51.7)	65 (54.2)	
Age, mean (SD), y	52.2 (0.6)	53.2 (1.8)	.13
Employment information, No. (%)			
Unemployed	23 (1.90)	26 (22.0)	.44
Employed	39 (33.0)	31 (26.0)	.32
Retired	58 (48.0)	63 (53.0)	.09
Annual income[&] per family member, No. (%)			
≤¥2000	22 (18.0)	23 (19.0)	.12
¥2001-¥3500	37 (31.0)	32 (27.0)	.32
≥¥3501	61 (51.0)	65 (54.0)	.13
Years with diabetes, mean (SEM)	8.30 (1.02)	9.03 (0.52)	.35
Diabetes medication, No. (%)			
Oral medication	55 (46.0)	55 (46.0)	.54
GLP-1 inhibitor	19 (16.0)	24 (20.0)	.50
Oral medication +GLP-1 inhibitor	46 (38.0)	41 (34.0)	.07
BMI, mean (SD)	25.8 (0.57)	26.1 (1.12)	.25
Waist circumference, mean (SD), cm	84.6 (1.17)	85.6 (0.03)	.37
Hip circumference, mean (SD), cm	90.0 (0.14)	89.6 (1.34)	.29
HbA_{1c}, mean (SD), %	8.10 (0.06)	8.12 (1.06)	.60

Note: Exchange rate of RMB against US dollar is about 6.5:1 (average).

Abbreviations: BMI, body mass index; GLP-1, calculated as weight in kilograms divided by height in meters squared, glucagon-like peptide 1; HbA_{1c}, hemoglobin A_{1c}.

RESULTS

Baseline patient characteristics

The control and intervention groups had statistically equivalent baseline clinical and biochemical characteristics, including gender, age, years with diabetes, diabetes medication, body mass index (calculated as weight in kilograms divided by height in meters squared), waist circumference, hip circumference, and hemoglobin A_{1c} (all $P > .05$; Table 1).

Effect of intervention on the function of the kidney and liver

At baseline (0 months), the 2 groups were similar for kidney function (urinary microalbumin to creatinine ratio, blood urea nitrogen, and serum creatinine) and liver function (albumin, aspartate aminotransferase, alanine aminotransferase, total bilirubin, and γ-glutamyltransferase) (all $P > .05$; Table 2). However, the unfavorably high concentrations of these indicators gradually decreased up to the 12-month time point in both groups.

Table 2. Effect of Intervention on the Function of the Kidney and Liver

Indicator	Control, mean (SD)	Intervention, mean (SD)	*P* value
Urinary microalbumin to creatinine, mg/g			
0 mo	73.26 (1.23)	75.63 (1.05)	.32
3 mo	71.21 (1.77)	72.6 (2.02)	.56
6 mo	70.3 (3.20)	71.3 (1.03)	.23
9 mo	70.2 (1.21)	70.3 (1.25)	.11
12 mo	68.2 (0.34)	65.0 (1.03)	<.001
Blood urea nitrogen, mmol/L			
0 mo	16.2 (2.30)	17.23 (1.32)	.89
3 mo	15.23 (1.33)	15.80 (1.56)	.34
6 mo	12.23 (1.09)	12.01 (1.20)	.41
9 mo	12.30 (1.88)	12.03 (0.32)	.12
12 mo	11.09 (0.88)	11.19 (0.02)	.23
Serum creatinine, μmol/L			
0 mo	132.98 (3.99)	135.25 (1.23)	.55
3 mo	130.6 (0.25)	130.8 (3.02)	.52
6 mo	125.99 (2.3)	121.63 (1.03)	.13
9 mo	120.79 (2.30)	120.9 (0.88)	.21
12 mo	119.3 (0.34)	105.36 (2.30)	.01
Albumin, g/L			
0 mo	50.72 (1.01)	51.22 (1.32)	.89
3 mo	48.63 (1.73)	48.32 (.35)	.40
6 mo	45.02 (0.21)	44.01 (0.23)	.25
9 mo	45.12 (2.22)	43.24 (1.87)	.02
12 mo	45.00 (2.30)	41.01 (0.25)	.01

Indicator	Control, mean (SD)	Intervention, mean (SD)	*P* value
Aspartate aminotransferase, IU/L			
0 mo	26.23 (2.30)	27.32 (1.20)	.12
3 mo	24.62 (0.78)	24.32 (1.23)	.54
6 mo	23.23 (1.28)	22.30 (0.26)	.27
9 mo	23.01 (0.24)	22.34 (1.89)	.54
12 mo	22.36 (2.35)	22.32 (0.24)	.41
Alanine aminotransferase, IU/L			
0 mo	25.57 (0.86)	26.24 (1.32)	.68
3 mo	24.23 (0.41)	24.32 (1.00)	.47
6 mo	23.57 (0.26)	21.03 (2.30)	.38
9 mo	23.02 (0.41)	23.74 (1.32)	.54
12 mo	23.41 (0.78)	23.32 (0.24)	.21
Total bilirubin, μmol/L			
0 mo	15.26 (3.36)	14.23 (0.21)	.98
3 mo	14.26 (2.03)	13.25 (0.21)	.54
6 mo	13.02 (0.25)	13.02 (1.02)	.13
9 mo	12.98 (1.24)	12.88 (0.56)	.08
12 mo	11.02 (0.14)	11.00 (0.23)	.22
γ-Glutamyltransferase, U/L			
0 mo	22.27 (1.14)	23.01 (0.23)	.57
3 mo	21.03 (25)	20.30 (1.23)	.65
6 mo	20.99 (0.99)	20.26 (0.45)	.11
9 mo	19.36 (0.82)	18.26 (2.30)	.24
12 mo	18.95 (0.62)	18.32 (1.03)	.81

Table 3. Examination of Blood Lipids and Uric Acid

Indicator	Control, mean (SD)	Intervention, mean (SD)	*P* value
Uric acid, μmol/L			
0 mo	462.02 (0.41)	468.0 (0.69)	.98
3 mo	423.27 (1.42)	415.35 (0.98)	.04
6 mo	410.98 (0.42)	400.02 (0.23)	.02
9 mo	401.78 (3.20)	360.36 (2.09)	<.001
12 mo	360.68 (0.24)	310.98 (1.32)	<.001
TC, mmol/L			
0 mo	7.90 (2.3)	8.0 (1.23)	.82
3 mo	6.35 (0.34)	6.30 (0.24)	.24
6 mo	6.0 (0.35)	5.83 (0.22)	.03
9 mo	6.01 (2.01)	5.83 (2.22)	.02
12 mo	6.11 (1.89)	5.62 (0.24)	<.001
TG, mmol/L			
0 mo	3.10 (2.30)	3.36 (0.31)	.43
3 mo	3.06 (0.24)	3.00 (1.35)	.56
6 mo	2.73 (0.24)	2.53 (0.78)	.02
9 mo	2.63 (2.35)	2.32 (0.36)	<.001
12 mo	2.47 (1.36)	2.07 (0.78)	.04

Indicator	Control, mean (SD)	Intervention, mean (SD)	*P* value
LDL-C, mmol/L			
0 mo	7.32 (1.33)	7.20 (0.69)	.21
3 mo	6.51 (2.33)	6.57 (1.44)	.89
6 mo	6.32 (0.12)	6.01 (1.33)	.52
9 mo	5.98 (1.55)	5.10 (2.30)	.03
12 mo	5.20 (2.30)	4.90 (1.30)	.02
HDL-C, mmol/L			
0 mo	1.71 (0.28)	1.73 (2.97)	.10
3 mo	1.79 (0.87)	1.80 (0.58)	.22
6 mo	1.80 (1.39)	2.3 (0.22)	.03
9 mo	2.10 (1.25)	2.3 (0.79)	<.001
12 mo	2.3 (0.54)	2.5 (1.89)	<.001

Abbreviations: HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; TC, total cholesterol; TG, triglycerides.

The urinary microalbumin to creatinine ratio and serum creatinine concentration remained equal between the control and intervention groups at 3, 6, and 9 months (all $P > .05$; Table 2). However, these 2 indicators were higher in the control group than in the intervention group at 12 months. The blood urea nitrogen concentration was higher in the control group at 9 months ($P = .12$; Table 2) and was lower in the control group at 12 months ($P = .23$; Table 2).

The concentrations of albumin, aspartate aminotransferase, and alanine aminotransferase were similar in both groups at 0 and 3 months. The albumin concentration was higher in the control group at 9 months ($P = .02$; Table 2) and at 12 months ($P = .01$; Table 2).

The total bilirubin and γ-glutamyltransferase concentrations did not differ between the 2 groups over the 12-month study time.

Effect of intervention on uric acid and blood lipid metabolism

The concentrations of uric acid, total cholesterol, triglycerides, and low-density lipoprotein cholesterol decreased in the control and intervention groups over the 12-month study time, and the concentration of high-density lipoprotein cholesterol increased in both groups over the same time (Table 3).

The concentration of uric acid was higher in the control group than in the intervention group at 3 months ($P = .04$), 6 months ($P = .02$), 9 months ($P < .001$), and 12 months ($P < .001$) (Table 3).

Table 4. Blood Glucose–Related Indicators

Indicator	Control (SD)	Intervention (SD)	*P* value
HbA_{1c}, %			
0 mo	8.10 (0.06)	8.12 (1.06)	.60
3 mo	7.23 (0.45)	7.19 (3.50)	.24
6 mo	7.09 (1.32)	6.90 (1.50)	.03
9 mo	6.33 (0.31)	6.50 (1.00)	.04
12 mo	6.31 (2.30)	6.01 (2.30)	<.001
Fasting plasma glucose, mmol/L			
0 mo	9.02 (2.30)	9.11 (0.32)	.23
3 mo	8.60 (0.34)	8.55 (1.11)	.65
6 mo	8.13 (1.35)	8.06 (0.24)	.78
9 mo	7.20 (2.35)	7.01 (0.56)	.03
12 mo	6.98 (0.03)	6.24 (2.03)	.03
2-h postprandial plasma glucose, mmol/L			
0 mo	10.98 (0.55)	11.25 (0.40)	.31
3 mo	10.98 (0.24)	11.05 (2.3)	.74
6 mo	10.66 (3.21)	10.69 (0.35)	.21
9 mo	9.85 (0.34)	9.50 (0.23)	.01
12 mo	9.55 (0.25)	8.68 (0.87)	<.001
OGTT, iAUC 0-180 min glucose, mmol/L × min			
0 mo	400.23 (2.68)	410.91 (0.23)	.37
6 mo	360.25 (2.30)	352.24 (0.89)	.01
12 mo	332.01 (2.32)	300.32 (0.78)	.03
INS 0 min, mU/min			
0 mo	11.02 (0.58)	11.28 (0.28)	.29
6 mo	10.25 (2.11)	10.10 (2.04)	.97
12 mo	10.17 (2.54)	8.98 (0.87)	.01
INS 60 min, mU/min			
0 mo	76.85 (1.58)	75.42 (2.36)	.56
6 mo	73.26 (1.11)	70.21 (0.35)	.03
12 mo	72.69 (2.98)	70.91 (0.98)	<.001
INS 180 min, mU/min			
0 mo	20.36 (2.30)	21.36 (1.99)	.26
6 mo	19.97 (1.02)	19.61 (2.07)	.79
12 mo	18.21 (0.52)	16.36 (3.12)	.01
C-peptide 0 min, ng/mL			
0 mo	1.92 (2.33)	2.01 (0.25)	.45
6 mo	1.90 (2.01)	2.10 (2.36)	.54
12 mo	1.91 (0.27)	1.92 (0.37)	.79
C-peptide 60 min, ng/mL			
0 mo	6.25 (0.74)	6.21 (1.58)	.07
6 mo	6.19 (0.87)	6.18 (0.24)	.06
12 mo	6.15 (0.98)	6.14 (0.17)	<.001
C-peptide 180 min, ng/mL			
0 mo	2.35 (1.03)	2.34 (0.98)	.14
6 mo	2.20 (0.24)	2.21 (0.48)	.57
12 mo	2.10 (0.54)	2.01 (0.87)	.01

Abbreviations: iAUC, incremental area under the curve; INS, insulin; HbA_{1c}, hemoglobin A1c; OGTT, oral glucose tolerance test.

The concentration of total cholesterol was higher in the control group than in the intervention group at 6 months ($P=.03$), 9 months ($P=.02$), and 12 months ($P<.001$) (Table 3).

The concentration of triglycerides was higher in the control group than in the intervention group at 6 months ($P=.02$), 9 months ($P<.001$), and 12 months ($P=.04$) (Table 3).

The concentration of low-density lipoprotein cholesterol was higher in the control group than in the intervention group at 9 months ($P=.03$) and 12 months ($P=.02$) (Table 3).

The concentration of high-density lipoprotein cholesterol was lower in the control group than in the intervention group at 6 months ($P=.03$), 9 months ($P<.001$), and 12 months ($P<.001$) (Table 3).

Effect of intervention on glucose metabolism

Glucose metabolism decreased in both the control and intervention groups over the 12-month study time (Table 4).

The concentration of hemoglobin A1c was higher in the control group than in the intervention group at 6 months ($P=.03$), at 9 months ($P=.04$), and at 12 months ($P<.001$) (Table 4).

The concentration of fasting plasma glucose was higher in the control group than in the intervention group at 9 months ($P=.03$) and at 12 months ($P=.03$) (Table 4).

The concentration of 2-hour postprandial plasma glucose was higher in the control group than in the intervention group at 9 months ($P=.01$) and at 12 months ($P<.001$) (Table 4).

The concentration of the incremental area under the curve for the oral glucose tolerance test (0-180 min glucose) was higher in the control group than in the intervention group at 6 months ($P=.01$) and at 12 months ($P=.03$) (Table 4).

The changes in insulin concentration and C-peptide concentration during the oral glucose tolerance test were similar with a level of glucose (Table 4).

Fasting insulin (0 min) was higher in the control group than in the intervention group at 12 months ($P=.031$) (Table 4).

Table 5. Assessment of Complications and Associated Risks

Method of abnormality detection	Control (n, OR)	Intervention(n, OR)	*P* value
Nerve conduction			
0 mo	47.1 (0.9)	47.98 (0.28)	.97
6 mo	39.12 (2.35)	35.12 (1.52)	.03
12 mo	30.25 (3.21)	28.26 (0.14)	.01
PWV and ABI lower extremity arterial ultrasonography			
0 mo	47.1 (0.9)	33.02 (2.36)	.21
6 mo	30.2 (0.14)	30.25 (0.11)	.23
12 mo	29.23 (0.23)	28.01 (2.02)	.01
Carotid artery ultrasonography			
0 mo	45.26 (0.35)	45.99 (0.25)	.33
6 mo	42.32 (2.54)	41.99 (0.24)	.24
12 mo	40.25 (0.26)	39.36 (2.36)	.03
Retinal blood vessels examination			
0 mo	21.05 (2.36)	22.03 (2.24)	.68
6 mo	19.60 (1.36)	18.03 (0.26)	.24
12 mo	19.25 (0.65)	17.03 (1.25)	<.001

Abbreviations: ABI, ankle-brachial index; PWV, pulse wave velocity. OR, odd ratio.

Complications and associated risks of diabetes

The complications and associated risks of diabetes were assessed at 0, 6, and 12 months. The percentage of nerve conduction abnormality was higher in the control group than in the intervention group at 6 months ($P=.03$) and 12 months ($P=.01$) (Table 5).

Table 6. Changes in Behavioral and Biological Outcomes Across Time

	Time 1		Time 2		Time 3		Group/Time; T1 vs T2; T2 vs T3; *F* (*df*) *P* value
	Control, mean (SD)	Intervention, mean (SD)	Control, mean (SD)	Intervention, mean (SD)	Control, mean (SD)	Intervention, mean (SD)	
Diet self-management activities	2.30 (0.32)	2.33 (0.03)	3.02 (1.03)	3.25 (0.89)	3.12 (0.25)	3.33 (0.99)	6.47 (2, 203) .01; 15.11 (6, 101) .03; 3.60 (1, 78) .78
Exercise self-management activities	2.68 (1.23)	2.59 (2.36)	2.80 (0.11)	2.98 (2.3)	3.09 (0.97)	3.20 (2.89)	4.55 (1, 200) .01; 7.32 (3, 100) .02; 6.23 (2, 96) .01
Blood sugar self-management activities	5.01 (0.03)	5.13 (2.30)	5.51 (2.08)	5.86 (1.25)	5.62 (0.23)	6.20 (2.89)	5.04 (2, 200) .01; 2.30 (1, 88) .02; 1.03 (1, 98) .18
Foot care self-management activities	4.50 (0.65)	4.47 (1.62)	5.20 (2.45)	5.30 (3.24)	5.49 (1.25)	5.89 (0.89)	3.04 (2, 188) .50; 4.23 (1, 96) .56; 1.09 (1, 99) .15
Medication self-management activities	5.23 (1.99)	5.14 (0.36)	5.40 (3.02)	5.43 (0.65)	5.62 (0.24)	5.70 (1.50)	1.03 (1, 168) .64; 0.53 (1, 66) .79; 0.31 (1, 89) .98
Total self-management activities	4.23 (0.36)	4.10 (0.32)	4.46 (1.89)	4.59 (0.69)	4.80 (1.28)	4.89 (1.98)	7.89 (3, 200) .21; 13.01 (1, 99) .30; 4.22 (2, 98) .51
Diabetes self-efficacy for health behaviors	3.48 (2.96)	3.50 (0.54)	3.62 (2.01)	3.80 (3.01)	3.72 (0.66)	3.97 (2.02)	5.23 (2, 166) .15; 6.23 (1, 89) .95; 7.26 (2, 99) .92
Diabetes self-efficacy for general health	3.98 (2.03)	3.91 (1.65)	4.01 (0.03)	4.11 (0.23)	4.21 (0.36)	4.42 (0.08)	4.58 (1, 99) .89; 4.57 (1, 200) .50; 0.02 (1, 94) .94
Total diabetes self-efficacy	4.23 (1.12)	4.20 (2.03)	4.44 (0.03)	4.51 (2.13)	4.62 (1.20)	4.69 (25)	5.23 (2, 96) .15; 2.56 (1, 99) .55; 8.23 (2, 200) .35
Emotional burden subscale	3.25(0.97)	3.12 (1.00)	2.90 (0.03)	2.89 (3.02)	2.80 (2.44)	2.77 (0.26)	3.20 (2, 99) .98; 5.23 (1, 89) .72; 5.64 (1, 98) .12
Physician distress subscale	1.45 (1.56)	1.49 (0.23)	1.42 (2.36)	1.42 (0.24)	1.40 (0.03)	1.41 (1.02)	5,28 (1, 100) .66; 4.62 (2, 99) .36; 5.88 (1, 200) .57
Regimen distress subscale	4.89 (1.33)	4.90 (0.26)	2.90 (0.03)	2.89 (3.02)	2.80 (2.44)	2.77 (0.26)	4.23 (1, 97.2) .78; 2.57 (1, 102.5) .19; 5.37 (1, 98) .14
Interpersonal distress subscale	1.90 (0.26)	1.89 (0.65)	1.82 (0.35)	1.81 (0.24)	1.75 (0.88)	1.74 (2.26)	3.25 (1, 97.2) .89; 4.23 (2, 200) .87; 5.02 (1, 188) .74
Total diabetes distress	14.56 (0.45)	14.60 (0.58)	13.69 (1.55)	13.54 (0.24)	13.10 (2.03)	13.00 (0.24)	1.92 (1, 198.2) .13; 5.52 (1, 98) .78; 6.32 (2, 98) .90
Fruits subscale	1.67 (1.34)	1.68 (1.01)	1.60 (0.54)	1.59 (1.57)	1.55 (0.89)	1.54 (1.00)	2.36 (1, 89.2) .58; 4.21 (2, 97.5) .69; 5.25 (1, 97) .36
Vegetables subscale	1.42 (0.89)	1.41 (0.74)	1.32 (0.08)	1.31 (0.87)	1.22 (0.52)	1.23 (0.71)	4.50 (1, 200) .22; 3.25 (1, 94.2) .89; 2.14 (2, 89.7) .10
IPAQ vigorous activity, MET min/wk	1822.02 (231.25)	1821.30 (242.58)	1888.78 (534.8)	1889.87 (114.58)	1892 (0.287)	1896.56 (232.14)	0.01 (1, 99.8) .87; 1.02 (1, 99) .13; 0.03 (1, 99.7) .23
IPAQ moderate activity, MET min/wk	1706.73 (234.57)	1711.05 (245.22)	1715.24 (154.21)	1720.24 (147.25)	1725.25 (452.36)	1729.65 (236.25)	2.68 (1, 299) .98; 1.33 (1, 189.7) .23; 0.74 (2, 89) .27
IPAQ walking, MET min/wk	1078.25 (278.25)	1080.28 (147)	1089.21 (247.12)	1090.20 (214.69)	1111.24 (321.01)	1119.28 (257.46)	0.57 (1, 119.2) .87; 0.34 (1, 99) .78; 0.01 (1, 89) .98
IPAQ total activity, MET min/wk	3247.35 (135.25)	3287.36 (425.55)	3255.63 (365.25)	3300.25 (147.58)	3331.25 (257.75)	3339 (245.14)	0.98 (1, 158.8) .35; 0.22 (1, 99) .24; 0.87 (1, 89.9) .33

Abbreviations: IPAQ, International Physical Activity Questionnaire; MET, metabolic equivalent; T1, time 1; T2, time 2; T3, time 3.

The percentage of abnormalities detected at 12 months was higher in the control group than in the intervention group for arterial ultrasonography ($P = .01$), carotid artery ultrasonography ($P = .03$), and retinal blood vessels examination ($P < .001$) (Table 5).

Participant changes in behavioral and biological outcomes

Table 6 shows that participants had significant changes over time in behavioral and biological outcomes when assessed by group·time interaction for diet self-management ($F_{2,203} = 6.47$; $P = .01$), exercise self-management ($F_{1,200} = 4.55$; $P = .01$), blood sugar self-management ($F_{2,200} = 5.04$; $P = .01$), and total diabetes distress ($F_{1,198.2} = 1.92$; $P = .13$) (Table 6).

DISCUSSION

In recent years, diabetes has been recognized as a major risk factor for cardiovascular and cerebrovascular disorders, imposing a significant burden on patients and their families.[20] Although the blood glucose levels of patients with diabetes are effectively controlled during hospitalization, patients often have poor compliance for medication, blood glucose monitoring, and self-management outside the hospital; this is partly driven by low awareness of the risks of complications and leads to negative long-term outcomes.[13,21] The provision of adequate health education to patients with diabetes helps patients regulate their blood glucose levels and reduces complications.[22-24] To address this issue, the Chinese health care workers established the MMC platform with the help of the government, which enables patients to access their diabetic health information, communicate with doctors, and receive remote health-education support. However, the effectiveness of the MMC is limited by a lack of patient motivation and autonomy. In this study, MMC + eKTANG significantly improved blood glucose levels, peripheral insulin resistance, lipid metabolism, uric acid levels, kidney function, and liver function in individuals with chronic glucose illness compared with MMC alone. Additionally, MMC + eKTANG effectively improved the behaviors of patients with diabetes in relation to diet, exercise, and glycemic self-management.

Diabetes is a chronic condition that necessitates long-term use of prescribed medicine as well as an active change in the patient's daily habits.[3,4] As a result, the patient's motivation and treatment autonomy are extremely important for health care promotion. However, because the majority of patients lack understanding of the risks of diabetes, postdischarge glycemic management of patients with diabetes is always unsatisfactory and that has been a major therapeutic issue.[22,23] The MMC + eKTANG intervention significantly improved the patients' glycemic parameters, especially after 6 months of adherence to the intervention. The improvement in hemoglobin A1c was evident by the 6th month of the intervention and continued until the 12th month. Fasting glucose, 2-hour postprandial glucose, and the oral glucose tolerance test all improved significantly by the ninth month. The MMC + eKTANG intervention helped the patients in our study maintain their glycemic index following discharge from the hospital. This might be because the MMC + eKTANG intervention not only creates a real-time bridge between physicians and patients, allowing patients to handle their medical problems quickly, but also enhances patients' knowledge about and attention to diabetes. eKTANG also boosts patients' motivation by encouraging them to seek medical aid and to appreciate the information and assistance supplied by doctors and healthcare workers.

Patients also demonstrated substantial improvements in lipid metabolism abnormalities and indicators of liver function, kidney function, and blood-glucose control. Diabetes is frequently associated with other systemic disorders.[4-8] In our study, markers of lipid metabolism, liver function, and kidney function were all considerably aberrant in patients with diabetes, although these markers all improved to varying degrees following the intervention. One of the main causes for these improvements was good glycemic control over a lengthy period of time. Besides medication, a healthy lifestyle and healthy habits are crucial in the prevention and management of diabetes, lipid metabolism disorders, and other metabolic illnesses.[25,26] The MMC + eKTANG intervention recognizes this important point by continually emphasizing the importance of good living for patients registered to the platform and by actively instructing and encouraging them to follow good lifestyle habits and to reverse their poor lifestyle habits to reduce their risk factor exposure. The patients' behaviors for nutrition, activity, and blood-glucose control all improved considerably following the intervention. In previous studies, patients' perceptions of diabetes risks increased when using online education for diabetic treatments,[27,28] but the application of particular behaviors was restricted, and the outcomes were not significant. In our study, MMC + eKTANG increased patient autonomy and led to positive behavioral change by charging patients a fee in addition to providing them with online education, individual education, and doctor consultations. This suggests that online education and medical services allow easy access to information and medical services, but other in-person services are still needed to improve patient compliance.

The incidence of complications of diabetes can be significantly reduced by managing glucose levels in patients with diabetes.[4-6] In our study, the MMC + eKTANG intervention improved kidney and liver function and the pulse wave velocity and ankle-brachial index, and ameliorated glucose metabolism disorders, lipid metabolism disorders, and diabetes-related comorbidities such as peripheral nephropathy and kidney vasculopathy. This result has important implications for clinical practice, as the impact of diabetes relates more to the serious complications of diabetes than to elevated blood glucose. The MMC + eKTANG intervention reduces the incidence of complications, suggesting that the convenience of online health services combined with patient autonomy in treatment can be an effective new approach in the management of diabetes complications.

This is the first study to deploy the MMC + eKTANG intervention that combines the convenience of online medical education with a patient-centered approach to provide a new way of thinking about outpatient clinical care for patients with diabetes. This combined treatment, in contrast to conventional treatment, can improve patient compliance after discharge, increase patient awareness of the disease, and improve patient confidence in treatments due to the timely feedback and advice provided to patients. All these factors drive the patient to adopt a positive lifestyle and attitude to further prevent and ameliorate the complications of diabetes. The cohort in this study was quite youthful, with few barriers to smartphone and internet use; nevertheless, this strategy may not produce the same results for older patients with diabetes, who are likely to have more restricted access to cellphones and the internet. Because the study's sample population was from Huizhou, Guangdong Province, China, a city with a high level of economic development, the intervention's application to other less economically developed locations may be limited.

CONCLUSION

The MMC + eKTANG intervention takes advantage of the internet's convenience and effectiveness to provide timely medical care, advice, and information on managing diabetes in daily life to patients with diabetes; it also employs a fee-based approach to increase patient motivation and initiative, resulting in an effective new way of thinking about diabetes management outside of the hospital.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are available from the corresponding author upon request.

AUTHOR CONTRIBUTIONS

FL and MF designed the study and performed the experiments, FL collected the data, MF analyzed the data, and FL and MF prepared the manuscript. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

FUNDING STATEMENT

This study did not receive any funding in any form.

ETHICAL STATEMENT

This study was approved by the Ethics Committee of Huizhou Central People's Hospital (KYLL2020056). All subjects signed the consent form before participation in the study.

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